Treated Timber Waste Minimisation Project

Milestone 1: Industry Overview

May 2013

Environment

Canterbury

Report No. R13/31

ISBN:
978-1-927234-87-7 (Hard copy)
978-1-927234-88-4 (Web)
978-1-927234-89-1 (CD)

Environment Canterbury
Regional Council
Kaunihera Taiao ki Waitaha

MINISTRY FOR THE ENVIRONMENT
WASTE MINIMISATION FUND PROJECT

TREATED TIMBER WASTE MINIMISATION

MILESTONE 1: INDUSTRY OVERVIEW

FRASER SCOTT, TRUE NORTH CONSULTING
MAY 2013

DISCLAIMER

This feasibility study document has been prepared for Environment Canterbury (ECAN) by True North Consulting (TNC), based on assumptions as identified throughout the text and upon information, data and conclusions supplied by others. Any calculations or findings presented here may be changed or altered and should not necessarily be taken to reflect ECAN or TNC's final opinions or conclusions.

TNC is not in a position to, and does not, verify the accuracy of, or adopt as its own, the information and data supplied by others. Some of this information has been prepared by third party contributors, as detailed in the document. While the contents of those parts have been generally reviewed by TNC for reasonableness and consistency for inclusion and incorporation into the document, they have not been fully audited or sought to be verified or supported by TNC. TNC does not provide and does not purport to provide financial advice.

In respect of all parts of the feasibility study document no express or implied representation or warranty is made by TNC or by any person acting for and/or on behalf of TNC to any third party that the contents of the feasibility study document are verified, accurate, suitably qualified, reasonable or free from errors, omissions or other defects of any kind or nature. Third parties who rely upon the feasibility study document do so at their own risk and TNC and ECAN disclaim all liability, damages or loss with respect to such reliance.

Neither ECAN nor TNC, nor any person acting for and/or on behalf of those organisations, assumes any responsibility, duty of care or liability to any person with respect to the contents of the feasibility study document or with respect to any inaccuracy, absence of suitable qualification, unreasonableness, error, omission or other defect of any kind or nature in or with respect to the feasibility study document.

Any disclosure of this report to a third party is subject to this disclaimer.

CONTENTS

1.0 EXECUTIVE SUMMARY

It is estimated that, over the next fifteen years, approximately 15,000 tonnes of treated timber will be produced annually in addition to the 24,000 tonnes of demolition waste treated timber likely to be among the large waste timber stockpile at Burwood Resource Recovery Park. Most of this volume will be from ordinary activity, with about 1,750 tonnes being contributed by earthquake rebuild activity. Most of this waste will be CCA or boron treated.

A number of the treatment chemicals used in timber are hazardous and harmful to humans if released into the air, soil or water table. For this reason Environment Canterbury has tight restrictions on the burning of treated timber or its use as fuel. These resource consent restrictions require any treated timber process to rigorously control air discharge, adding significant cost to many potential processing technologies and rendering a number uneconomic.

There are a number of key issues that Christchurch faces in finding economically viable and sustainable outlets for treated timber waste:

- The lack of a large centralised demand for heat energy, due to the demolition of much of the CBD, renders some potential options uneconomic and generally requires any waste to energy utilisation to produce energy which can be stored and/or transported.
- Processing treated timber is generally expensive from a capital investment perspective and requires a certain scale to justify this investment and achieve economies of scale. Christchurch does not have a large population or large industries which overwhelmingly justify such an investment.
- In general, those pathways that are more researched and refined appear to offer less revenue potential than those that are novel and untested.
- There are limited active markets for *untreated* waste wood suggesting that the economics of utilising *treated* waste wood, which will typically require extra processing and handling, are challenging.

Processes such as incineration and gasification operate at high temperature and volatilise treatment chemicals, requiring expensive gas filtration systems which may produce additional hazardous waste streams. This negatively impacts their viability compared to other options.

Most of the processes which actually remove treatment chemicals from wood, with the possible exception of wet oxidation, are unlikely to be feasible because of the high costs of such processes and the difficulty in competing economically with untreated waste wood streams.

The potential market for utilising treated timber waste as a boiler fuel is large, but this market is already hesitant to use untreated timber, and the negative impact of treatment chemicals on boilers as well as air discharge issues makes this pathway unfeasible.

Electricity and heat cogeneration, which is a common end use for waste to energy projects, is made extremely difficult by the need to distribute heat through insulated reticulation. The markets for heat and electricity in Christchurch are currently unpredictable and do not present an attractive option given the high capital investment that would be required.

Recycling of treated timber waste into other products is also unlikely to be a large scale solution as options are limited and there are low incentives for manufacturers to utilise treated wood waste. Recycling also merely delays dealing with hazardous waste rather than offering a definitive solution.

The options most likely to prove feasible, based on the analysis undertaken in this report are:

- Using pyrolysis to create biofuels and charcoal
- Using torrefaction to create cement kiln fuel
- Using unprocessed (but ground) treated timber as cement kiln fuel
- Using hydrothermal processing to create biofuels
- Using the TERAX process to create saleable acetic acid

2.0 INTRODUCTION

The Treated Timber Waste Minimisation project was launched on 4 March, 2013 with its overall goal being "to test the feasibility of, and subsequently develop a sustainable business model for the large scale collection and reuse, recycling and/or recovery of hazardous treated timber waste, with a particular focus on earthquake-related building and demolition waste."

This Environment Canterbury led project has received $144,900 towards the project's overall cost of $190,900 from the Waste Minimisation Fund, which is administered by the Ministry for the Environment, with the remainder coming from the project's governance group, consisting of:

- Environment Canterbury (ECAN) – Project owner
- Christchurch City Council (on behalf of the Canterbury Joint Waste Committee)
- BRANZ Limited
- Scion Research

The feasibility study has three key objectives:

- Identify and/or create a business case, supply chain and financial model, and end use for the collection, reuse, recycling and recovery of up to 20% (5,000 tonnes) of waste treated timber in Canterbury in such a way that it presents compelling economic and/or brand benefits to all participants in the supply chain (waste owners, processors, logistics providers and end users).

- Identify an appropriate, effective, easy to use and low-cost tool to be used by demolition companies and/or waste processors[1] for identifying treated timber on demolition and/or waste processing sites[2].

- Increase collaboration between timber waste minimisation stakeholders including demolition, timber and waste industries, Environment Canterbury, Canterbury territorial authorities, construction interest groups and the wider community to improve waste minimisation management of treated timber over its lifecycle.

Overall, the project is aimed at creating a sustainable and economically viable process for the productive use of waste treated timber.

The project has been split into five key milestones:

1. **Industry Overview** (due 10 May, 2013)

   A situation analysis and overview of the current waste treated timber industry and potential applications for treated timber waste.

2. **International Industry Trends** (due 14 June, 2013)

   An overview of key international trends and technological developments in the waste treated timber industry internationally and how the application of different elements of these might work in New Zealand.

[1] Target users are demolition workers, transfer station workers, builders and surveyors
[2] Primarily it would be used on the demolition site, but could also be used at transfer stations, landfills and re-use locations.

3. **Part 1 – Potential Scenarios** (due 16 August, 2013)

   A report detailing potential new waste treated timber collection and reuse, recycling and/or recovery systems for application in New Zealand, and the risks, financial implications and potential benefits of each scenario.

   Part 2 - Timber Identification Tool Development (due 16 August, 2013)

   A report providing an overview of international research related to waste treated timber identification on demolition and/or waste processing sites and undertake a feasibility study on the application of this research to create a tool or toolkit suitable for use in New Zealand.

4. **Detailed Business Cases and Stakeholder Collaboration** (due 4 October, 2013)

   Detailed business cases for each preferred scenario, including pilot trial plans.

5. **Pilot Trials** (due 20 December, 2013)

   A final report detailing pilot processes and outcomes, and scenario details and implementation plan for the preferred option.

This report addresses the requirements of the first milestone 'Industry Overview' which are to:

- Identify key stakeholders including waste owners, processors and end users.
- Analyse the existing industry and mechanisms for recycling, recovering and reusing waste treated timber in Christchurch.
- Undertake interviews with key stakeholders to build understanding of industry activities, issues and relationships.
- Identify and explore key barriers, issues and limitations to recycling/recovery/re-use of waste treated timber in the current market.
- Identify and explore potential end-uses for treated timber and assess feasibility.

Currently there is no substantial market activity in Christchurch related to the productive utilisation of waste treated timber. It is therefore not possible to outline existing activities and related mechanism. Instead this report is focused on understanding the sources of treated timber waste, potential end uses for the waste (and the potential issues around these uses) and potential processing technologies for transforming raw treated timber waste into a form suitable for end use.

Much of the information in this report is based on interviews with key stakeholders in the waste industry and those that have been involved in developing or evaluating potential technologies or practical uses for treated timber waste. An extensive literature review has also been undertaken to aid in the evaluation of the feasibility of proposed processing technologies and end uses, although this has been focused on technologies and end uses that are available or are being developed in New Zealand currently, or which have already been broadly evaluated for application to the New Zealand context. The latest international trends, developments and research will be considered in Milestone 2.

3.0 WASTE TREATED TIMBER SOURCES

3.1 Treated Timber in New Zealand

In New Zealand, prior to the 1920s, chemical treatment of timber to prevent decay was rare. Native timber species such as kauri, rimu, miro and matai were commonly used, but without treatment of any kind. Many of these native timbers will decay if wet, so in the 1920s some began to be treated with creosote (a preservative made from coal tar). This practice continued until the 1940s when imported species such as pinus radiata and Douglas fir became more common. Pinus radiata became the standard timber used for building shortly thereafter, but it was not commonly treated until 1952, when boric and pentachlorophenol (PCP) treatments become the usual practice (BRANZ, 2013). From the 1950's through to the late 1980's PCP based fungicides were widely used in the New Zealand timber industry. For most of this period, virtually all freshly sawn timber produced in the country, predominantly radiata pine, was routinely surface treated to prevent the proliferation of fungi (MBIE, 2008).

Boron or boric treated timber is still common and is typically used as internal framing timber treated to hazard class H1.2 (see Table 3.1). Boric treatment protects against attack from borer (woodboring beetles) and also prevents decay caused by exposure of the wood to moisture. The US Environmental Protection Agency and the EU's chemicals agency ECHA have determined that boric acid should be considered hazardous due to its potential to cause eye and skin irritation, and there is some concern in New Zealand about the potential toxicity of boric treated timber (Scoop, 2011)

Table 3.1 – Treated Timber Hazard Classifications Guide (DBH, 2007)

HAZARD CLASS	EXPOSURE	SERVICE CONDITIONS	BIOLOICAL HAZARD	TYPICAL USES
H1.1	Protected from the weather, above ground	Protected from the weather, always dry	Borer	Interior finishing timber – see NZS 3602
H1.2	Protected from the weather, above ground, but with a possibility of exposure to moisture	Protected from weather, but with a risk of moisture content conducive to decay	Decay fungi and borer	Wall framing – see NZS 3602
H3 **(AS/NZS 1604)**	Exposed to the weather, above ground	Periodic wetting, not in contact with the ground	Decay fungi and borer	Plywood – see NZS 3602
H3.1	Exposed to the weather, above ground	Periodic wetting, not in contact with the ground	Decay fungi and borer	Cladding, fascia, joinery – see NZS 3602
H3.2	Exposed to the weather, above ground or protected from the weather but with a risk of moisture entrapment	Periodic wetting, not in contact with the ground, more critical end uses	Decay fungi and borer	Decks, pergolas, external beams, posts not in ground
H4	Exposed to the weather, in ground or in fresh water	Ground contact, or conditions of severe or continuous wetting	Decay fungi and borer	Fence posts, landscaping timbers not requiring a building consent
H5	Exposed to the weather, in ground or in fresh water	Ground contact, or conditions of severe or continuous wetting, where uses are critical and where a higher level of protection than H4 is required	Decay fungi and borer	House piles and poles, crib walling, posts in ground for decks, verandas, pergolas

Copper chrome arsenate (CCA) treatment was introduced into New Zealand in 1955 for application to timber exposed to weather, initially being just fencing and similar applications (BRANZ, 2013). In terms of the three chemical elements within CCA treatment "copper is used to control fungi and marine borers, arsenic to control insects and some copper-resistant fungi, and chromium to fix the copper and arsenic in the wood" (Read, 2003). CCA treated timber is recognised as being potentially hazardous internationally, and has been banned from use in countries such as Japan and Germany (Love, 2007).

CCA treated timber began to be used extensively for high decay areas in New Zealand housing in the 1970s, and is the primary timber treatment used in these areas to this day (BRANZ, 2013). In 1998 a change to the New Zealand standards for timber treatment allowed the use of untreated timber in wall framing. This change, combined with novel and relatively untested building practices and materials, contributed to the 'leaky homes' problem where many New Zealand homes experienced rotting of internal framing timber (Consumer, 2013). This issue has allegedly created scepticism among consumers and suppliers about alternative timber treatments and has likely increased CCA treated timber usage (Keene et al, 2009). The latest Acceptable Solution (B2/AS1 – Amendment 7, dated 4 April, 2011) which allows a builder to demonstrate compliance with the building code, requires that virtually all enclosed framing timber be H1.2 treated (DBH, 2011).

In addition to boric and CCA treatments, a number of other chemical treatments of timber are or have been in use in New Zealand at lower levels, including:

- *Alkaline or ammoniacal copper quaternary* (ACQ) – a water-based preservative consisting of a mixture of copper, a fungicide and a form of ammonium (EPA, 2012)
- *Copper azole* (CA-B / CA-C) – a water-based preservative that protects against fungal and insect attack (EPA, 2012a)
- *Light Organic Solvent Preservatives* (LOSP) *Azoles* – LOSP is a white-spirits based wood preservative that allows the timber to be rated to H3 (NZTPC, 2004). While potentially harmful chemicals are used, no heavy metals are impregnated into the wood (Keeling, 2011)
- *Light Organic Solvent Preservatives* (LOSP) *Organic Tin* – LOSP treatments containing tributyltin oxide (TBTO) and tributyltin naphthenate (TBTN) are white-spirits borne wood preservatives that allow the timber to be rated to H3.1 (NZTPC, 2004)
- *3-Iodo-2-propynyl butylcarbamate* (IPBC) – a "non-formaldehyde-releasing" chemical based on iodine. Effective against fungus and bacteria" (Keeling, 2011).
- *Copper Naphthenate* – "an organometallic compound formed as a reaction product of copper salts and naphthenic acids derived from petroleum" (Keeling, 2011).
- *Pentachlorophenol (PCP)* – Pentachlorophenol is a manufactured chemical typically used to treat posts and power poles. It has also been widely used in New Zealand to treat house framing timber, but ceased to be used in 1988. In the USA it is a commonly used pesticide (ECY, 2013).

Wood may also be 'contaminated' with creosote, waste oil, paint, stains or other chemicals.

The following table shows the most recently available production estimates for treated timber, from 2006, demonstrating the relative popularity of different treatment types:

Table 3.2 – Common Treated Timber Types in New Zealand

Treatment Type	Estimated 2006 Production (m^3)	% of Total Production
CCA	574,750	69%
Boron	175,000	21%
LOSP (all types)	86,000	10%
ACQ and Copper Azole	5,000	0%
All Types	**830,250**	**100%**

(Love, 2007)

For the purposes of this report 'treated timber' refers to any and all of these treatment types, unless otherwise specified. Where 'treatment chemicals' are mentioned, this will typically refer to copper, chromium, arsenic and boron, but may also include pentachlorophenol.

3.2 Health Effects Related to Treated Timber

The most common timber treatment chemicals are chromium, copper, arsenic and boron. Other treatments, such as light organic solvent preservatives and pentachlorophenol have also been used in New Zealand but are no longer common. These chemicals are used because they have hazardous properties; they are fungicidal, herbicidal and/or pesticidal and are employed to prolong the life of the timber. As well as being toxic to pests, these substances tend to be hazardous to humans.

The main risks these chemicals present to human health are through contamination of natural resources such as air, water and soil. In Canterbury this risk is greatest in terms of water and air. Any treatment chemicals that reach the drinking water aquifers beneath the Canterbury Plains in large volumes would be potentially detrimental to public health. The uncontrolled large-scale burning of treated timber is also likely to pose a significant health risk to the general public.

The main ways these chemicals can enter the human body are through:

- Ingestion – directly, or through ingestion of plants where contaminant uptake has occurred, or through water where contaminants have polluted drinking water
- Inhalation of contaminated dusts, particles or aerosol mists
- Direct contact with the skin

The risk is greatest for people directly handling treated timber, but for people not coming into direct contact with treated timber the primary risks are exposure through inhalation of contaminated particles and ingestion of drinking water or plants that have been exposed to treated timber (OSH, 1994). In terms of specific treatment chemicals, the primary health risks are as follows:

- *Copper*: Chronic exposure to significant concentrations of copper can cause liver and kidney damage if ingested (DES, 2005).
- *Chromium*: The 'trivalent' form of chromium is a sensitising agent, which can cause symptoms such as skin irritations, irritation of mucous membranes and asthma (Beca, 1998). 'Hexavalent' chromium, which is the typical form used in timber treatment, is much more hazardous than trivalent chromium and has been confirmed as a human carcinogen, particularly in relation to lung cancer.
- *Arsenic*: Inorganic arsenic causes a range of carcinogenic and non-carcinogenic effects and a link has been identified between arsenic in air and water supplies and increased instances of skin, bladder and liver cancers in various countries around the world (Beca, 1998). One of the challenges with arsenic and chromium in particular, is that they *volatilise* (vaporise and become more volatile) at high temperatures, resulting in hazardous air emissions.
- *Boron*: Boric acids, oxides and salts are used as a lower hazard class of treatment, being less toxic than CCA treatments. Boric acid can have acute and chronic effects on human health, including irritation to the eyes and skin, effects on the endocrine system and metabolism (EPA, 1993).
- *Pentachlorophenol (PCP):* Chronic PCP exposure can lead to irritation of the skin, mucous membranes and the respiratory tract. It can also cause depression, headaches, porphyria and

changes in the liver and kidney functions. The US EPA suggests that prolonged exposure to PCP may increase the risk of cancer (EPA, 2007). When burned, PCP can cause the creation of dioxin, which can cause skin irritations, mild liver damage and may also be carcinogenic (MFE, 2011).

3.3 Treated Timber Waste Sources

Table 3.3 - Timber Treatment Identification (DBH, 2007)

HAZARD CLASS	METHODS OF IDENTIFICATION		
H1.1	End branding		
H1.2	Permethrin plus TBTO, TBTN or IPBC		Blue
	Boron		Pink
H3 (AS/NZS 1604)	Face branding		
H3.1	H3.1 framing shall be face branded along the length at 1500 mm centres only on its face or edge.	TBTO TBTN	No added colour or, if coloured green, the colour is to be distinctly different from the green of the H3.2 preservative treatment (colour green 368).
H3.2	No added colour, the natural colour of treated timber is varying shades of green/brown.		
H4			
H5			

Whereas almost all of the rebuild waste from the Canterbury earthquakes is likely to be treated, demolition waste from homes built prior to the 1970s is unlikely to be treated with anything other than creosote, except where the home has been extended or modified, or from outdoor structures. Most of the timber waste that is treated will be CCA or boron treated.

As is shown in Table 3.3, colour coding will enable identification of timber type in some circumstances. The green colouration on higher hazard class treated timber is not always evident, fading over time.

Tom Clark, the Bulk Process and Recycling Manager for Frews Contracting, says that despite the limitations in relying on colour coding of treated timber the age of a home is a "good guide" for those working in residential demolition, and there is usually "very little doubt" as to whether timber in a given location is treated or untreated. This ability has not been independently verified, however, and it is difficult to see how this could be done with accuracy.

There are three key sources of treated timber waste in Christchurch, each of which is considered in the following sections:

- Extraordinary waste treated timber from demolition activity linked to the Canterbury earthquakes
- Extraordinary waste treated timber from rebuild activity linked to the Canterbury earthquakes
- Ordinary treated timber waste from building, agriculture and other activities

3.4 Earthquake Demolition Waste

The earthquakes that struck Canterbury in 2010 and 2011 resulted in building demolition activity unprecedented in New Zealand's history. Over 1,300 commercial buildings have been approved for demolition in Christchurch, most of which have already been levelled (BF, 2012). Tom Newton, Project Manager at Project Management Office (PMO) Arrow International, estimates that of the total of 12,000 residential dwellings that are to be demolished, over 2,000 have already been completed.

Beyond this basic information, estimating the amount of treated timber waste that will eventually result from the Canterbury earthquakes is extremely difficult, and becomes a matter of 'educated guesswork' based on often inconsistent data.

Most of the earthquake demolition waste will be sent to the Burwood Resource Recovery Park (BRRP). The Christchurch City Council and BRRP Ltd, a subsidiary of Transwaste, as co-owners of the BRRP have received resource consents to process and recycle earthquake waste at BRRP, and permanently dispose of earthquake waste at Burwood Landfill (CCC, 2012). Gareth James, General Manager of Transpacific (part owner of Transwaste) estimates that by the conclusion of demolition activity, about 500,000 tonnes of earthquake-related waste will have been sent to Burwood, "the majority of which is wood". Newton estimates that Arrow International has sent about 70,000 tonnes of timber waste to BRRP, and that about 160,000 tonnes of timber may be left to demolish, mainly in residential dwellings. As Arrow International has responsibility for 38% of the residential demolition (about 4,500 properties) this would suggest a waste timber total across all PMOs of 300 – 400,000 tonnes of earthquake related waste timber, which appears to align with Transpacific's estimate.

Newton advises that Arrow International are completely 'flatpacking' and reusing about 5% of homes and a further 5% of older homes are being relocated but that all other earthquake waste is being sent to BRRP or to Frews Contracting.

Figure 3.1 - Untreated timber stockpile at Frews Contracting on Johns Rd, Christchurch

Tom Clark of Frews Contracting advises that any "light loads", including treated timber framing, go directly to BRRP. The heaviest loads, approximately 15% of total volume or 600 tonnes a month, are taken to Frews' sorting line on Johns Rd near Christchurch airport.

Untreated timber is visually sorted on the line and then sent for processing at Cass St Recycling (CSR) in Sydenham. CSR processes the untreated timber using a shredder and sells the resulting wood chips as boiler fuel.

Frews are motivated to sort where they can, as they pay only $40/tonne to dispose of untreated timber versus $120/tonne to dispose of waste at BRRP. Clark says that they are very keen to find outlets for treated and untreated timber (there is an evident concern that CSR may not continue to take untreated timber for much longer) and would gladly pay up to $80 per tonne to dispose of treated timber and $60 a tonne for untreated timber. Newton advises that the majority of the incentive for recycling treated timber rests with the demolition companies such as Frews but that a viable outlet for treated timber would potentially allow cost savings "to filter through the system" for the benefit of all.

Both Clark and Newton are confident in the ability of their teams to visually sort untreated timber from treated timber, but say that it is not really economic to do so, and that the waste that is being sent to BRRP is an unsorted mix of treated and untreated wood. It is unlikely, however, that visual sorting is a reliable method for treated timber as visual clues to treatment may not be present.

Clark estimates that treated timber comprises 3% of the total timber volume (9,000 – 12,000 tonnes in total) whereas Newton believes that about 10% of the timber handled is treated (30,000 – 40,000 tonnes in total). This estimate range (3% - 10%) compares reasonably well to historical studies undertaken in

Florida which concluded treated timber represented approximately 5.9% of the C & D timber waste stream (Rhodes, 2010).

No specific data on the age of homes being demolished could be obtained for this report, but it is probable that most of the homes will be of pre-1980s construction, suggesting they will not contain large quantities of copper-treated timber. However, Newton advises that the remainder of homes to be demolished in Christchurch will be completed within the next year, with fences then becoming the major focus. Fences have largely been left untouched so far in terms of demolition in Christchurch and most of these will be constructed of H4 treated timber, substantially increasing the volume and proportion of treated timber waste at BRRP.

With these factors in mind, a total waste timber estimate of 400,000 tonnes will be adopted for the purposes of this report, with a total treated timber estimate of 24,000 tonnes, or 6%. Of this, based on the estimates noted in Table 3.2, approximately 16,500 tonnes will be CCA-treated, 5,000 will be boric treated and the remainder will be LOSP or copper-treated.

In fact, the proportion of timber that is treated may be somewhat unimportant in practice. Transpacific's Gareth James has confirmed that Transwaste plans to landfill all treated and untreated timber until a productive use for it can be found. It is highly likely that the economics of individually sorting each piece of timber will be prohibitive, and thus the entire stockpile must be handled as if it is *all* treated. The proportion only becomes useful in estimating the concentration of treatment chemicals that is likely to be present in a load of mixed timber waste from BRRP.

3.5 Earthquake Rebuild Construction Waste

In addition to waste timber from the earthquake demolition, further volumes will be generated by building activity specifically linked to the earthquake. As with demolition timber waste, there are few sources of 'hard data' to rely on in estimating future rebuild volumes and timing.

Christchurch City Council figures show that residential building consent figures have recently grown to an average of 31 per week, up from 24 per week for the same time period in 2008 (RC, 2013). This suggests, as expected, that the residential rebuild is beginning to gain momentum.

The Land Use Recovery Plan (LURP) Summary recently released by Environment Canterbury estimates that some 36,150 new residential dwellings will be required in Canterbury between now and 2028, with demand steadily increasing over that time (ECAN, 2013). About one third of this demand will be directly attributable to earthquake-related demolitions with a further unknown proportion attributable to other earthquake-related activities such as housing for workers engaged in the rebuild itself. If 36,150 new homes are built over the next fifteen years, this equates to 2,410 homes a year on average, although the LURP suggests this activity will start slowly and grow more quickly towards the end of this time period.

The 2006 census showed that 521,832 people lived in the Canterbury region at this time, of which 348,435 or 67% lived in Christchurch. Additional Statistics New Zealand data shows that, between Q1, 2005 and Q4, 2010 (preceding the earthquakes) 21,009 residential building consents were issued in Canterbury, with an average floor area of slightly above 200m^2. Combining this information it is estimated that, pre-earthquake, a total of 2,346 new homes were built each year in Christchurch, compared to 2,410 per year over the next fifteen years.

This data gives the impression that the volume of timber waste from the residential rebuild will not be significantly greater than the volume of timber waste seen prior to the rebuild in Christchurch, although the proportion of this waste that is treated will increase due to changes in the building code relating to the use of treated timber.

A recent report into waste generated by residential building activity undertaken by Beacon Pathway suggests that about 5.6 tonnes of waste per home is generated in the construction of a three bedroom home, and that typically 40% (or 2.2 tonnes) of this would be timber (Kazor et al, 2013).

Another study estimated that 0.14 cubic metres of timber is used for every square metre of a typical residential dwelling (Buchanan et al, 1999). BRANZ estimates that 11% of timber used in residential construction will be wasted (BRANZ, 2013). As pinus radiata weighs approximately 480kg per m^3, calculating these figures together means a $200m^2$ home constructed from pinus radiata would utilise about 15.3 tonnes of timber (assuming the figures from the Buchanan report are ex-wastage), and waste 1.7 tonnes of timber.

Another industry estimate suggests a figure of 1.15 tonnes per $100m^2$ of floor space, indicating a total of 2.3 tonnes of timber wasted for a $200m^2$ home (Wilson et al, 2012).

The approximate average of these three figures, 2 tonnes of timber waste per new home constructed, will be utilised for this report.

The latest revision to the Building Code (amendment 7 April 2011) requires that virtually all of the timber used in new construction is treated so utilising the figure of 2 tonnes of waste timber per home for 36,150 new homes would give a total of over 72,300 tonnes of waste treated timber from the residential rebuild alone, or roughly 4,820 tonnes a year.

The biggest challenge in handling these estimates is understanding the relationship between data for 'ordinary' waste treated timber streams to landfill and data relating to predicted waste streams from earthquake-related residential building activity over the next fifteen years. Simply adding the estimates above to typical waste timber data for Christchurch landfills will overestimate volumes as the data from the LURP includes typical building activity in Christchurch that would have occurred even without the earthquake.

As approximately 12,000 homes are being demolished, it is assumed for the purposes of this report that this is the total amount that represents 'extraordinary' building activity related to the earthquake. At an estimated treated timber wastage estimate of 2 tonnes per home, this gives a total figure of 24,000 tonnes, or 1,600 tonnes per year for the fifteen year period.

Additional timber waste will be generated from commercial rebuild activity, although data on this is even more difficult to come by. Approximately 1,300 commercial buildings have been or will be demolished in Christchurch, although no specific data is available on total floor area of these sites. The amount of timber likely to be utilised in these buildings, and hence the amount likely to be wasted, will depend largely on the design and materials specifications used. Modern commercial buildings, particularly the concrete 'tilt-slab' variety, often use relatively small quantities of timber, mainly for wall framing. There is a push from organisations such as NZ Wood and the Structural Timber Innovation Company (STIC), however, to promote technologies such as Laminated Veneer Lumber (LVL) for structural use in new commercial buildings (Stuff, 2013).

To form an estimate of likely commercial rebuild treated timber waste volumes, the starting point needs to be an understanding of how much floor space has been lost, with an assumption that this will be rebuilt. As of September 2010 the Christchurch CBD office stock totalled $446,002m^2$, with hotel rooms totalling approximately $136,000m^2$ and retail space adding another $40,000m^2$ (CERA, 2012). If, as is commonly stated, half of the commercial buildings in the CBD have or will be demolished and rebuilt this suggests about 310,000m^2 of earthquake-related commercial rebuilding will be undertaken (BF, 2012).

As with residential construction it is estimated that 0.14 cubic metres of timber is used for every square metre of a typical office building (Buchanan et al, 1999). Using the same wastage (11%) and wood weight (480kg/m^3) figures as employed to determine residential treated timber waste, it is estimated that total treated timber waste from commercial rebuilding will be about 2,300 tonnes, or approximately 150 tonnes per year for 15 years.

3.6 Non-Earthquake Related Waste

Ministry for the Environment survey data on landfill volumes suggests that in 1996 10,000 tonnes of timber was sent to landfill in Christchurch, representing 4.6% of total landfilled material. In 1999 this had increased to 21,985 tonnes or 9.6% (MFE, 2004). In the 2011/2012 financial year the total amount of waste sent to landfill in Christchurch was down to 205,000 tonnes from the 1999 figure of 228,267 tonnes (Stuff, 2013b). The latest figures from MFE suggest that timber makes up 11% of landfill waste across the country (MFE, 2009). Assuming this waste composition is reflected in Christchurch, approximately 22,550 tonnes of timber was sent to Christchurch landfills in 2011/2012.

Recent waste audits undertaken to determine the composition of waste timber suggest that about 60% of timber waste is likely to be treated or otherwise ‘contaminated’ with paint, oil, stain or other treatment chemicals (Wilson et al, 2012). Using this proportion suggests a figure of about 13,500 tonnes per year of treated timber waste from ‘ordinary’ activities. This may vary from year to year but serves as a reasonable baseline estimate for treated timber waste.

3.7 Estimated Total Treated Timber Waste Flows

The estimates produced in the preceding sections are utilised here to provide an overall prediction of waste treated timber flows. As the estimated capital lifespan of much of the equipment that can potentially be used to process treated timber waste is fifteen years, and given this is the extent of the projected housing demand data from Environment Canterbury, volumes are estimated over this timeframe. Therefore, the following flows of waste treated timber are expected in Christchurch over the next fifteen years:

Table 3.4 – Total Estimated Treated Timber Flows in Christchurch (2013 – 2028)

Waste Source	Approx. Expected Tonnage (per annum)	Approx. Expected Tonnage (15 year total)
Earthquake-related demolition	1,600 *	24,000
Earthquake-related residential construction	1,600	24,000
Earthquake-related commercial construction	150	2,250
Non-earthquake-related activity	13,500	202,500
Totals	**16,850**	**252,750**

* Assuming the stockpile is used evenly over the fifteen year period

It is evident from these estimates that, while timber waste generally has been greatly increased by the Canterbury earthquakes, *treated* timber waste has only been boosted in volumes by about 25%. This emphasises that the issues around treated timber are not simply earthquake-related, but have been and continue to be present from ordinary activities.

4.0 POTENTIAL PROCESSING TECHNOLOGIES & METHODOLOGIES

There are many processing technologies and methodologies which may be applied to waste treated timber in order to transform it into a safe and useful resource. The following section considers only those that are known to be currently used in New Zealand, or which have or are being actively developed or evaluated in New Zealand for use with treated timber. Emerging technologies which are in use or development outside of New Zealand will be considered in the report for Milestone 2 of this project.

The technologies and processes considered here are those that move the waste from one state to another. End uses or end of life options are considered in Section 5.

4.1 Incineration

Incineration of waste treated timber by 'traditional means' involving air discharge and ash production is very difficult in any location, including Christchurch. The consenting requirements to undertake such a venture (and indeed any process that involves burning of treated timber) are stringent due to the potential environmental hazards involved in burning treated timber.

The first of these hazards is hazardous air discharge. In Canterbury, the rules around air discharge are set and enforced by Environment Canterbury (ECAN). Kevin Swete, Consents Investigating Officer for ECAN advises that no resource consent application for burning treated timber in Canterbury has ever been received, likely reflecting the fact that such a consent would not be easy to obtain. It is important to note, however, that no outcome for a resource consent application is predetermined and that the outcome depends on the particular make-up and merits of that application.

The reason for this is that "studies show that, depending on the combustion conditions, 10-90% of the arsenic present in CCA-treated wood may be lost to air, either as volatilised As_2O_3 or particulate matter." (APVMA, 2003)

Rule AQL12 of the Canterbury Natural Resources Regional Plan (CNRRP) states that "burning of chemically treated timber (other than specially manufactured pellets) can cause the discharge of treatment chemicals such as copper, chromium and arsenic. Long term accumulation of these chemicals in the environment may cause negative health effects". The use of treated timber in small scale burners (less than 40kW) is completely prohibited to prevent residential use, whereas for larger burners utilising wood which is CCA treated or 'stained or oiled' for fuel is considered a 'non-complying activity' under Rule AQL12a of the CNRRP, meaning that a resource consent is required to undertake the activity. This rule specifically states that there are likely to be instances where burning of CCA treated wood waste does not create a "significant adverse effect" and that doing so will require "purpose built high temperature large scale fuel burning devices." As well as the discharge of timber treatment chemicals, ECAN also regulates the discharge of PM_{10}, which would be a potential issue with any incineration activity

Swete advises that, under s95A of the Resource Management Act 1991, any resource consent application to burn treated timber waste is likely to be publically notified, offering the public the right to submit on and appeal the resource consent decision. In addition to any public objection to the burning of treated timber waste, which is likely to be significant, ECAN would focus on the nature of the potential air discharge itself.

Where a consent is sought, advises Swete, the application would be looked upon more favourably if the activity:

- Is conducted in a rural or semi-rural location outside the Christchurch clean air zones; and
- Ceased during winter months; and
- Has low or no particulate discharge; and
- Has no contaminant discharge.

It is clear that these requirements would be very difficult to meet for anyone burning treated timber and would require expensive filtration systems if standard combustion technologies were used. Aside from this, no one has undertaken an assessment of environmental effects for this activity so it is unknown what the environmental effects would be. One major barrier in obtaining a resource consent is proving to the regulatory authority that the incineration activity does not cause unacceptable adverse effects - something that has not yet been attempted in Canterbury.

In addition to air discharge, the ash generated by burning treated timber is also likely to be hazardous and require specialist handling. Furthermore, the combustion process results in ash that contains arsenic and chromium in particularly hazardous forms, with more arsenic being produced by weathered wood (such as from earthquake-related demolition) than from unweathered wood (Solo-Gabriele et al, 2004). Ultimately "the ash produced contains all the copper, chromium and arsenic that were present in the treated wood before burning, less any loss of arsenic to the atmosphere" (AVPMA, 2003).

Due to the challenges involved in combustion of treated timber ECAN rightly state that any such operations would involve 'purpose built high temperature large scale fuel burning devices'. One potential process that could be utilised is that created by Auckland-based Combustech.

Figure 4.1 - A Combustech plant (Combustech Flyer)

Combustech has over twenty years' experience in developing waste to energy combustion systems and provide their own proprietary technology called Alternative Energy Plants (AEPs) which are specially designed to burn waste wood. The AEP units are designed to produce heat energy, with the potential for cogeneration of electricity. The heat plants are typically in the 1MW to 10MW range but Combustech can produce larger units.

Combustech Managing Director Sean Appleby says that the AEPs are built on specialised technology developed by his grandfather. The heat plants run at low temperature – avoiding volatilisation of the treatment chemicals in treated timber – and are smokeless and odourless.

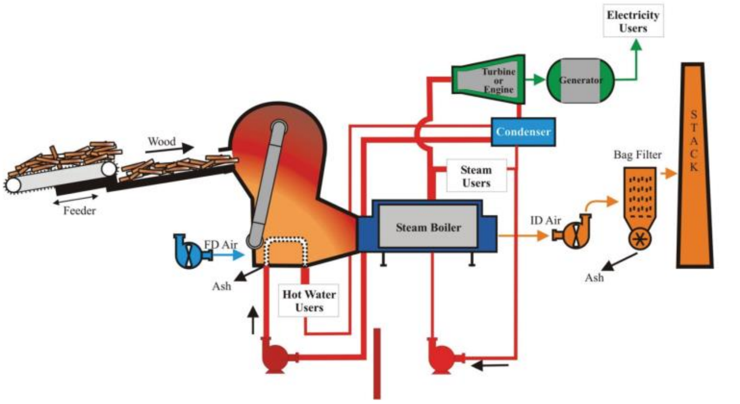

Figure 4.2 - The Combustech process (Combustech Flyer)

Combustech has a worldwide patent on their particular technology and has commissioned a number of plants, but recently "they have had to downscale their efforts". Combustech are currently looking for investment and growth opportunities.

A prototype 5MW Combustech AEP was constructed in Auckland in 1987 to incinerate untreated wood waste destined for landfill. Appleby advises that this facility met all council requirements, even when tyres, plastics and other non-traditional fuel sources were burned.

One of the key advantages of the AEP is simplicity. The unit is essentially a "one-man operation" according to Appleby, and can take wood of all shapes and sizes, avoiding the need to invest in sorting or shredding equipment which can significantly increase capital expenditure requirements in other wood waste processes. The AEP can also handle other alternative fuels including tyres, steel, oil and paint, so long as 60% of the total feedstock is wood.

As the fuel is burnt it forms charcoal which creates a 'natural filter' through which exhaust gases are passed to enact a secondary combustion. Appleby says this filtration is a key benefit and innovation in the Combustech technology and reduces air discharge issues.

Combustech is now working to break into the Christchurch market and seek ECAN 'approval in principle' of the AEP technology in terms of air discharge. Appleby acknowledges that this is potentially a significant barrier, but is confident that their air discharges will meet council requirements.

Specifically, Combustech plans to focus marketing efforts on companies using large industrial coal boilers, with a view to offering an alternative. A 1MW unit would likely cost $3 – 4 million, with heat being the major output, whereas the largest users such as Synlait or Fonterra may need at least a 5MW plant. Appleby says he has calculated that users moving to AEPs would enjoy significant operational cost savings, but the capital costs of changing to an AEP would clearly be large.

Appleby does think that locating a larger centralised plant at the Burwood Resource Recovery Park is an option, but feels that the economics of focusing on electricity production are unappealing and the logistics of providing heat to the market from this location are not feasible.

Appleby believes it is particularly unfortunate that the "2 – 3%" of the demolition waste wood from the earthquakes that is treated may prevent the entirety of the waste wood from being used in their process, and would like to engage in sample testing of the stockpile to actually determine how much treated timber they are likely to encounter.

It is clear that Combustech are still grappling with the challenges of potentially using treated timber as a fuel source. Appleby says that, when moving from coal to treated timber waste as a fuel, the reductions in sulphur dioxide and PM_{10} particulates must be balanced against potentially increased arsenic and chromium emissions. Combustech intends to utilise bag filters or wet scrubbers to prevent hazardous air discharge, but has not yet received advice from the manufacturers as to whether such filters or scrubbers will suffice. Appleby acknowledges that such filters are likely to be expensive and may negatively affect the economics of the system, but that “they will deploy whatever is required”.

No specific consideration has yet to be given to ash handling, although Appleby says that the ash produced by the AEP will certainly “contain nasties” and will need to be disposed of in a “special landfill”, which in actuality would be Kate Valley.

In summary, Combustech offers a combustion heat to energy system that apparently produces a lower level of hazardous air discharge than would be produced by a simple combustion unit. The unit is designed to utilise energy as heat and/or energy, the challenges of which are considered in the following section.

The economic challenges in the business model being advanced by Combustech are not difficult to identify. In addition to requiring large capital investment in moving from existing boiler units, Combustech’s AEPs will also require significant ongoing expenditure in terms of air discharge filtration and scrubbing, which is likely to be prohibitive. Users will also be required to handle a new waste stream, being hazardous ash from the combustion units. This will also incur additional cost. Finally, there will potentially be substantial costs involved in transporting fuel from BRRP to remote locations in accordance with Combustech’s strategy of promoting a number of smaller decentralised units (likely outside of Christchurch to meet consenting requirements) rather than a single, larger unit.

Based on the probable lack of economic feasibility of this approach when compared with retaining existing coal-fired boilers, and on the likely difficulty in securing resource consents for burning treated timber, combustion via Combustech’s AEP process is not considered feasible as a solution for waste treated timber in Christchurch while the existing barriers remain in place.

4.2 Gasification

The abundance of wood waste in New Zealand has naturally generated interest in utilising wood as a fuel source, particularly in the forestry sector. One of the key emerging technologies being considered for wood waste utilisation is gasification.

Unlike combustion technologies, gasification starves the process of oxygen and directly converts carbon-based materials directly into a gas. There is no combustion of the fuel, but rather a “high temperature chemical conversion process” at temperatures between 700 - 900°C as opposed to temperatures above 900°C which are typical in incineration (GTC, 2011).

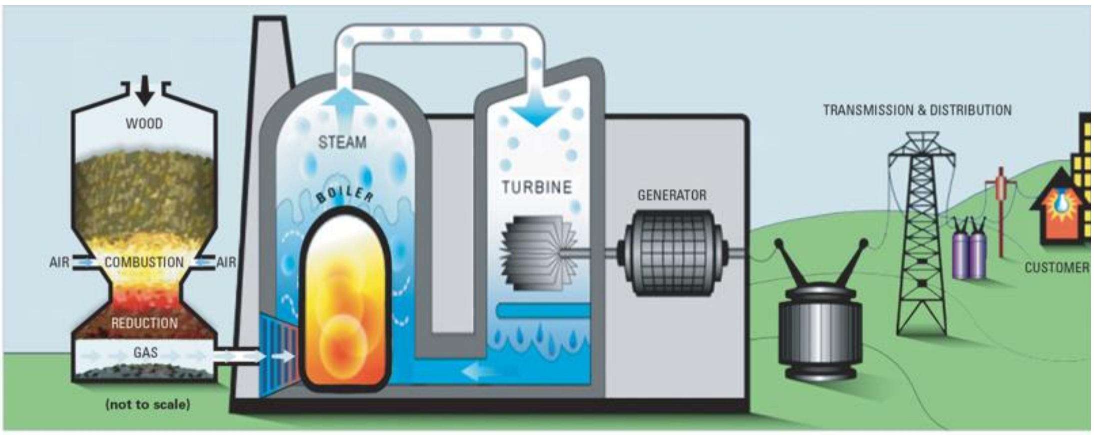

Figure 4.3 - Biomass Gasification Process (www.bermanbes.co.uk)

The resulting 'producer gas' or 'syngas' which is composed of carbon monoxide, hydrogen and methane, can be cooled and filtered to provide fuel for combustion processes, or it can be scrubbed and used to fuel a gas engine for the generation of electricity (EECA, 2009).

Gasification is considered a more efficient solution from the conversion of waste to energy than combustion technologies, with nearly twice the energy recovery potential as conventional waste to energy plants typically achieve (GTC, 2011).

The primary concerns with gasification of treated timber waste are the same issues that make incineration unacceptable from an environmental perspective: volatilisation of the treatment chemicals present, particularly arsenic and the production of hazardous ash. These concerns are the reason why there are currently no known commercial operations for the gasification of treated waste wood (Love, 2007).

One of the leading researchers into gasification technology development in New Zealand, Dr Shusheng Pang of the University of Canterbury's Wood Technology Research Centre, believes that these issues make gasification of treated timber uneconomic. Vapourised arsenic gas can be handled with the use of a liquid scrubber, which uses a solvent to trap pollutants in flue gas, but this is likely to be "very expensive" and "very difficult at high volumes", according to Pang. Large volumes of solvent would be required, which creates a new waste stream that must be carefully handled and disposed of.

Pang believes that the consideration of any processing technology for wood waste must focus on the economics of handling the metals in the treated timber waste. Gasification would create both a hazardous gas issue and a hazardous ash issue. Recovery of the metals from these waste streams would then require another process – chemical extraction – which would also be expensive and further diminish the feasibility of the overall approach.

The high waste handling costs involved in gasification of treated timber, and the availability of preferable processing technologies (see the following sections) suggest that gasification is not a viable option for treated timber waste in Christchurch.

4.3 Pyrolysis

Pyrolysis is similar to gasification in that it directly converts biomass into another state through the application of heat in the absence of oxygen. The primary differences between pyrolysis and gasification are that pyrolysis occurs at lower temperatures (typically 400 - 600°C as opposed to 700 - 900°C for gasification) and the main outputs are carbon-rich biochar, pyrolysis oil and, to a lesser extent, pyrolysis gas.

One of the key advantages of pyrolysis over gasification and incineration is that there tends to be much lower instances of arsenic volatilisation, to the point where a process like chemisorption (where one substance is chemically bound to another) can extract arsenic rather than the more expensive flue-gas cleaning filters or scrubbers (Helson et al, 2004).

Dr Shusheng Pang of the University of Canterbury's Wood Technology Research Centre notes that "60 – 70%" of published literature on disposal of treated timber concludes that low-temperature pyrolysis is the preferred thermochemical process for treatment of CCA-treated wood waste. Pang still believes that further testing and refinement is required before pyrolysis will be suitable for commercial deployment in New Zealand.

Pyrolysis is, however, being used internationally in at least one location to process CCA-treated timber waste. The Bordeaux, France based company Thermya has created a large commercial pyrolysis plant that handles treated timber and a number of other organic wastes at a rate of 10,000t/year (Hery, 2004). The Chartherm process handles hazardous substances well and avoids them reaching the atmosphere, but an additional process would be required to separate residual metals at the end of the process if they are to be reused (Love, 2007). The key saleable output of the Chartherm process is a clean carbon product which can be sold as Carbon Black, a fine powder used in ink and paint (Keene et al, 2009). One tonne of timber waste can produce 280kg of clean carbon, worth about US$1.00 a kg. This would indicate the Chartherm plant could generate US$2,800,000 in revenue from the sale of its carbon output (Hery, 2004). It should be noted, however, that the Chartherm process is not completely self-sustaining and requires energy input (Love, 2007).

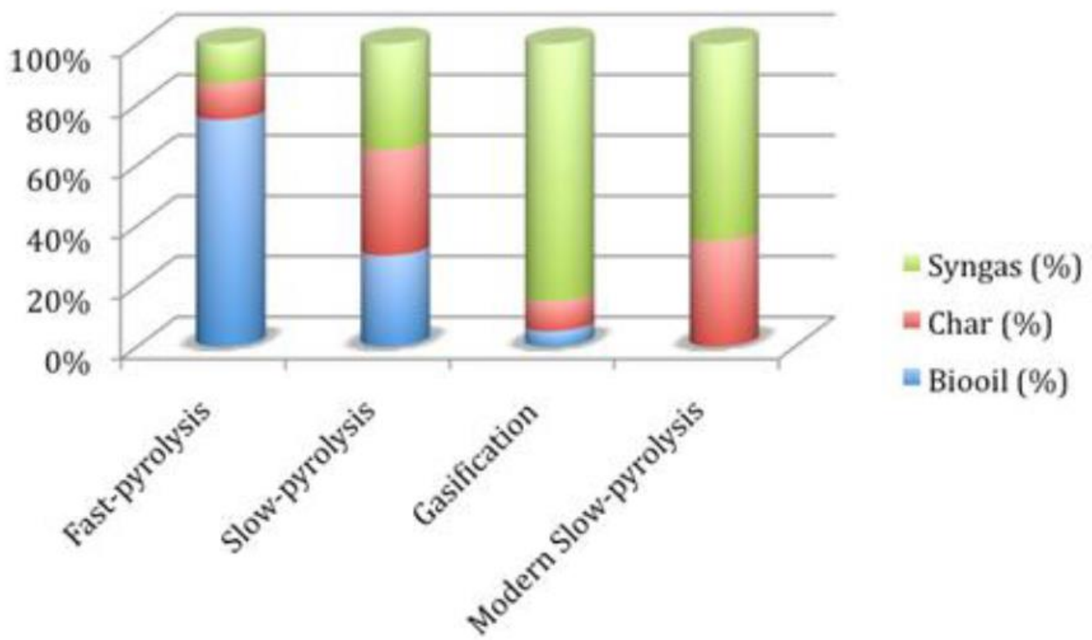

Figure 4.4 - Pyrolysis and gasification outputs (Downie, 2011)

Other pyrolysis plants earn revenue from sales of biochar, bio-oil or syngas. Biochar is particularly useful as a soil conditioner and can be “added to soils with the intention to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases, although there would need to be a high degree of confidence that no CCA treatment chemicals were present in the biochar before it could be used in this manner. Biochar also has appreciable carbon sequestration value. These properties are measurable and verifiable in a characterisation scheme, or in a carbon emission offset protocol” (IBI, 2012). Despite these properties, Hamish MacKinnon of Australian-based environmental consulting firm Earth Systems, and former student of Dr Shusheng Pang, believes that biochar is required to a lesser degree to improve New Zealand soil conditions compared to countries such as Australia.

Bio-oil can be used to fuel space heaters, furnaces and boilers and can also be used to fuel combustion turbines and reciprocating engines to produce electricity, an end use for which it is particularly efficient (Badger et al, 2006). It can also be refined and used as a transportation fuel or biodiesel (Laird, 2008). Syngas can be burned directly as fuel or can also, like bio-oil, be refined as transportation fuel (Laird, 2008).

An international study undertaken in 2005 considered the viability of pyrolysis to transform organic matter including wood, in a city in Mexico (Snow et al, 2005). The proposed plant would use pyrolysis to process untreated wood waste and generate revenue from the sale of biochar, while also producing electricity. While the information in this study is not directly applicable, in that treated timber was not being considered as fuel and it is located in Mexico, the financial model contained in the study gives some idea as to potential capital outlay and ongoing costs for a similar plant in Christchurch.

The revenue from the plant was assumed to be US$10 per tonne for a 'gate fee' for disposed wood, plus US$400 per tonne revenue from biochar sales and 10c/kWh for electricity production. The capital equipment was designed to last 15 years receiving 75 tonnes of wood per day (about 26,000 tonnes per annum) at a total capital cost of US$11.3 million. Annual revenue streams of about US$4.1 million and annual operating costs of about US$1.9 million were forecast. This would give a payback period of about 5 years (Snow et al, 2005).


Figure 4.5 - Char Maker Mobile Pyrolysis Plant (www.esenergy.com.au)

As an alternative to building a pyrolysis plant for use in Christchurch consideration may be given to using mobile technology.

Australian firm Earth Systems supplies mobile pyrolysis units that primarily produce biochar. The units, which are the size of a 40 foot shipping container, process waste wood of any normal size at a rate of approximately 4 tonnes per hour. It is not known whether the use of treated timber waste in this unit is viable.

The Earth Systems website (www.esenergy.com.au) states that optional 'bolt-on' systems for electricity generation, thermal generation and bio-oil production are in development. While pricing information is not known, and long-term deployment in Christchurch may prove too expensive, the Earth Systems mobile units may afford the opportunity to trial waste treated timber processing in a 'real-life' environment on site.

An Otaki-based company has also developed a potentially feasible mobile pyrolysis unit. Waste Transformation Limited (WTL), which is a new entity formed by two technology companies with an interest in pyrolysis technology (KILNZ Bio Energy and Sectionz), has developed its mobile unit to produce domestic charcoal from untreated wood waste at a commercial scale. They have also been working with Massey University to investigate the use of other waste feedstocks including bio-solids, tyres and forestry waste.

WTL believe, based on international research, that low-temperature pyrolysis offers a viable solution for disposing of CCA-treated timber. Their confidence is such that they have developed a priced proposal to locate a mobile pyrolysis 'cluster' at BRRP. This cluster, costing about $210,000, would consist of four batch pyrolysis units with a combined input requirement of 2.5 tonnes of wood waste per day, and a combined output of 900kgs of charcoal per day. These units could potentially be shipped to Christchurch in a single 40’ container, and the units located and relocated adjacent to the waste pile being processed. The cluster would be manned by a team of four, including a foreman.

WTL’s proposal states that untreated timber would be used to generate domestic charcoal (assuming this had been isolated by Transwaste’s sort line on site, which is not likely) with the remainder used to generate charcoal for commercial applications, such as:

- Boiler/furnace fuel
- Odour suppression from the decomposition of organic wastes
- Filtration of organic residues from landfills and cesspits to prevent leaching into water systems
- Mixture with clay and other materials for use as landfill capping

Of these potential end uses, the first stands out as potentially feasible, whereas the remaining three would be challenging to achieve and represent probably small markets.

As the operation grows, and dependent on demand, WTL says that additional clusters could be shipped to Christchurch to process higher volumes. WTL’s preference is to structure the overall cost as a lease over four to five years, with an annual maintenance and support charge after this period. Costs and revenue would be the responsibility of the lessor which, it may be assumed from WTL’s proposal, would be Transwaste.

WTL does not have any ‘real-life’ research data based on processing treated timber through their units, nor do they state with evidence that the hazardous treatment chemicals within treated timber will be captured and handled appropriately or rendered harmless. Despite this, the proposal offered suggests a low capital cost per tonne of waste processed, with potential revenue streams to defray capital and operational costs. WTL has been asked for further evidence demonstrating the viability of the proposed income streams (the proposal was received very late in the Milestone 1 timeframes) and further consideration and analysis of their solution is certainly warranted. The ‘mobile pyrolysis cluster’ approach is attractive in its flexibility and scalability, but it should be noted that the daily processing volume from one cluster is quite low, at 2.5 tonnes a day, and either multiple clusters would be required to handle expected volumes or other concurrent solutions would need to be deployed.

Pyrolysis is clearly an emerging technology with promise as a processing solution for treated timber waste. It is clearly preferable to gasification or incineration for this purpose and has already been deployed to utilise treated timber waste. Determining viability will require a more detailed economic analysis, based on selection of the best end use or uses for pyrolysis outputs. At this stage, it is concluded that pyrolysis may be feasible for use with treated timber waste, and that further investigation is certainly warranted.

4.4 Torrefaction

Torrefaction is a form of pyrolysis that occurs at even lower temperatures, typically ranging from 250 - 350°C (Koppejan et al, 2012). When waste wood is torrefied, the output is called ‘bio-coal’, which is suitable as a replacement at any coal-fired power installations (DTA, 2013).

Figure 4.6 - Bio-coal
(www.dutchtorrefactionassociation.eu)

Using unprocessed wood waste directly as a fuel is difficult because it has relatively low energy content, high water content and is bulky. It is also 'non-homogenous' in that the fuel does not always behave consistently and is highly variable, and is difficult to grind in the same manner as coal (Dutta et al, 2011).

Conversely, bio-coal has approximately 30% more energy per kg than waste wood, resulting in a drier, high-density fuel and substantially reduced costs where the fuel is to be transported or stored (NEAF, 2008). The fuel also becomes 'hydrophobic', meaning it can be stored outside without absorbing water, much like coal, and can also be easily ground and used as a fuel (Koppejan et al, 2012). Bio-coal's heating is typically rated at 22GJ per tonne, only 10% less than coal at 25GJ per tonne (Dutta et al, 2011).

The application of treated timber to torrefaction has apparently not been widely tested, but the same issues that must be faced in undertaking pyrolysis are likely to be faced with torrefaction. One study notes that flue gas cleaning equipment would be required in the form "baghouse filters with active carbon injection, or wet scrubbers", which are expensive solutions likely to diminish the financial viability of torrefaction of treated timber (Koppejan et al, 2012). However, it is unlikely that torrefaction would require greater levels of air filtration than pyrolysis, where chemisorption appears to suffice. The low operating temperature of torrefaction also means that treatment chemicals from treated wood may also be present in relatively high concentrations in the bio-coal (Koppejan et al, 2012). Using this fuel source would, therefore, likely require filtration of hazardous substances at both the fuel creation stage and the fuel utilisation stage.

Despite this, it is understood Holcim Cement are actively evaluating torrefaction of waste wood, including treated timber, as an alternative fuel supply source for their cement plant in Westport. The potential cost savings of using a coal-like fuel produced from waste, and optimised for transportation may offset hazardous material disposal costs. As is discussed later in this report, Holcim's cement kiln is also likely to appropriately handle fuel containing timber treatment chemicals so it is likely only the torrefaction plant itself (which would be based in Christchurch) would require additional equipment for filtration of chemicals such as arsenic and chromium.

The interest of Holcim in this technology, and the apparent rapid progress being made in developing waste to energy systems utilising torrefaction, suggests that torrefaction may be feasible as a processing solution for treated timber in Christchurch. The economics around such a process will need to be more carefully considered, and the latest international developments closely analysed to understand whether the technology is ready for commercial application to waste processing.

A very recent analysis of the technology (Koppejan et al, 2012) notes that scaling up torrefaction from pilot stage to full commercial deployment (5 – 10t/hour of biomass input) is challenging because of throughput limitations in the torrefaction reactors. This report also specifically states in terms of torrefying wastes: "the attractiveness of co-firing torrefied wastes still needs to be explored further. At this stage, energy companies are hesitant in co-firing torrefied wastes, due to the associated emission legislation…as well as possible negative influences on ash quality, emissions and boiler performance. It is yet uncertain if the additional operational cost associated with these factors is compensated by a lower price per GJ."

These factors require further consideration in order to definitively determine whether torrefaction presents a truly economically feasible option for Christchurch's treated timber waste.

4.5 Hydrothermal/Supercritical Water Reactor Processing

Hydrothermal processing of biomass such as timber through a supercritical water reactor (SCWR) is an emerging process technology that appears successful at the pilot scale. Supercritical water is sometimes thought of as like a 'fourth state' of water (in addition to liquid, solid and gas) and occurs at pressures higher than 221 bar and temperatures above 374 °C (BTG, 2013). Almost any biomass can be processed using supercritical water to create stable biofuels (Licella, 2013). The process is often described as mimicking the natural process of converting organic material to oil under pressure.

Christchurch-based chemical and mechanical engineer Chris Bathurst began productive use of SCWR technology in 1999 with the development of the company Solvent Rescue. This operation specialises in treating dry cleaning waste chemicals, as well as other hazardous wastes from the painting and printing industry. Much of this chemical volume is able to be processed and reused using Solvent Rescue's technology. Bathurst explains that as part of its ongoing development and growth Solvent Rescue designed and constructed a continuous process SCWR in 2005, and patented their technology. A continuous process SCWR (as opposed to batch processing) is the most efficient form of the technology. This development enabled them to take the residual hazardous chemicals they could not reuse and convert them into sodium chloride (salt) and crude oil.

Further experimentation with the process enabled Solvent Rescue to successfully process algae, sewage sludge and seaweed into bio-crude oil using SCWR technology. In Solvent Rescue's SCWR the water/biomass mixture is "heated [with water] under pressure until the complex organic molecules break down into simple hydrocarbons, which then separate out as bio-crude. The technology also has great potential to degrade hazardous organic compounds to harmless residues" (NIWA, 2013). This activity attracted the attention of an American aircraft manufacturer who expressed an interest in converting algae into jet fuel. A small-scale testing process was undertaken and the resulting fuel exceeded the US military's fuel standards. This then led to a joint venture with NIWA to develop a larger 'algae to bio-oil' plant and algae ponds near the wastewater treatment plant in Christchurch. This became the largest algae ponds for fuel in the world.

The viability of this venture depended on the continuous process technology developed by Bathurst. Typical hydrothermal processes use slower 'batch-processing' technology, which would not have yielded enough jet fuel to be of interest to customers in the aviation industry, and there are only a few continuous process reactors in the world like the one Bathurst has built "from scratch" (Pure, 2010).

The plant, established in late 2009, consisted of 5 hectares of algae growing space, with an expected full-capacity output of 90,000 litres of crude oil a year; enough to supply 40,000 litres of diesel and 18,000 litres of petrol (NIWA, 2010).

Figure 4.7 - The 'Algae to Bio-oil' Plant in Christchurch before the 2011 earthquake (Pure, 2010)

NIWA's Dr Rupert Craggs, who was part of the team that developed the site, believes that the technology and process has genuine potential and worked well. While there were small technology issues to resolve, the confidence of NIWA in the project and the technology's ability to deliver a viable biofuel were high. Unfortunately, the February, 2011 Canterbury earthquake destroyed the site in east Christchurch and, according to Bathurst, insurers have said it will not be insured if rebuilt, preventing this from being undertaken. However, development of this technology has not ceased, and Solvent Rescue and its associated companies have continued to attract international interest in their technology and its ability to convert abundant biomass, such as algae, into biofuel.

In 2012 Bathurst established a new company, Lignin Polymers, to commercialise a companion technology to the SCWR plant, aimed particularly at extracting value from waste timber. This proprietary, patented technology extracts lignin, the 'resin-like' substance that holds the cellulose in wood together. Lignin is potentially valuable for use in polyurethane foams, resins, paints and carbon fibre, and provides another potential revenue stream from processing waste timber.

Also in 2012, a small trial was undertaken by Solvent Rescue in conjunction with Environment Canterbury to determine the potential for utilising CCA-treated timber waste in the two stage (lignin extraction and SCWR) process developed by the company. Samples of new H5 CCA-treated timber were processed (representing the 'worst case scenario' in terms of treatment chemicals). Bathurst considers the initial results to be 'staggeringly good' in that very little copper, chromium or arsenic was found to be present in the main products, being cellulose and lignin 'black liquor' after running through the lignin extraction process. The process undertaken has now been patented. However, it is important to note that the results were not produced by a registered laboratory and a portion of the chromium and arsenic present in the treated timber samples was unaccounted for in the testing. This, explains Bathurst, indicates that further testing will be required.

On the basis of the promising test results, Solvent Rescue is now seeking funding from the Ministry for the Environment to undertake larger scale testing specifically aimed at processing treated waste timber into lignin and bio-crude, and investigating the extraction and reuse of the timber treatment chemicals. Funding sought is to scale up the current process to enable processing of 1 tonne of waste timber a day. If successful, Solvent Rescue aims to move to 20 tonnes and eventually 100 tonnes a day. Bathurst says that a 20 tonne a day system would cost about $26 million to build.

Bathurst states that for every tonne of treated timber processed the approximate outputs will be as follows:

- Lignin – 300kg
- Bio-crude oil – 300kg
- Timber treatment chemicals – 10kg
- Inorganic residues – 50kg (potentially to be sent to landfill)
- Other by-products such as carbon dioxide – 350kg

Bathurst states that about 60% of the input timber waste will be recovered in the form of usable products, including about 90% useful recovery of the timber treatment chemicals. Solvent Rescue's own forecasts for establishment of a 20 tonne plant suggest a strong return on investment based on revenue generated from sales of useful products generated and 'gate fees' for disposal of waste treated timber, although this has not yet been independently verified.

Andrew Campbell of Fuel technology, who worked with Chris Bathurst on development of Solvent Rescue's process, believes that the technology itself has strong potential and scaling it up to produce significant volumes of fuel should be relatively straightforward. Campbell is somewhat sceptical about the economic potential of lignin, however, stating that while it is certainly valuable, no market for it currently exists in New Zealand and servicing international markets would require large volumes. Even then, Campbell believes such markets are "several years away at least".

The potential markets for biofuels from hydrothermal processing are considered later in this report, in Section 5.6.

Solvent Rescue is not alone in New Zealand in advancing the commercialisation of hydrothermal processing of waste wood. Australian-based Licella possesses a technology similar to that developed by Solvent Rescue and appears to have substantial capital backing.

Licella has developed partnerships with a number of large companies, including Air New Zealand and Virgin, and has also received funding from the Australian Government's Advanced Biofuels Investment Readiness Programme (Licella, 2013b). Professor Thomas Maschmeyer from the University of Sydney comments: "Licella can create fuels that are stable; they are liquid, they are storable, they are transportable, and they are blendable" (Ecocitizen, 2013).

Licella has also joined with Z Energy and Norske Skog to seek government funding for a $50 million 'wood waste to fuel' demonstration plant in Kawerau. This plant, which would convert sawdust and forest residues to fuel, is intended to demonstrate the potential for such processes and their potential to generate "about 10 percent of [New Zealand's] crude oil requirements" (NBR, 2013). The initial intention is to produce 125,000 barrels of bio-crude a year, growing to a million barrels annually courtesy of a planned $400 million plant. This larger plant would utilise 400,000 tonnes of waste wood annually (NZH, 2012).

Andrew Campbell says that those involved with the Kawerau plant are confident in its ability to handle CCA-treated timber waste, but it is not yet known whether doing so is part of their strategy. It is also not yet known whether this venture has succeeded in securing government funding, or whether it would proceed without government funding.

Overall, hydrothermal processing appears to be a technology with strong potential, but its novelty and lack of large-scale commercial implementation makes its feasibility difficult to assess. Its ability to actually extract useful substances from waste treated timber appears established, and the potential to extract and reuse timber treatment chemicals is a strong benefit. Challenges exist in the logistics of using lignin and biofuels (see Section 5.6), but the current level of investment and activity around hydrothermal processing in New Zealand currently, including Solvent Rescue's upcoming pilot trials, suggests that the process may be feasible and should be considered further.

4.6 Wet Oxidation

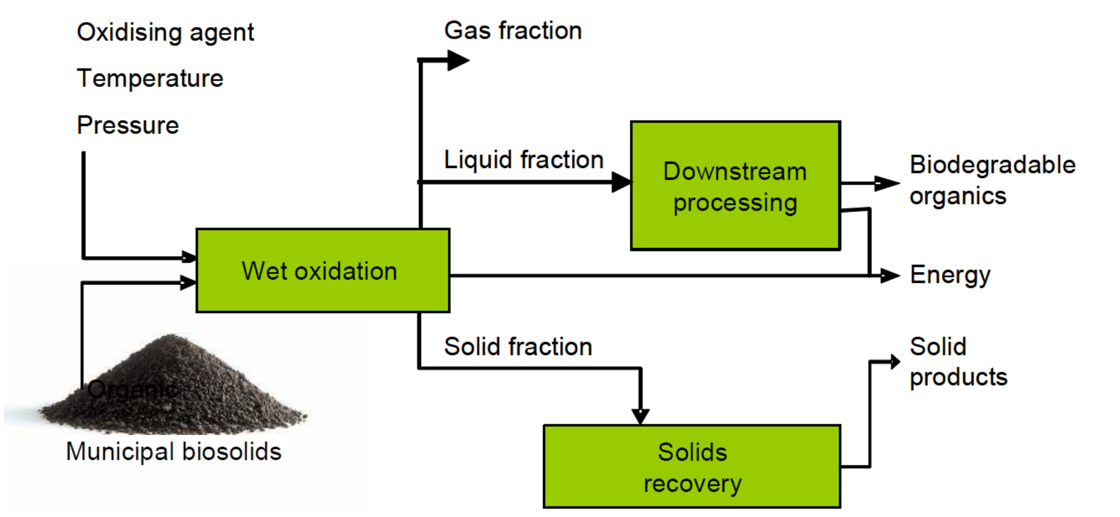

Figure 4.8 - Wet oxidation of municipal biosolids (Gielen, 2011)

Wet oxidation is a treatment process that uses heat and pressure to reduce the input material to carbon dioxide, ash and water, with the potential for energy generation. The process has been used to treat waste water and sewage sludge since the 1960s (Gielen et al, 2011).

One of the key advantages of wet oxidation for municipal biosolids is its ability to reduce the dry weight of the biosolids by about 95% while recovering energy from the process.

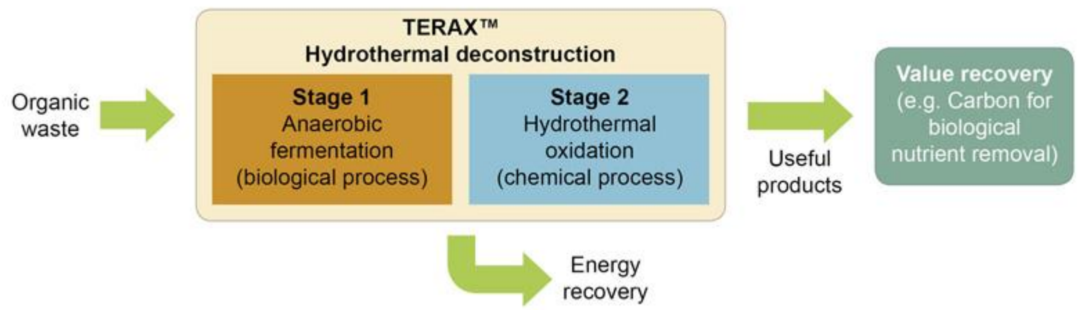

Figure 4.9 - The TERAX process (Scion, 2013)

In 2008 New Zealand Crown Research Institute Scion partnered with the Rotorua District Council to form the 'Waste 2 Gold Alliance' with a view to considering whether wet oxidation presented a viable sewage treatment technology for the local context.

As a result of the partnership and the developments made by Scion in utilising wet oxidation-based processing, a new patented process called TERAX was created. TERAX is a process designed to treat "very high moisture content organic solid wastes" and builds on wet oxidation as a foundation by adding an initial biological stage that uses bacterial cultures to pre-treat the waste before oxidation, to reduce its volume and make it easier to pump (Scion, 2013).

Two key outputs of this process are heat, which can be recovered and used, and acetic acid which can be used to generate methane for use in electricity generation or heating. The potential also exists for the process to generate “feedstocks for industrial applications such as de-icing chemicals, bioplastics production or conversion to liquid biofuels” (Scion, 2013).

While currently focused on sewage sludge, Scion has identified the potential to apply their technology to other organic wastes, including timber waste. Trevor Stuthridge, one of the developers of the technology at Scion, says that CCA-treated timber waste was always considered a potential feedstock for the TERAX process, and testing with untreated wood waste has shown positive results. As with sewage waste, use of wood waste would produce acetic acid which could be used to produce methane gas for electricity and/or heat generation. Because the process runs at low temperature (200 - 300 ° C), the risk of volatilisation of the CCA treatment chemicals is very low, and most of these elements would be contained in the ash, which would then need to be disposed of. Acetic acid can also be sold as a high value output for use in plastics, paint and a number of other industrial products, at a market rate of about $400 a tonne.

Stuthridge estimates that a TERAX plant to process 100 tonnes of timber a day would cost about $20 – 30 million, and is confident in its ability to process treated timber, although as yet this ability has not been tested. There remain questions as the extent to which these claims are supportable. There are likely to be a number of issues when using treated timber (Hooper, 2013):

- The treatment chemicals in the timber may negatively interfere with the biological stage of the process (although this stage can be omitted if necessary)
- The combination of heat and pressure in the process may in fact cause volatisation of the treatment chemicals
- The potentially valuable outputs would most likely be contaminated with treatment chemicals, rendering them unusable (although Scion believes the treatment chemicals would be concentrated in the ash)

TERAX, which is an apparent material improvement on traditional wet oxidation technology, is clearly feasible as a solution for municipal biowaste. The ongoing and substantial investment by the Rotorua District Council in the process, and the recent $4.7 million grant by the Ministry for the Environment’s Waste Minimisation Fund towards TERAX development strongly supports this feasibility. Yet it is very difficult to determine whether TERAX is a feasible solution for waste treated timber because, as far as can be determined, the use of this waste in the process is only conceptually feasible and no specific testing has been undertaken. Compared with some other processing technologies, the capital costs of the TERAX process are not exorbitant, which encourages consideration of the processing of treated timber. Yet the available information as to how the process would handle the hazardous chemicals from CCA-treated timber requires a cautious approach. Unless the treatment chemicals can be safely extracted, TERAX would certainly not be feasible for treated timber, as usable outputs would be contaminated and inappropriate for any end use.

In summary, while TERAX cannot be deemed unfeasible, neither can it be deemed feasible based on a lack of information specific to the processing of treated timber and indications that such processing would not be practical. Should actual testing of the TERAX process with treated timber waste be undertaken, feasibility should be re-evaluated based on the results, particularly given the potentially high value of acetic acid.

4.7 Chemical Extraction of Treatment Chemicals

One of the greatest challenges that any end use of treated timber waste faces is appropriately handling or disposing of the treatment chemicals within the timber, particularly arsenic and chromium. Ideally, any process considered would either render these chemicals harmless in some way or, preferably, recover them for reuse. There are a number of chemical processes in use, and a number more being developed internationally, which may enable treated timber waste to be processed so that it essentially transforms into untreated timber waste. Any end use considered can then include those for which only untreated timber is a suitable feedstock.

One of the key objections to chemical extraction of treatment chemicals in previous analyses of end of life options for treated timber is the need for the timber waste to be chipped or ground into fine particles for processing (Love, 2007; Keeling, 2011). In fact, such pre-processing is likely to be necessary for almost all end-uses and, while this adds additional cost, it is not sufficient grounds to reject chemical extraction in terms of feasibility.

Another common ground for rejecting chemical extraction is the concern over the resulting extraction liquid, which will be contaminated with the chemicals from the treated timber waste (Love, 2007; Rhodes, 2010). Again, while this is a serious issue, it is one common to almost all of the potential pathways for treated timber waste, with a few possible exceptions. The chemicals must go somewhere, and most often some kind of additional waste processing will be required. As with pre-processing costs, this barrier does not appear sufficient to reject chemical extraction outright.

There are a number of chemical processes that can extract the treatment chemicals from CCA-treated timber, including those using oxalic, citric, acetic, nitric, formic and sulphuric acids (Clausen et al, 2011). One group succeeded in removing over 94% of the treatment chemicals in treated sawdust using hydrogen peroxide heated to 50°C (Kazi et al, 1998). Another group achieved nearly 100% extraction of chemicals in just a few hours using sodium oxalate and oxalic acid heated to 75°C (Kakitani et al, 2007). Other techniques such as bioremediation and electrodialytic remediation have been considered, but the time required for these processes to act (in excess of a day) renders them unfeasible for large-scale adoption based on the current state of these technologies (Love, 2007).

Ultimately, the main factor that appears to have impeded development of most of the technologies aimed at successful and viable chemical extraction of treatment chemicals from timber waste is economics. The processing chemicals are very expensive and all of the processes require high energy inputs to work successfully (Clausen et al, 2011). In fact, the hydrogen peroxide approach outlined above recorded a total processing cost (chemicals and energy) of US$310 per tonne, excluding any capital costs (Kazi et al, 1998). This may be why, based on research undertaken to date, no full commercial-scale chemical extraction plants are yet in existence for treated timber waste anywhere in the world.

It must also be noted that, even once the waste has been rendered harmless through a chemical process at high cost, an end use must still be found for the resulting material. While there are such potential end uses, such as boiler fuel, it is difficult to imagine why any commercial operation would incur the costs of chemical extraction when untreated timber waste is readily available. Therefore, while the latest international developments in chemical extraction processes will be considered as part of Milestone 2, based on current information chemical extraction of treatment chemicals from treated timber waste is not considered feasible.

5.0 POTENTIAL END USES AND END OF LIFE OPTIONS

This section deals with different end of life or end use options for treated timber waste, being different ways of disposing or extracting value from the waste. This is distinct from processing options, as considered in Section 4, which look only at preparing the waste for use or transforming it into a more useful state.

5.1 Disposal in Landfill

While not technically an 'end use' most treated timber waste in New Zealand currently ends its life in a landfill and the feasibility and desirability of continuing to send such waste to landfill must be evaluated to provide a basis for comparison with other options.

There are two key options for landfilling of treated timber waste in Christchurch:

1. *Temporary landfilling at the Burwood Resource Recovery Park (BRRP)*

   BRRP is consented to receive earthquake-related waste only. Gareth James, of BRRP operators Transwaste, says that it is the intention of Transwaste to bury unsorted waste timber at Burwood until such time as an appropriate and feasible end use for the waste is found. Burying and then extracting timber has two key issues associated with it: firstly it is likely to be expensive and time-consuming because of double handling, and secondly the propensity for the recovered timber to introduce contaminants into any processing is very high unless it is thoroughly cleaned prior to processing. The possibility also exists, of course, that the economics of extraction and processing will result in the timber being left in the ground.

2. *Permanent Landfilling at BRRP or Kate Valley*

   The Kate Valley Landfill is designed and regulated to ensure that any treated timber disposed of within it will not have an adverse effect on the environment (Keene et al, 2009). However, Kate Valley Landfill will eventually be filled and the process of creating a new landfill is far from straightforward. The flow of waste treated timber will most likely extend well beyond Kate Valley's life span. In addition the costs of transporting treated timber waste to Kate Valley from Christchurch City are very high and the costs of disposing of waste in landfills continue to increase. It is also not clear whether, should treated timber be permanently landfilled at Burwood, there is any resultant material environmental risk. This will likely depend on the potential hazards from leachate as considered below, and the way that the landfill is engineered.

The key advantages to landfilling treated timber waste are that it utilises existing infrastructure and requires no short-term capital investment, although provision for new landfilling space must be made. If, as is indicated, Transwaste does bury waste timber at BRRP, then there will be no additional direct costs in leaving it buried. Extracting the timber and transporting it to Kate Valley will obviously be considerably more expensive.

There may also be a carbon sequestration benefit to burying waste timber in the ground. Carbon sequestration is the capture and long-term storage of carbon dioxide. Capturing carbon dioxide in this way may help to mitigate the effects of burning fossil fuels and potentially reduce or defer contribution to climate change. However, under the Kyoto Protocol, landfilled treated timber is not considered sequestered carbon (Love, 2007). Likewise such activity is not accepted by institutions such as the Chicago Climate Exchange (UMN, 2008).

Mark Milke of the University of Canterbury's Department of Civil and Natural Resources Engineering has suggested that the New Zealand government may allow such credits under the Emissions Trading Scheme, based on the precedent set by non-Kyoto compliant forestry credits.

Recent activity within the Emissions Trading Scheme, including the banning of two types of carbon credits by Climate Change Issues minister Tim Groser where the environmental credentials of projects are 'suspect', suggests that the government may be increasingly stringent in determining the acceptability of sequestration activities (Stuff, 2012). In addition, with a recent carbon credit price of just 14c/tonne for Emission Reduction Units and $2.50/tonne for New Zealand carbon credits, the revenue generating potential from carbon sequestration of timber is not strong, nor will it be for the foreseeable future based on carbon price trends in New Zealand.

Another major issue to be considered in the ongoing disposal of treated timber waste in landfill is leachate. The presence of chemicals such as copper, chromium and arsenic in treated timber waste raises the possibility that these chemicals may leach into the soil or water sources. Landfilling of treated timber is banned in a number of countries, including Germany, due to environmental concerns (Love, 2007).

A study was undertaken by the University of Florida in 2004 to simulate the production of leachate in different landfill situations so as to determine the leachate risks from treated timber. Three landfill simulations were undertaken: a wood monofill, a C & D waste landfill and a municipal solid waste (MSW) landfill. Predictably the CCA-treated wood monofill simulation showed the greatest concentration of chemicals in the leachate. Arsenic and chromium levels in this simulation would classify the leachate as hazardous waste and disposal costs would likely be high. The results of the other two landfill simulations suggested that while copper concentrations would remain low, arsenic and chromium levels were raised, although not to 'hazardous material' levels (Jambeck et al, 2004).

While it has been suggested that the apparent use of new treated timber in these tests would cause stronger concentrations of treatment chemicals than would be seen in typical real-world landfills, leachate is certainly a concern to be aware of, particularly if unprecedented levels of treated timber may be sent to landfill, as is the current situation in Christchurch (Keeling, 2011). In a lined landfill such as Kate Valley, the presence of CCA-treated timber will result in increased arsenic concentrations in the leachate, which presents an increased cost of disposal (Dubey et al, 2004).

Disposing of wastes such as treated timber in a landfill where a feasible alternative exists will, of course, hasten the landfill reaching capacity and prompt the need for new, expensive landfill creation. Whereas the lifetime of a landfill can be as low as twenty years, the contamination that leachate may cause to the land can continue for hundreds or thousands of years. Even with lined landfills, such as Kate Valley, it is unlikely that the lifespan of the lining will be as long as the contamination problem persists. The ongoing costs for maintenance of contained landfills must also be considered. These costs are understood to be considerable.

While there are risks in landfilling treated timber waste it is clearly feasible as it is already taking place and will continue to do so. Further investigation into this 'baseline' option will be required to understand the processes and costs involved in landfilling extraordinary timber sources in Christchurch, and also to consider the increased risk that may come from unusually high concentrations of treated timber waste in landfills as a result of earthquake-related activity.

The specific option of generating carbon credits from carbon sequestration is speculative, and the rapidly decreasing price for carbon credits is not encouraging. Landfilling large volumes of treated timber for this purpose (which has an environmental focus) will also be subject to the leaching potential addressed above. If no other viable option for treated timber is found, and it is sent to landfill, then obviously investigating the potential to earn carbon credits is advised.

5.2 Incineration

In terms of end use, incineration here refers to the destruction of wood waste with no energy recovery. The incineration of untreated wood waste by combustion has already been broadly considered in Section 4.1 above, concluding that it is a very challenging undertaking due to the air discharge and ash handling issues and costs.

Despite this, incineration of treated timber does occur internationally. One of the prominent examples of an international treated timber waste incineration plant is the Demolite Oy facility in Finland. The facility, which operates at a very large scale utilising 50,000 tonnes of waste treated timber annually, has a flue gas cleaning system to avoid air discharge issues (Love, 2007). This facility utilises the energy from the waste as cogeneration, so is able to earn revenue from the incineration process.

Given the extreme difficulty that any operator would face in securing a resource consent for incinerating waste treated timber in Christchurch with traditional means, and the economic costs involved in filtering air discharge and handling contaminated ash, it is not considered feasible to burn treated timber waste. The economics of incinerating treated timber waste are made even less attractive once the costs of transporting the waste to a location outside Christchurch (which may need to be the case to secure a resource consent) are factored in. It must also be noted that, if pure incineration of waste is the end of life option, and the energy inherent in the waste is not recovered, the potential for revenue is limited to any gate fee that can be charged for disposal of the waste.

5.3 Boiler Fuel

Large boilers are common in industrial and heating applications throughout New Zealand. The major users of large boilers are dairy processing, wood processing, meat processing, hospitals and other manufacturing plants. Primarily, these units are either gas, electricity or coal fired but a small number use wood or wood waste (CRL Energy, 2011). The potential exists, therefore, for treated timber waste to be utilised as a fuel source of such boilers.

The largest boiler system in Christchurch is at Christchurch Hospital. This system consists of two 8MW coal-fired boilers and a diesel-fired boiler. These units provide steam for heating and for processes such as sterilisation. The boilers operate continuously, seven days a week.

In 2009, as the Canterbury District Health Board was preparing to replace the previous boilers, two feasibility studies were commissioned (Enercon, 2009 and Watson, 2009) to consider whether other fuels could be used as alternatives to coal. Three options were considered: wood chips, wood pellets and biofuels. Treated timber was not considered in any form.

Biofuels were immediately rejected due to the increased equipment costs, the higher degree of 'human oversight' required and the lack of fuel storage space on site. Pellets were also rejected based on cost, with energy inputs likely to cost in excess of twice the price of coal.

Conversely, wood chips were seen as a feasible and potentially attractive option. Wood chips cost roughly the same as coal (2 – 3c/kWh versus 2.1c/kWh for coal in 2009) and also presented a strong security of supply chain with a number of potential suppliers in Christchurch. Budgeted costs for purchasing wood chips were $90 – 100 per tonne, with ash disposal being the responsibility of the wood supplier. It was estimated that the hospital would consume 10 – 12,000 tonnes of wood chips per annum (Watson, 2009).

While the boilers ultimately purchased by the CDHB for Christchurch Hospital were not designed to be wood fired, suggesting they were not compelled by the argument to adopt wood chips as a fuel source immediately, the boilers have the ability to be converted to utilising wood fuel and it is understood this is currently under review.

Two additional larger boilers in use in Christchurch are housed at the Christchurch City Council Biosolids Drying Plant located in Bromley. This facility, operated by Energy for Industry (EFI), consists of two separate units: a 4.5MW boiler that uses wood chips as fuel and a 4.3MW unit that uses landfill gas as fuel. The boilers are focused primarily on providing energy for drying biosolids sludge for wastewater treatment, but also have the capacity to supply heating for council facilities.

Figure 5.1 - Christchurch Biosolids Drying Plant boilers

EFI Asset Manager Alistair Fisher advises that the wood-fired boiler uses untreated wood chips largely sourced from wood processing waste. They usually have more fuel available than they require. At least one trial has been undertaken using construction and demolition waste, but this proved very problematic for them and introduced contaminants into the boiler which were not easy to handle.

According to Fisher, who has worked on many boiler projects, utilising treated timber as a boiler fuel is not feasible. The primary issue is air discharge. Expensive 'wet scrubber' systems would need to be installed to prevent hazardous chemicals in treated timber waste from being released into the air. These types of systems use a liquid scrubbing agent to capture pollutants in exhaust gas streams to prevent them being discharged into the air. The need to utilise wet scrubbers would negatively impact the economics of using waste treated timber as fuel, particularly when an abundance of untreated timber waste is available. They would also simply replace one hazardous waste stream – treated timber – with another – hazardous liquid waste – which is also challenging to economically and appropriately dispose of.

Handling of the resulting ash, which would be contaminated, is a further issue. Eco Central currently takes the ash from the plant, but it is unlikely they would be willing to take ash contaminated with chemicals such as arsenic and chromium. This ash would then be an additional hazardous waste stream to contend with and would be more costly to treat and dispose of.

Perhaps the 'fatal blow' to utilising treated timber waste in boilers, however, is the fact that, as Fisher points out, the salts in CCA or boron treated timber would quickly corrode the boiler itself. These chemicals would immediately begin to degrade both the boiler and the flue and it is estimated that the boiler lifespan would be halved if any significant volumes of treated timber waste were used. Fisher advises that consideration had previously been given to utilising treated timber as a fuel, but that their boiler manufacturer Lyttleton Engineering, had confirmed that the boilers would essentially corrode or "rot out" along with any exposed steel and even Goretex filters, commonly used to control air discharge.

This issue is not confined to a particular technology or type of boiler, and would apply equally to other boiler applications such as Christchurch Hospital or the large boilers in industrial settings such as Fonterra and Synlait. In fact, Fisher advises, no industrial boiler in New Zealand is using treated timber waste as a fuel, or as a component in fuel.

Despite this, there is the possibility that at low concentrations – perhaps 5% or less – the air discharge or boiler corrosion issues may not be material, and treated timber could be used safely. It should be noted that the chemicals in CCA treated timber are also present in other fuels, particularly in coal, which is the primary fuel for boilers in New Zealand (Smith, 2005). This suggests that there may be some safe level of treated timber waste in boiler fuel. Further research would be required to evaluate this possibility. If a safe level can be found, processors would need to invest in robust systems to determine the level of treated timber waste in a wood waste stream, which could also prove challenging.

Even with this possibility however Brian Cox, Executive Officer of the Bioenergy Association of New Zealand, says wide-scale growth of the market for wood fuels would be needed before treated timber waste became viable. Cox says that many users of coal-fired boilers are reluctant to consider alternative fuels such as untreated wood because of the perceived immaturity of the biomass market. The potential for issues with reliability, consistency and quality of wood fuels have tended to cause risk-averse boiler operators to avoid wood as an alternative fuel, and coal remains popular even with abundant and cost-competitive wood fuel sources. Most of the boilers that are currently using wood fuel are, according to Cox, located at sawmills or wood processing facilities that are using their own waste as fuel. Cox believes that wood fuel will be utilised at greater levels once quality and consistency improves in the market, and particularly if coal prices increase.

Weighing the apparently risk-averse behaviour of boiler owners in relation to untreated timber, and given the very real risks to boilers and in terms of air discharge with the use of treated timber, it can therefore be concluded that utilising treated timber waste as a fuel for industrial boilers is not feasible in the current environment. However, there may be merit in testing the impact on boilers and air emissions from using treated timber waste at varying concentrations in the hope that a safe proportion is possible. This may then open up opportunities to use mixed timber waste streams in the future.

5.4 Electricity/Heat Generation

Combined electricity and heat generation, or cogeneration, could potentially utilise thermal energy from waste treated timber at a commercial scale. Cogeneration commonly utilises steam from a boiler to fire a steam turbine for electricity generation. Because such a process usually involves losing at least half of the energy as heat, cogeneration improves overall efficiency by seeking to utilise both the electricity generated as well as the heat. This can improve efficiency up to 80% or more, and result in a much higher energy return for the fuel used.

Using waste timber as a fuel source for cogeneration is not uncommon. The plant shown in Figure 5,2, which is located in France, operates a 45MW boiler powered by wood waste. Using unprocessed treated timber waste in a boiler is not considered feasible for the reasons detailed in Section 5.3, so any treated timber waste used for cogeneration would need to be pre-processed.

Figure 5.2 - Cogeneration Plant in Metz, France (Wikipedia)

Thus, any consideration of cogeneration as an option for treated timber waste must focus on waste that has been processed in some way to handle the chemicals contained therein. This will, of course, add substantial costs and diminish the viability and attractiveness of such an option, especially when large volumes of untreated, cheaper hog fuel is currently available in Christchurch.

For the purposes of fully considering the general viability of cogeneration, concerns around fuel source hazards and processes will be temporarily set aside and the feasibility of cogeneration considered in isolation.

The capital costs involved in establishing a cogeneration plant are difficult to estimate and are largely specific to the particular location and application, but are certainly significant. Project costs from actual projects are also difficult to estimate with any accuracy.

Known cogeneration plant costs include:

- Fonterra’s Whareroa plant near Hawera, the largest milk processing site in the world, was converted to cogeneration in 1996. The plant consists of four gas turbines (10MW each) and a 28MW steam turbine. The plant cost approximately $70 million to construct (PWCL, 2013). The plant produces 380GWh of electricity a year, and more than 60 per cent feeds into the national grid. Waste heat is used to run the site’s milk processing plants. (Fonterra, 2013)

- A “modular, all in one” (approximately) 0.15MW unit was installed for a cutting tool manufacturer in Massachusetts in 2011 and cost US$5.5 million. It is projected to save US$2 million in electricity costs annually (2G-Cenergy, 2011).

- The University of Connecticut installed three 7.5MW cogeneration gas turbines in 2005 for a combined cost of US$80 million. It was expected to save about US$11 million in energy costs per annum (ASME, 2011)

Unless heat produced during cogeneration is to be used on site for heating or some industrial application, the heat must be distributed in order to generate revenue. This then leaves two potential options: either the plant is located where the fuel is located (which is currently Burwood Resource Recovery Park) and heat shipped to some other industrial or commercial site or sites, or the plant is located closer to where the heat would be used and fuel is transported to the processing site.

The distribution of heat in liquid or gas form requires the use of insulated pipes, which are understood to be very expensive over anything other than small distances. Likewise, the transportation of fuel is expensive over anything other than short distances.

Initially it was considered that the District Energy Scheme (DES) being proposed for Christchurch may provide the solution to this dilemma by allowing heat to be distributed based on the reticulation created for this project.

The DES is a concept that has worked successfully in Europe, North America and Asia, including in cities such as London, New York and Tokyo. A DES involves a central heating, cooling and/or electricity generation plant that supplies its outputs to localised commercial premises and/or residential dwellings. The key advantage of a DES is the improved efficiencies that come from a centralised plant, as opposed to many smaller scale units.

In New Zealand, the most notable District Energy Scheme is the Dunedin Energy Centre. Operated by Energy for Industry, the Dunedin Energy Centre comprises four large coal-fired boilers that supply steam and hot water to a number of local businesses including Cadburys and the University of Otago (EFI, 2013).

Merv Altments, Chief Executive of the Christchurch Agency for Energy (CAFE), advises that cogeneration has definitely been part of the thinking as the Christchurch DES has developed, but that initially it was intended that the DES, like the Dunedin Energy Centre, would only supply heating capability. The DES concept for Christchurch would be based around a central coal-fired unit providing hot water, with wood waste and straw becoming primary fuels over time. Individual building owners within the CBD, who would be the target customers, would be billed based on the temperature differential of water entering and exiting their premises. The advantage of this, says Altments, is that should building owners invest in their own generation capacity (such as solar), they could potentially generate credits and earn revenue through the scheme by contributing energy to the network. Altments advises that the scheme is currently being reviewed by Christchurch City Holdings Limited (CCHL).

Peter Houghton of CCHL, who is heading the review of the DES, believes that it is unlikely that any centralised DES will happen in Christchurch, and says that the programme has evolved into the consideration of 'heat hubs'. This concept would see the use of a number of distributed smaller boilers being utilised to provide heating, so as to avoid the prohibitive costs of insulated reticulation. Rather than purchase capital equipment for these hubs, the intention instead is to utilise excess capacity within existing plants.

The first of these heat hubs is likely to be based on the Christchurch Hospital heating plant. This boiler system is rated at approximately 28MW, but is only using 8MW of this capacity for current operations. Houghton believes this excess capacity can be exported, and generate revenue efficiently, so long as users are within 500m of the hospital to minimise piping costs. This approach minimises capital expenditure and makes a more efficient use of an existing capital asset, and requires no 'fringe or unproven technology'. Houghton also advises that, as part of the evolved DES concept, aquifer-driven heat pumps may be utilised to offer cooling capabilities.

Based on this amended strategy for the DES, it is unlikely that a wide insulated pipe network will be created, and hence any centralised cogeneration plant would need to also invest in reticulation. Furthermore, if the heat hubs concept works as intended, the market for heat will potentially be a competitive one and a centralised option is unlikely to be cost-competitive against a hub-based approach utilising existing capital assets.

Cogeneration does, of course, also produce electricity, and this market must also be considered in assessing broad feasibility. Bruce Rogers, Pricing Manager at Orion New Zealand, confirms that electricity-only generation is unlikely to be commercially viable and that cogeneration with a profitable market for excess heat is necessary to justify that capital expenditure required for a large-scale plant.

Rogers advises that the best case scenario for electricity generation in Christchurch, based on network loads, is to locate the generator near the old AMI Stadium site on the edge of the CBD. As this is unlikely to be feasible given the industrial nature of the process, consideration was given to the logistics involved in electricity generation from the Burwood Resource Recovery Park (BRRP) site, where a large volume of waste timber currently resides.

Orion is planning to build a substation in Marshlands, some 4km from BRRP in 2018. While this may be later than desirable for utilising electricity generation, a large scale plant (in the 10 – 20MW range) would need to directly connect to a substation, and this new station will be considerably closer than any existing alternative. The cabling required to make this connection is approximately $200 per metre, requiring nearly $1 million in expenditure simply to connect to the network, in addition to the generation asset expenditure and other equipment at the generation site to connect into the network.

Currently Orion would offer savings credits to a larger-scale generator of approximately $100/kW/year. Based on this, a 10MW generator would theoretically generate credits of $1,000,000, but only if the generation capacity is consistently available, any failure of the generation, especially at peak times, would quickly diminish these credits. In any case, explains Rogers, the industry is experiencing a "volatile, regulatory environment" and such credits may soon no longer be available.

In addition to any funding from Orion, Transpower may give consideration to providing limited capital funding if a new generation asset allows them to defer their own generation asset capital expenditure. Any such funding is speculative without a more firm concept being developed.

Once generation capacity was connected to the network and online, actual generation revenue would come from an electricity retailer such as Meridian or Contact Energy. Based on the historical spot price market, it is likely that generated electricity would be sold at approximately 8c/kWh. If a 10MW generation plant ran 24 hours a day, seven days a week, this would accrue potential revenue of approximately $5 million per annum, although in reality the actual revenue is likely to be less than this due to price fluctuations and plant outages. Whether this return is acceptable will depend on initial capital outlay and revenue streams from excess heat, but given the known challenges around these, this likely revenue stream is not considered compelling.

This market is made even more unpredictable based on the unknown future of the Tiwai Point Aluminium Smelter. Rogers advises that if this very large user of electricity ceases operations then, while any Orion and Transpower funding may actually increase, electricity spot prices are likely to decrease. Overall, it appears that the current and near future markets for electricity generation are precarious and carry no small degree of risk for new generation.

In summary, the viability of cogeneration is considered low. Any successful deployment of cogeneration utilising treated timber as a fuel source would require some form of pre-processing, which is likely to be expensive, and will require extensive investment in heat plant and generation plant as well as distribution reticulation. The economic viability of this is likely to be marginal in a city the size of Christchurch. While electricity generation may be profitable, although capital costs are very high, there is no obvious market for heat production which is the major output of cogeneration.

5.5 Cement Kiln Fuel

Processing of hazardous wastes in cement kilns is not new or uncommon. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal released technical guidelines in 2011 describing how to handle such wastes in an environmentally sound manner (UNEP, 2011).

These guidelines state that “although the practice varies among individual plants, cement manufacture can consume significant quantities of wastes as fuel and non-fuel raw materials. This consumption reflects the process characteristics in clinker kilns, which ensure the complete breakdown of the raw materials into their component oxides and the recombination of the oxides into the clinker minerals” (UNEP, 2011). The guidelines also indicate that treated timber waste may be an appropriate fuel source. “The non-volatile behaviour of most heavy metals allows most to pass straight through the kiln system and be incorporated into the clinker [but] wood treated with preservatives containing copper, chromium and arsenic also requires special consideration with regard to the efficiency of the exhaust gas cleaning system” (UNEP, 2011).

The guidelines also comment that “chromium content can adversely affect cement quality and may cause allergic reactions in sensitive users [and] leaching of chromium from concrete debris may be more prevalent than leaching of other metals.” Leaching may also be an issue with arsenic: “certain metals such as arsenic [and] chromium may have a more mobile leaching behaviour, especially when the mortar or concrete structure is crushed or comminuted (for example, in recycling stages such as use as aggregates in road foundations, or in landfilling)” (UNEP, 2011). The presence of PCP treated timber waste, albeit at low concentrations, may also cause additional issues in terms of leaching.

Despite these potential concerns, Golden Bay Cement has recently commenced the inclusion of treated timber waste as a fuel in their cement plant near Whangarei.

Golden Bay Co-processing Engineer Russell Dyer advises that untreated wood waste began to partially replace coal fuel in 2004. This consisted mainly of sawdust and wood chips from wood processing operations.

In 2009 a trial began with mixed timber waste from construction and demolition activities. This included treated timber waste. The trial was tightly controlled and included careful air discharge monitoring with a focus on CCA chemical components. The trial was successful to such a degree that the ability to utilise mixed wood waste did not require any alteration to Golden Bay’s existing resource consent as the air discharge was within acceptable limits.

Golden Bay is currently utilising wood waste as 50% of its fuel requirement on a weight basis and 32% on an energy input basis. Their desire is to increase this to an even split on an energy basis. Dyer estimates that, of the 38 tonnes an hour of waste wood used currently, 10% is construction or demolition waste, with construction waste being the majority of this amount. Of this 3.8 tonnes an hour of C & D waste, Dyer estimates that about 10%, or 380kg, is CCA treated. Thus Golden Bay would, at full operating capacity, utilise about 3,000 tonnes of treated timber waste per annum. Currently, due to market conditions, the plant is only operating at 75% capacity.

The primary reason Golden Bay’s kiln is able to effectively handle treated timber waste is the design of the kiln itself. As a dry process unit, the Golden Bay kiln is particularly effective at trapping chemicals in the clinker (cement clinker is a dark grey nodular material made by heating ground limestone and clay. The nodules are ground up to a fine powder to produce cement, with a small amount of gypsum added to control the setting properties). This reduces the risk of air discharge or leaching. Dyer points out that all of the chemicals in CCA treated timber – copper, chromium and arsenic – are already in coal, and hence already in cement. He stresses that research into leaching over many years has proven the ability of cement to retain these chemicals over time with no substantial risk to public health or the environment. Testing has indicated that the concentrations of CCA chemicals in the wood fuel are not sufficient to materially alter the concentrations of those chemicals in Golden Bay’s air discharge or final product.

The ability of Golden Bay's kiln to handle timber waste is also aided by the fact that it has a two stage firing process. The first stage burner in the kiln operates at 860°C, as opposed to the second burner which operates at 1400°C. This initial lower temperature requirement is what permits use of wood waste, which has a lower 'fuel value' than coal, without material loss of performance in the kiln.

Overall, Golden Bay are very satisfied with the use of timber waste and, as previously noted, would like to increase quantities. Doing so is challenging however, as the increased gas output from using wood fuel, as opposed to coal, causes a bottleneck in the firing process. The volume of wood fuel is also limited in terms of supply.

Golden Bay's wood fuel is supplied by Auckland-based Kalista. Director Graeme Bowkett estimates that of the timber they use 40% is untreated, 40% is boric treated and 20% is CCA treated, although he acknowledges there is no real way to know compositions with certainty.

Kalista take a gate fee on the disposal of the timber, and also make revenue on its sale to Golden Bay. Bowkett acknowledges that the wood fuel requires more handling for Golden Bay and has a lower fuel energy value, but points out that even with these limitations "Golden Bay saves money on using wood as fuel". Surprisingly, Bowkett says they are under constant pressure to meet the volume demands of their long-term supply agreement as they often cannot secure as much timber waste as they would like. The agreement has never been broken, but the reserve stockpiles are often quite small.

The proven usefulness and acceptability of wood waste, including treated timber waste, as a fuel for cement kilns suggests that this should also be considered as an option at the only other cement kiln in New Zealand: Holcim's plant in Westport.

In 2011 Holcim cement undertook an internal feasibility study to consider the use of demolition wood wastes as a fuel at their Westport plant, with particular regard to earthquake-related waste. The study noted that another of Holcim's Canadian plants, which is very similar to the Westport plant, had successfully used treated wood waste, however calculations showed that the Westport kilns would probably suffer a significant loss in maximum clinker production due to the lower calorific value of the wood compared with coal.

The feasibility study found that the wood would have to be shredded into relatively small particles and that the feasible rate of wood utilisation was considered to be in the range of 20 - 25,000 tonnes per annum considering the expected loss in kiln productivity. This represented a fuel energy substitution rate of 13-17%.

Based on this positive feasibility assessment, Holcim secured quotes for the capital expenditure required to upgrade their kiln to handle wood as a fuel. Unlike Golden Bay's cement kiln, Holcim's does not have a two-stage firing process (it is a much older plant) and so would require some capital upgrading to handle and utilise wood fuel.

A project team that also included Mastagard and Hawkins was formed in early 2012 to develop a business plan around Holcim's use of wood waste as fuel and to seek funding from the Ministry for the Environment's Waste Minimisation Fund. The overall project cost, including a timber shredder to be supplied and funded by Mastagard was approximately $6.6 million. $4.9 million in funding was sought from MFE on the basis that utilising the wood waste would cause a loss of production for Holcim. Holcim has confirmed that they are unlikely to achieve a capital expenditure rate of return sufficient to satisfy internal corporate requirements, but that the project would have substantial environmental benefits for New Zealand.

The project was declined by MFE in part due to the uncertainty of the Westport plant's future (Holcim may be seeking to build a new plant near Oamaru) and partly because MFE felt that the commercial operators themselves should fund the project and enjoy its financial returns.

One of the aspects that was not emphasised in the application (to avoid air discharge consenting concerns and because it was believed that waste timber arising from demolished houses in the Canterbury area would contain low concentrations of treated wood) was the use of treated timber, which the process would allow. Holcim believes that the use of shredded treated timber in the kiln would not result in increased air discharge or leaching of treatment chemicals, and assert that this view is supported by their own research and international studies. Certainly the use of treated wood as a cement kiln fuel takes place in many countries and detailed trials have shown that the clinker effectively locks in the hazardous chemicals present (Rhodes et al, 2010).

Since unsuccessfully applying for funding, Holcim have initiated a study to consider torrefaction of shredded timber in Christchurch to minimise transport costs of the wood to Westport. This suggests Holcim is still evaluating use of timber waste fuel, but means that any hazardous chemicals present in the timber waste will need to be considered at the point of torrefaction as well as in the cement kiln. It is not yet known whether Holcim is committed to this process or whether it intends to pursue the kiln upgrades necessary to handle wood fuel.

Based on the successful operation of the Golden Bay plant, and the expressed interest from Holcim in doing likewise, it is considered that the use of waste treated timber as a cement kiln fuel for Holcim is potentially feasible and justifies further consideration.

5.6 Biofuel Production

A number of the processing technologies considered in Section 4 of this report produce biofuels in some form as an output. The feasibility of each of these processes to actually produce bio-crude or bio-oil has already been considered, but once such outputs are available a further level of feasibility analysis must be undertaken: evaluation of the processes involved in transforming the outputs into useable industrial or transport fuels.

There are a number of key advantages in utilising recovered energy from waste treated timber in the form of biofuels. A good quality bio-crude should be able to replace conventional oil, which is currently worth close to US$100 a barrel. A barrel of crude oil weighs approximately 140kg, suggesting bio-crude is worth approximately US$700 a tonne. In fact, biofuels tend to be discounted in the marketplace, indicating a price closer half that of crude oil (REW, 2012). Even at these lower prices, however, there are few outputs from processing waste wood that could potentially compare in terms of revenue with biofuels.

Another advantage of biofuels is the ability to store and transport energy. Converting waste to energy in the form of heat or electricity means that its use must be in the immediate vicinity of production or the costs of distribution become prohibitive. The production of biofuels allows the energy to be stored and used on site as required, or transported to where it may be needed, although both of these elements add significant cost.

Tim Taylor from the Energy Efficiency and Conservation Authority (EECA) believes that biofuels present the best option for utilising the energy within waste treated timber, and suggests this is a strategic investment that should be taken very seriously. Peter Weir, from forestry company Ernslaw One, says they have also looked closely at different options for timber waste and believe that a 'storable' output like bio-oil is a good option. Weir and a number of others with experience in the biofuels industry are quick to point out, however, that the bio-oil or bio-crude output from various processing technologies is "a long way from being a transportation fuel" but could be used as a boiler fuel.

Weir believes that the economics of refining bio-crude or pyrolysis oil into a useable fuel are very unattractive. Bio-oil tends to be unstable and is not "well-liked" by refineries. Weir says that any refining of this output could only be done at large volumes in order to attract the interest of refineries such as Marsden Point near Whangarei. Andrew Campbell from Fuel Technology echoes this view and believes that instead of focusing on transportation fuels initially, the fuel should be split into grades and sold appropriately.

Using this approach, some of the output bio-crude may be able to be sold as high quality fuel, whereas most of it would be better to be sold as an unrefined fuel, useful for burning in applications with a high fuel-quality tolerance, such as Holcim's cement kiln. As volumes increase it may be economically feasible to invest in local refining capability, but in order to attain high yields from larger volumes outputs would need to be refined at Marsden Point. Campbell believes the transportation costs involved in sending bio-crude to Marsden Point may be prohibitive, and may result in a product that cannot compete with bulk crude oil. This situation is made even more challenging by the relatively low current price of oil. Campbell does not believe the price of oil will increase significantly for some time.

Ultimately, the challenge in producing biofuels is the fact that the output is typically not 'ready to use' and tends to be low-grade. The options are then to sell the fuel at a low price for a narrow pool of potential uses, or invest in the extensive equipment or transportation costs required to refine the fuel for transportation use. Despite these challenges, the potential returns from the sales of biofuels, particularly compared to other alternatives that also require high capital investment, make biofuel production a potential end use for treated timber waste that cannot yet be dismissed. More work will need to be done to determine if such an avenue is, ultimately, economically feasible.

5.7 Recycling

Reusing or recycling waste timber in some way has the appeal of extending the life of the resource and diverting it from landfill. It must be noted, however, that if the reuse option does not extract or in some way render the chemicals within the treated timber harmless, then at best the process is only delaying dealing with the treated timber waste, rather than actually addressing the problem.

It is common practice for builders to recover and reuse useful lengths of timber in the building process, and it is known that demolition waste treated timber that is deemed useful is being retained for sale or reuse by demolition companies such as Frews, although this requires considerable time and cost. It is probable that these quantities are low, however, particularly in terms of useful lengths of timber from earthquake-related demolition, as they are unlikely to meet the 'building-worthiness' requirements of the Building Regulations 1992 (Keeling, 2011).

The next most 'simple' form of recycling is the use of treated timber as a mulch or compost. The propensity for such products to leach arsenic at a relatively high rate due to their increased surface area quickly render them unfeasible as a useful outlet for waste treated timber (Love, 2007).

A commonly considered recycling option for waste treated timber is use in processed timber products such as fibreboard or particleboard. The potential to use treated timber waste in the manufacture of particleboard, chipboard or oriented strand board certainly exists, but raises some difficult issues. In the UK and Europe use of treated timber in such products is limited to 1% of the total wood used in production (Love, 2007). In 2006 New Zealand produced 11,170m^3 of fibreboard and particleboard, or approximately 6,000 tonnes. If a limit three times as high as that imposed in Europe was applied in New Zealand and 3% of the production input was treated timber, this would use only 180 tonnes of waste treated timber annually, or approximately 1% of Christchurch's estimated annual treated timber waste over the next fifteen years.

In addition, particleboard made with treated timber has a relatively high rate of arsenic leaching, and also results in a hazardous water waste stream from processing that must be appropriately disposed of. Such use is banned in Auckland by the regional council, but would only be prohibited in Canterbury if there is a hazardous discharge (Love, 2007).

Figure 5.3 - CLRT building construction in Europe (www.xlam.co.nz)

Another possibility is the use of treated timber waste in the manufacture of structural wood panels such as Cross Laminated Recycled Timber (CLT) panels.

CLT has been used extensively in Europe for commercial and residential buildings. Since the 2009 Italian earthquake, 4,000 new homes have been built using CLT materials (TH, 2012).

XLAM NZ Ltd has recently commissioned the "first CLT facility in the southern hemisphere" in Nelson. The wood panels produced are an alternative to 'tilt slab' concrete panels and can be completely formed in advance with holes for windows and doors pre-configured.

In addition, XLAM promotes its products as having 'zero-embodied carbon', offering 'carbon storage' and generating low or no wastage. Their website also says that, at end of life, the panels can be recycled into new buildings (XLAM, 2013).

Figure 5.4 - CLRT panels used as flooring (www.xlam.co.nz)

XLAM does not currently utilise any timber waste in its products, and it is difficult to see how this would be possible, given the timber lengths currently used and the state of C & D treated timber waste in Christchurch.

XLAM has not been contacted directly, but rather the potential of the technology has been identified by a Christchurch-based architecture graduate and entrepreneur, Duncan Craig. Craig believes that small lengths of treated timber waste can be 'finger-jointed together' and used in CLT panels to offer the end-product some of the benefits that treated timber offers, such as weather and insect protection. Again, it is difficult to see how this would work at larger production volumes, and there is little international precedent that could be identified for utilising waste timber in the production of CLT panels, whether the waste is treated or untreated. One study, based in Utah, considered the use of C & D waste for the production of CLT panels. While the study appears to consider this technically feasible it concludes that the use of C & D waste in this context is "not a socially, economically or environmentally sustainable solution" (Smith, 2011).

It is unlikely that treated timber waste will prove a suitable raw material for CLT construction but Craig intends to set up an operation in Christchurch. If this progresses, and the technical challenges of using treated timber waste are overcome, this may be a technology and end use that offers scope to utilise large volumes of treated timber, albeit without actually grappling with the issues presented by the treatment chemicals.

A further option for reuse of treated timber waste is in wood-plastic composites; products made from a combination of plastic and wood fibre.

Figure 5.5 - Hybrideck decking (BRANZ)

The only BRANZ-appraised wood-plastic composite product is Hybrideck, manufactured by Nelson-based Access Lumber Ltd. Access Lumber Director Virginia Gibson confirms that the product uses 60% waste timber fibre, but that this is untreated timber processing waste. The product is currently made in China, although Access Lumber aim to manufacture in New Zealand in the future, and so the use of treated timber waste would not currently provide a solution for New Zealand waste. Gibson advises that they would be reluctant to utilise treated timber waste because their current customers “don’t like chemicals” and would be resistant to such waste being used in the product.

Another wood-plastic decking product, Futurewood, is made from “recycled HDPE (old milk bottles and other post-consumer plastic waste) and discarded rice husks or hulls” (FW, 2012). The latter suggests the product is also not made in New Zealand.

Although wood-plastic decking products may not yet offer a feasible outlet for treated timber waste, Scion and other research agencies internationally are looking closely at the potential applications of wood-plastic composites based on the increased strength wood fibre offers to plastics. In fact, Scion’s research has shown that wood fibre can increase the strength of polypropylene by 118% (EN, 2013).

Much of this research, however, focuses on ‘virgin’ wood fibre, and not on treated timber waste, especially when untreated timber waste is so readily available in large quantities. An added challenge may be the decay potential that wood-plastic composites present when using treated timber, and the potential impact of treatment chemicals on binding of the plastic and wood (Rhodes, 2010).

Ultimately there is little evidence that the large scale use of treated timber in the production of wood-plastic composites is feasible. The technology clearly has real potential, but the incentives to face the additional challenges that treated timber may bring appear minimal and unquantified. There is potential for some treated timber waste to be reused or recycled, but none of these uses adequately deal with the hazardous chemicals contained in the waste. At best such issues are delayed or new waste streams are created. In addition, these uses are currently low in volume with only speculative potential for substantial increases in activity. For these reasons none of these options are considered feasible as a large scale end use for waste treated timber in Christchurch.

6.0 CONCLUSIONS AND FEASIBILITY

Accurately estimating the exact volumes of treated timber waste in Christchurch that currently exists at the Burwood Resource Recovery Park, or which will continue to flow over the next fifteen years is difficult. However, based on known information and justifiable predictions of forthcoming activities, the following volume estimates have been produced:

Table 3.4 – Total Estimated Treated Timber Flows in Christchurch (2013 – 2028)

Waste Source	Approx. Expected Tonnage (per annum)	Approx. Expected Tonnage (15 year total)
Earthquake-related demolition	1,600 *	24,000
Earthquake-related residential construction	1,600	24,000
Earthquake-related commercial construction	150	2,250
Non-earthquake-related activity	13,500	202,500
Totals	**16,850**	**252,750**

* Assuming the stockpile is used evenly over the fifteen year period

Again, the exact composition of this waste is indeterminate, but it may be assumed that approximately 16,500 tonnes will be CCA-treated, 5,000 will be boric treated and the remainder will be LOSP or copper-treated. In fact, the importance of understanding the proportions of timber waste that is treated and untreated really lies in understanding the likely chemical concentrations in a mixed treated and untreated timber waste stream, as current indications are that sorting of the two is not feasible in terms of time and cost. The current waste timber stockpile consists of mixed treated and untreated wood, and Transwaste has no intention to sort it. Only if future activities result in on-site sorting is this likely to take place.

Instead, an ideal solution for treated timber waste will be able to handle treated and untreated wood waste, regardless of treatment chemical concentration or type. The nature of the timber waste stream is that some of it will be untreated, whereas other parts will consist of entirely H4 treated timber wastes. Any solution that cannot handle these variations will require expensive sorting mechanisms.

The following provides an overview of the different processing technologies and methodologies considered in this report:

Table 6.2 – Overview of Potential Treated Timber Processing Technologies/Methodologies

Process	Key Advantages	Key Disadvantages	Assessed Feasibility	Further Investigation Warranted
Incineration	• Proven technology • Can take any timber type • Can handle large volumes of timber waste • Can take other waste types e.g. tyres • Potentially low running costs • Usually no pre-processing/shredding required	• Volatilisation of treatment chemicals - hazardous air discharge • Unlikely to obtain resource consent • Expensive air filtration required • Solvent waste stream from wet scrubbers likely • Hazardous ash produced	Low	No

Process	Key Advantages	Key Disadvantages	Assessed Feasibility	Further Investigation Warranted
		• Limited revenue generation opportunities • High capital costs		
Gasification	• Potential revenue streams via use of syngas • Higher waste to energy efficiency than incineration	• Volatilisation of treatment chemicals - hazardous air discharge • Unlikely to obtain resource consent • Expensive air filtration required • Solvent waste stream from wet scrubbers likely • Hazardous ash produced • High capital costs	Low	No
Pyrolysis	• Volatilisation of treatment chemicals unlikely • In use for treated timber internationally • Lower filtration requirements • Diverse outputs and potential revenue streams • Low to moderate capital costs • Low to moderate operating costs • Units can be mobile, and are scalable • Local development and manufacturing capability • Low energy input requirements	• Hazardous ash produced • Markets for outputs uncertain • May only process moderate volumes	Med - High	Yes
Torrefaction	• Output suitable as a coal replacement, inc. 'grindability' • Reduces fuel bulk for transportation • Concentrates fuel energy • Volatilisation of treatment chemicals less likely due to lower temperatures • Potentially effective in cement kilns	• Not widely tested for treated timber • May require expensive air filtration • Treatment chemicals may be present in outputs requiring air filtration when used • Scalability difficult • Users may incur extra costs versus coal	Med	Yes
Hydrothermal/ Supercritical Water Reactor Processing	• Potentially strong revenue streams • Positive results from small-scale testing with treated timber • Very low or no air discharge or other waste streams • Potential recovery and reuse of treatment chemicals • International interest in New Zealand technology	• High capital costs • Limited testing with treated timber • Uncertain existing markets for outputs • Expensive refining for outputs likely	Med	Yes
Wet Oxidation	• Low risk of treatment chemical volatilisation • Potentially high value acetic acid output	• Limited revenue streams • Not tested with treated timber • Hazardous ash produced • Arsenic may inhibit process • Outputs may be contaminated with treatment chemicals	Med	Yes
Chemical Extraction of Treatment Chemicals	• Removes hazardous chemicals from timber • High extraction rates possible • Expand potential use options	• Timber must be ground • Produces hazardous liquid waste stream • Requires extended timescales	Low	No

Process	Key Advantages	Key Disadvantages	Assessed Feasibility	Further Investigation Warranted
	• Potential to recycle chemicals with further processing	for extraction • Requires high cost chemicals for processing • Requires high energy inputs • Not being undertaken anywhere at commercial scale • Limited uses for processed timber		

The following provides an overview of the end use/end of life options for waste treated timber:

Table 6.3 – Overview of Potential Treated Timber End Use/End of Life Options

Option	Key Advantages	Key Disadvantages	Assessed Feasibility	Further Investigation Warranted
Disposal in Landfill	• Uses existing infrastructure • No short-term capital investment required • Low operating cost • If done temporarily, allows development of new processing technologies • Potential carbon sequestration benefit	• If subsequently used, results in expensive double handling and contamination of waste • May be intended for reuse, but costs prevent this • If sent to Kate Valley, transportation costs are high and available space is limited • Carbon credits unlikely and carbon price currently low • Potentially expensive and hazardous leachate • Takes up valuable landfill space	Med – high	No
Incineration	• Proven technology • Can take any timber type • Can handle large volumes of timber waste • Can take other waste types e.g. tyres • Potentially low running costs • Usually no pre-processing/shredding required	• Volatilisation of treatment chemicals - hazardous air discharge • Unlikely to obtain resource consent • No energy recovery • Expensive air filtration required • Solvent waste stream from wet scrubbers likely • Hazardous ash produced • Limited revenue generation opportunities • High capital costs	Low	No
Boiler Fuel	• Substantial local demand for boiler fuel • Potential cost savings for users • Recovers energy from treated timber	• Abundance of untreated timber waste available with little demand from potential users • Treatment chemicals corrode boilers and bag filters • Fuel typically unreliable and inconsistent • Volatilisation of treatment chemicals - hazardous air discharge • Unlikely to obtain consent • Expensive air filtration required • Solvent waste stream from wet scrubbers likely • Pre-processing of feedstock required • Hazardous ash produced	Low	No

Option	Key Advantages	Key Disadvantages	Assessed Feasibility	Further Investigation Warranted
Electricity/Heat Generation	• Efficient use of heat energy • Potentially strong returns from electricity production • Recovers energy from treated timber	• Timber waste must be processed before use or expensive filtration required • Very high capital costs • Transportation of fuel or distribution of heat/electricity is very expensive • District Energy Scheme likely to be a competitor, not a partner • No clear, viable market for heat • Electricity credits, market and spot price uncertain	Low	No
Cement Kiln Fuel	• Internationally recognised as an acceptable use of treated timber • Successfully utilised in Golden Bay's cement kiln • No air discharge concerns • Strong financial drivers for supply chain • Low to moderate capital costs • Potentially renders treatment chemicals unavailable to cause harm • Recovers energy from treated timber	• Potential leachate issues from cement • Limited to 25,000t of wood waste annually (perhaps only 2t of treated timber) • May require torrefaction to minimise transport costs	High	Yes
Biofuel Production	• High potential revenue streams • Ability to store and transport energy • Diverse potential applications based on fuel grade • Recovers energy from treated timber	• High refining and transportation costs • High capital costs • Bio-crude tends to be unstable and difficult to refine • Oil prices low and likely to stay low for some time • Potential treatment chemical contamination	Low - med	Yes
Recycling	• Productive use of waste • Extends life of wood • Low energy input to process and reuse • Relatively low cost • Replaces 'new' wood in products	• Simply delays the issue – doesn't deal with hazardous substances • Options and volumes very limited • Potential recycled products not made in New Zealand • Little incentive to use treated timber over untreated timber given chemical risks	Low	No

Based on the analysis of processing technologies and potential end uses as outlined above, the options considered to be most likely to be feasible for the large scale use of treated timber waste in Christchurch are:

- Using pyrolysis to create biofuels and charcoal
- Using torrefaction to create cement kiln fuel
- Using unprocessed (but ground) treated timber as cement kiln fuel
- Using hydrothermal processing to create biofuels
- Using the TERAX process to create saleable acetic acid

There are a number of key factors that influence the current situation in Christchurch, the likely environment over the next fifteen years and the kinds of processes and end uses available for treated timber waste. These factors make the productive utilisation of waste treated timber in Christchurch particularly challenging and will shape this project as it progresses:

- The absence of commercial buildings from the CBD (the demolition of which has provided a significant proportion of the treated timber waste) removes much of the potential demand for waste to energy projects which may have utilised the treated timber waste. The lack of a large centralised demand for heat energy renders some potential options uneconomic and generally requires any waste to energy utilisation to produce energy which can be stored and/or transported. The alternative is to wait for the completion of the rebuild, which may be fifteen to twenty years away.
- Processing treated timber is generally expensive from a capital investment perspective. Processing and generating energy from waste requires a certain scale to justify this investment and achieve economies of scale. Christchurch has a substantial supply of raw materials for such a project but does not have a large population or large industries (on a global scale) which clearly justify such an investment. The economics of any process and end use being considered in this project are unlikely to be overwhelmingly compelling.
- There is an apparent trade-off in terms of processing technologies and end uses: track record versus revenue potential. This is not absolute, but in general those pathways that are more researched and refined appear to offer less revenue potential than those that are novel and untested. This may, of course, indicate that the potential revenue of such technologies is overstated and may be more modest once deployed at a commercial scale.
- There are limited active markets for *untreated* waste wood suggesting that the economics of utilising *treated* waste wood, which will typically require extra processing and handling, are challenging. Ideally a solution will be ambivalent in terms of wood waste treatment status so that the entirety of the waste timber stream can be utilised without sorting.

7.0 NEXT STEPS

Milestone 1 of this project has focused on trends and developments that are currently active in New Zealand. Milestone 2 moves the analysis into a global context, focusing on:

- Researching technological advancements and emerging trends in the collection and reuse/recycling/recovery of waste treated timber internationally.

- Reviewing published research and presentations detailing successes and failures in the implementation of waste treated timber reuse/recycling/recovery systems.

- Exploring the impacts that new technologies and systems could have on the collection and reuse/recycling/recovery of waste treated timber in New Zealand.

Particular attention will be paid to new technologies that are emerging and the latest research developments in the application of existing technologies. Research will also be undertaken into any international applications of the solutions that offer 'base-case' feasibility in Milestone 1. This will include understanding how limitations in these approaches have been mitigated and whether expected benefits have been realised.

These learnings will then feed forward into the creation of potential scenarios in subsequent milestones.

8.0 REFERENCES

2G Cenergy (2011), *High Efficiency Cogeneration Plant saving 150 Jobs and dramatically lowering Energy Costs by 25 to 30%* Press Release, http://www.2g-cenergy.com/PDFs/Press%20Release%202G%20-%20CENERGY%20-%20February%2020%20-%202011.pdf

ASME (2011), *A Greener, Less Expensive Cogeneration Plant*, American Society of Mechanical Engineering, http://www.asme.org/kb/news---articles/articles/energy-efficiency/a-greener,-less-expensive-cogeneration-plant

APVMA (2003), *The Reconsideration Of Registrations Of Arsenic Timber Treatment Products (CCA And Arsenic Trioxide) And Their Associated Labels (Review Summary)*, Australian Pesticides And Veterinary Medicines Authority

Badger, P and Fransham, P (2006), *Use of mobile fast pyrolysis plants to densify biomass and reduce biomass handling costs—A preliminary assessment,* Biomass & Bioenergy

Beca, S (1998), *Timber Treatment Contamination Issues from Timber Preserving Activities in Canterbury*. Report prepared for Environment Canterbury

BF (2012), *The Progress of Earthquake-Related Demolitions in Christchurch,* Buddle Finlay, http://www.buddlefindlay.com/article/2012/02/15/the-progress-of-earthquake-related-demolitions-in-christchurch

BRANZ (2013), *Use of Timber,* http://www.renovate.org.nz/1940-60s/walls-and-cladding/use-of-timber/

BRANZ (2013a), *Building Basics: Minimising Waste,* Draft only, not yet published

BTG (2013), *Reforming in supercritical water,* Biomass Technology Group, http://www.btgworld.com/en/rtd/technologies/supercritical-water-reforming

Buchanan, A and Levine, S (1999), *Wood-based building materials and atmospheric carbon emissions*, Environmental Science and Policy 2 (1999)

CCC (2012), *Burwood Resource Recovery Park,* Christchurch City Council, http://www.ccc.govt.nz/homeliving/rubbish/burwoodresourcerecoverypark.aspx

CERA (2012), *CERA Christchurch Central City Commercial Property Market Study Part 2,* http://cera.govt.nz/sites/cera.govt.nz/files/common/cera-christchurch-central-city-commercial-property-market-study-part-2-may-2012-released-20130208.pdf

Clausen, C and Lebow, S, *Managing Treated Wood in Aquatic Environments – Reuse and Disposal,* Forest Products Society, Edited by Morrell, J, Brooks, K and Davis, C

Consumer (2013), *Why Homes Leak: Background to the Problem*, http://www.consumerbuild.org.nz/publish/leaky/leaky-background.php

CRL Energy Ltd (2011), *Heat Plant in New Zealand*, http://www.eeca.govt.nz/sites/all/files/heat-plant-database-report-august-2011.pdf

DBH (2007), *Timber Treatment Summary information from NZS 3602: 2003*, Department of Building and Housing

DBH (2011), *Pink is Tough: A Quick Guide to Timber Treatment for Enclosed Framing,* Department of Building and Housing

DES (2005), *Copper: Health Information Summary,* New Hampshire Department of Environmental Services, http://des.nh.gov/organization/commissioner/pip/factsheets/ard/documents/ard-ehp-9.pdf

Downie, A (2011), *PacPyro Slow-Pyrolysis Technology: Waste to Energy and Biochar*, WasteMINZ Presentation

DTA (2013), *Torrefaction: The future of energy*, Dutch Torrefaction Association, http://www.dutchtorrefactionassociation.eu/en/

Dubey, B, Townswend, T, and Solo-Gabriele, H (2004), *Leaching of Copper, Chromium and Arsenic from CCA Treated Wood in Sanitary Landfill Leachate,* Department of Environmental Engineering Sciences, University of Florida

Dutta, A and Leon, M (2011), *Pros and cons of Torrefaction of Woody Biomass*, Guelph Turfgrass Institute presentation, University of Guelph

ECAN (2013), *Developing Choices for Greater Christchurch: Preliminary Draft Land Use Recovery Plan Summary,* Environment Canterbury

Ecocitizen (2013), *Licella Bio Oil Plant Australia,* Australia Ecocitizen, http://www.ecocitizenaustralia.com.au/bio-oil-licella-australia/

ECY (2013), *Pentachlorophenol Treated Wood,* Washington State Department of Ecology, http://www.ecy.wa.gov/programs/hwtr/dangermat/pentachlorophenol_treated_wood.html

EFI (2013), Study: Dunedin Energy Centre Southern District Health Board, http://energyforindustry.co.nz/experience/dunedin-energy-centre/

EN (2013*), Bright future for wood in plastics,* New Zealand Engineering News, http://www.engineeringnews.co.nz/node/274

Enercon (2009), *Wood Fuel Feasibility Study - Christchurch Hospital CDHB*

EPA (1993), *R.E.D. Facts; Boric Acid*, US Environmental Protection Agency

EPA (2007), *Pentachlorophenol,* US Environmental Protection Agency, http://www.epa.gov/ttnatw01/hlthef/pentachl.html

EPA (2012), *ACQ - An Alternative to CCA*, US Environmental Protection Agency, http://www.epa.gov/oppad001/reregistration/cca/acq.htm

EPA (2012a), *Copper Azole - An Alternative to CCA,* US Environmental Protection Agency, http://www.epa.gov/oppad001/reregistration/cca/copperazole.htm

EECA (2009), *Gasification momentum builds in New Zealand,* Energy Efficiency and Conservation Authority Technical Guide 1.0

Fonterra (2013), *Whareroa*, Fonterra, http://www.fonterra.com/nz/en/About/Our+ Locations/NewZealand/Whareroa

FW (2013), *Timber Free Stylish Decking Materials,* Futurewood, http://www.futurewoodnz.co.nz/ composite-decking-plastic-decking

Gielen, G, Love, S, Lei, R, Gapes, D, Strong, J, McGrouther, G and Sthuthridge, T (2011), *Wet Oxidation technology – A Potential Biosolids Management Alternative,* IPENZ Transactions 2011/2

GTC (2011), *Gasification: The waste to Energy Solution,* Gasification Technologies Council

Hekkert, M (2000), *Improving Material Management to Reduce Greenhouse Gas Emissions*, Unpublished PhD Thesis, Utrecht University, Netherlands

Helsen, L and Van den Bulck, E (2004), *Review of Thermochemical Conversion Processes as Disposal Technologies for Chromated Copper Arsenate (CCA) Treated Wood Waste*, Environmental Effects of Preservative-Treated Wood Conference 2004, Technical Paper

Hery, J-S (2004), *A Complete Industrial Process to Recycle CCA-Treated Wood,* Environmental Effects of Preservative-Treated Wood Conference 2004, Technical Paper

Holcim (2011), *Demolition Wood Wastes as AFR at Westport*

Hooper (2013), Personal communication with R J (George) Hooper, Maidstone Associates Ltd

IBI (2012), *What is Biochar,* International Biochar Initiative, http://www.biochar-international.org/biochar

Jambeck, Y, Townsend, T and Solo-Gabriele, H (2004), *Leachate Quality from Simulated Landfills Containing CCA-Treated Wood*, Paper from 'Environmental Impacts of Preservative-Treated Wood Conference'

Kakitani, T, Hata, H , Katsumata, N, Kajimoto, T, and Imamura, Y (2007), *Chelating extraction for removal of chromium, copper, and arsenic from treated wood with bioxalate*, Environmental Engineering Science 24(8)

Kazi, F, and Cooper, P (1998), *Recovery and reuse of chromated copper arsenate (CCA) wood preservative from CCA treated wastes*. Presentation to the Canadian Wood Preservation Association Conference.

Kazor, M and Koppel, J (2013), *Scoping Waste in the Residential Built Environment Final Report,* Prepared for Beacon Pathway Ltd

Keeling, C (2011), *Treated Timber Disposal Options Appraisal,* prepared for internal Environment Canterbury use

Keene, S and Smythe, C (2009), *End of Life Options for Construction and Demolition Timber Waste: A Christchurch Case Study*, University of Canterbury ENNR429 Final Year Project

Koppejan, J, Sokhansanj, s, Melin, S and Madrali, S (2012), *Status overview of torrefaction technologies*, Procede Biomass BV, Netherlands

Laird, D (2008), *The Charcoal Vision: A Win–Win–Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, while Improving Soil and Water Quality*, Journal of Agronomy.

Licella (2013), *Our Technology,* Licella Pty Ltd, http://www.licella.com.au/technology/our-technology.html

Licella (2013b), *Key Partnerships,* Licella Pty Ltd, http://www.licella.com.au/about-us/key-partnerships.html

Love, S (2007), *Extended Producer Responsibility of Treated Timber Waste*, Sustainable Business Conference 2007 paper.

MBIE (2008), *Health outcomes in former New Zealand timber workers exposed to pentachlorophenol (PCP) - Archive*, Ministry of Business, Innovation and Employment, http://www.dol.govt.nz/publications/research/pcp-report-2008/final_pcp_report_jan_2008_05.asp

MFE (2004), *SWAP Results 2004 Spreadsheet,* Ministry for the Environment, http://www.mfe.govt.nz/issues/waste/waste-data/swap-baseline.html

MFE (2009), *Solid Waste Composition Environmental Report Card*, Ministry for the Environment

MFE (2011), Dioxin - Frequently asked questions, Ministry for the Environment, http://www.mfe.govt.nz/issues/hazardous/contaminated/dioxin-faq/

NBR (2013), *Z Energy and Norske Skog seek govt support for sawdust-to-crude plant,* National Business Review, 2 April 2013

NEAF (2008), *Torrefaction – A New Process in Biomass and Biofuels,* New Energy and Fuels, http://newenergyandfuel.com/http:/newenergyandfuel/com/2008/11/19/torrefaction-%E2%80%93-a-new-process-in-biomass-and-biofuels/

NIWA (2010), *Win:win – extracting energy from wastewater*, National Institute of Water and Atmospheric Research, https://www.niwa.co.nz/publications/wa/water-atmosphere-1-july-2010/solutions

NIWA (2013), *Bio-oil from wastewater algae,* National Institute of Water and Atmospheric Research, https://www.niwa.co.nz/our-science/freshwater/research-projects/biofuel-from-wastewater-algae

NZH (2012), *Put a tree in your tank,* New Zealand Herald, 19 October, 2012, http://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=10841322

NZTPC (2004), *Losp Treated Timber*, New Zealand Timber Preservation Council, http://www.nztpc.co.nz/lospTreatedTimber.php

NZTPC (2013), *Woodmark Information – Boric Treated Timber,* New Zealand Timber Preservation Council

OSH (1994), *Approved Code of Practice for the Safe Use of Timber Preservatives and Antisapstain Chemicals*, Occupational Safety and Health Service/Department of Labour

Pure (2010), *How Waste May Fuel the Future,* Pure: New Perspectives by Reciofil, Issue 01/10

PWCL (2013), *Cogeneration*, http://www.pwcl.co.nz/cogeneration.php

RC (2013), *Council hires staff to handle deluge of consents,* Rebuild Christchurch News, http://www.rebuildchristchurch.co.nz/blog/2013/4/press-business-rebuild-news-council-hires-staff-to-handle-deluge-of-consents

Read, D (2003), *Report on Copper, Chromium and Arsenic (CCA) Treated Timber*, Report for the Environmental Risk Management Agency New Zealand

REW (2012), *Everyday Low (Fuel) Prices: Drop-in Advanced Biofuels for Under $100 per Barrel,* Renewable Energy World, http://www.renewableenergyworld.com/rea/news/article/2012/11/everyday-low-fuel-prices-drop-in-advanced-biofuels-for-under-100-per-barrel

Rhodes, S and Dolan, L (2010), *Recovery and Disposal Options for Treated Timber*, WasteMINZ Conference Paper

Scion (2013), *TERAX Technology Development Summary 2008 – 2013,* Scion Research

Scoop (2011), *New mandatory timber chemicals toxic, says EU*, http://www.scoop.co.nz/stories/PA1103/S00258/new-mandatory-timber-chemicals-toxic-says-eu.htm

Smith, R (2011), *Interlocking Cross-Laminated Timber: Alternative Use of Waste Wood in Design and Construction,* BTES Conference 2011

Smith, S (2005), *Recycling Waste Treated Wood as Fuel: An Environmentally Responsible Option*

Snow, M and Lopez, K (2005), *Pyrolysis Transformation of Organic Wastes – Results of Full-Scale Trial Demonstrations,* Simeken Inc Technical Paper

Solo-Gabriele, H., Khan, B., Townsend, T., Song, J-K., Jambeck, J., Dubey, B., Yang, Y-C., Cai, Y. (2004), *Arsenic and Chromium Speciation of Leachates from CCA-Treated Wood*, Florida Center For Solid And Hazardous Waste Management

Stuff (2012), *Carbon credit glut irks forestry body*, http://www.stuff.co.nz/business/industries/8096654/ Carbon-credit-glut-irks-forestry-body

Stuff (2013), *Wood finds a niche in rebuild designs,* http://www.stuff.co.nz/the-press/business/the-rebuild/8553962/Wood-finds-a-niche-in-rebuild-designs

Stuff (2013b), *New policy aims to slash landfill load,* http://www.stuff.co.nz/the-press/news/8380824/New-policy-aims-to-slash-landfill-load

TH (2012), *Cross Laminated Timber is Ready for Prime Time,* Treehugger Blog, http://www.treehugger.com/modular-design/cross-laminated-timber-ready-prime-time.html

UMN (2008), *A Landowner's Guide to Carbon Sequestration Credits*, University of Minnesota Center for Integrated Natural Resources and Agricultural Management

UNEP (2011), *Technical guidelines on the environmentally sound co-processing of hazardous wastes in cement kilns*, Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (decision BC-10/8)

Watson, P (2009), *Canterbury District Health Board Christchurch Hospital Boilerhouse Wood Firing Feasibility Report*, Prepared for EECA

Wilson, D, Middleton, B and Eve, L (2012), *Construction Wood Waste Data Research,* Report prepared for Scion

XLAM (2013), *Sustainability,* XLAM NZ Ltd, http://www.xlam.co.nz/Sustainability