MARCH 2016

PREPARED FOR

Otago Regional Council

PREPARED BY

Emily Wilton, Environet Ltd

www.environet.co.nz

Environet ltd

Air Quality Specialists

Domestic home heating technologies – review of existing and emerging technologies promoting low emissions

EXECUTIVE SUMMARY

Technology has been used as an effective method for reducing particulate emissions from domestic scale solid fuel burners in a number of urban areas of New Zealand. Typically technology based improvements have been affected through implementation of the National Environmental Standard design criteria for wood burners or in areas with particular air pollution issues the introduction of lower emission limits (than specified in the NES) using Natural Resources Regional Plans for Air Quality. Both the Air Plans and the NES design criteria have relied on AS/NZS 4012 and 4013 which specify test methodology for emissions and efficiency.

The AS/NZS 4012 and AS/NZS 4013 standards were designed to enable particulate emissions from wood burners to be tested and compared in terms of their relative impact on the environment (with respect to particulate emissions) rather than as a measure of their absolute impact ("real life" particulate emissions). They are deliberately highly prescriptive in method, procedure and fuel quality to minimise variation in emissions occurring as a result of parameters unrelated to the design of the burner.

Despite the test method (AS/NZS 4013/4012) not replicating real life emissions it was assumed when introduced as a management tool that technology that could achieve low emissions when operated in accordance with the test criteria would also result in lower emissions than other technologies when operated in real life, on average. However, ongoing reductions in the emission limits allowed under this method is unlikely to result in corresponding real life improvements owing to the impact of behavioural aspects of burner operation and potential variability in fuel quality.

In many areas of New Zealand phasing out older technology and replacement of burners with those meeting the NES design criteria for wood burners (emission limit of 1.5 g/kg and 65% efficiency when tested to NZS 4013/ 4012) is sufficient to achieve ambient air quality standards. However, there are a number of areas within New Zealand where the above approach is unlikely to provide sufficient improvements in particulate concentrations and additional technology advances are required if households are to be able to continue to use solid fuel for home heating.

As no further technological improvements were likely under the existing testing regime Environment Canterbury introduced a new test which attempts to simulate real life conditions and new emission criterion being 0.5 g/kg of particulate. The new process is referred to as the Ultra Low Emission Burner (ULEB) authorisation procedure and compliant burners are referred to as ULEB.

Four burners technologies had been approved as ULEB at the time this work was undertaken. These are the Rias Bionic priced at $7870, the Jayline Watherm prices at $10,999, the Xeoos X8 solo priced at around $6950 and the Xeoos madden priced at $10950 both plus flue kit, and the TropicAir Duo priced at $5490. Prices exclude flue kits which range from around $650-$800) and installation. The fundamental technology is the same for all burners and is down draught burner with secondary combustion chamber. However, the Rias Bionic is an advanced design in that the switch to down draught mode is automated. The remaining three burners although approved by Environment Canterbury do not comply with the specification outlined in their proposed Air Plan that "*the burner cannot be operated in such a way as to bypass the technology that results in ultra-low emissions".*

A further two appliances were authorised prior to finalisation of this report but were not available on the market at the time of writing. These were the TropicAir wetback and the Masport Mystique.

An evaluation of international technologies and progress with emissions testing indicates that a move to "real life" testing is also underway in Europe. The "beReal" testing procedure has been developed and is in the latter stages of testing for replicability. Workshops focusing on progressing techniques and technologies for improving emissions from wood burners included as additions to the BIOENERGY2020 conference for several years now indicate that the issue is now a major consideration internationally. The technology focus for improving emissions from those workshops is automation of the combustion process (to reduce operator involvement). Technique advancements include the use of simulation of combustion using computation fluid dynamics (CFD).

Secondary technology for reducing particulate emissions have be authorised for use in countries such as Germany. One of these devices, the Oekotube utilises electrostatic precipitation (ESP) to remove particles from

the air flow through the chimney and is available for purchase in New Zealand. Tests done on the Oekotube in New Zealand suggest that it is an effective method for reducing particulate emissions from both wood and coal. The cost is around $2800 + GST for an individual unit (plus installation if applicable) but the price reduces significantly if purchased in bulk (around $2300 + GST installed).

The table following outlines the operational costs associated with different heating options for the Otago Region. This indicates that the most cost effective energy sources for residential space heating for the Region are wood and heat pumps.

	Otago	Otago	Consumer – national 2015	
	Lower end c/kWh	Upper end c/kWh	Lower end c/kWh	Upper end c/kWh
Wood	10	17	8	28
Coal	12	14		
Pellet burner	17	26		
Unflued gas (LPG)	21	40	31	41
Flued gas (LPG)	19	19	19	23
Electricity – heat pump Dunedin	8	10	6*	12*
Electricity – heat pump Otago	8	13		
Electricity Dunedin	23	29	16*	35*
Electricity Otago	25	40		

* national rather than area specific

The potential for community (district) heating schemes was also considered. Areas with low housing density historically have not historically been considered well suited to community heating schemes because of energy loss in the transfer of heat. New Zealand towns are typically low density compared with overseas locations where district heating schemes are typically used to heat apartments, blocks of flats or high density housing areas. Case studies of three relatively recent district heating schemes were presented. A heat pump scheme from Norway was included in support of a proposal by Bodeker Scientific to examine the potential for use of the Clutha River for a heat pump district heating scheme for Alexandra. In the United Kingdom there has been an increase in the number of biomass fuelled district heating schemes to reduce fossil fuel consumption. Two examples of wood chip fuelled schemes are given. In one, the energy loss along the pipelines is given as less than 0.01^{o}C per 100 metres. The pipelines extend only 1.4 kilometers for the scheme and heat is supplied to 27 units. Further investigations into the viability of a district heating scheme for small towns in the Region would be of value.

TABLE OF CONTENTS

1 INTRODUCTION

The use of technological advancements for reducing discharges to air from domestic scale solid fuel burners is a common air quality management tool in New Zealand and has been effective in a number of locations (e.g., Wilton, 2014d).

The initial technology based approach was to introduce mandatory emission limits using the joint New Zealand Australian test standard for wood burners (AS/NZS 7402 (1992) and AS/NZS 7403 (1992). This standard itself specified a particulate emission limit of 5.5 kilograms of total suspended particulate per kilogram of fuel burnt. However, the emission limit was not mandatory in either New Zealand or Australia and was only adopted as a requirement in Christchurch from 1992 where it was selected to replace the previously used 35 g/hr rate by the Canterbury Regional Council[1] and was applied to the burning of any solid fuel. In 1999 NZS 7402 and 7403 were replaced with AS/NZ 4012 and AS/NZ 4013 which included a revised non mandatory emission limit 4.0 g/kg.

The Canterbury Regional Council revised emission limits between 1997 and 2002 settling on an emission limit of 1.0 g/kg in 2002 and a number of other Councils followed suit with varying requirements (for example, Nelson City Council - 1.5 g/kg and 65% space heating efficiency, Otago Regional Council - 0.7 g/kg and Auckland Regional Council 4.0 g/kg). Environment Canterbury and Nelson City Council both prohibited the installation of solid fuel burners in houses using non solid fuel options in Christchurch and Nelson effectively limiting the number of households that could use solid fuel. Some exceptions were made for low emitting pellet fuel burners in both areas.

The AS/NZS 4012 and AS/NZS 4013 standards were designed to enable particulate emissions from wood burners to be tested and compared in terms of their relative impact on the environment (with respect to particulate emissions) rather than as a measure of their absolute impact ("real life" particulate emissions). They are deliberately highly prescriptive in method, procedure and fuel quality to minimise variation in emissions occurring as a result of parameters unrelated to the design of the burner.

As a result of an increasing awareness of high concentrations of particulate in urban areas of New Zealand caused by domestic home heating, the Ministry for the Environment (2004) introduced a particulate (TSP) emission limit of 1.5 g/kg and an efficiency criterion of 65% (AS/NZS 4013/4012)for all new installations of wood burners on properties with an area of less than 2 hectares from September 2005.

The test method (AS/NZS 4013/4012) was not intended to be a replication of real life emissions from the burners but it was assumed when introduced as a management tool that technology that could achieve low emissions when operated in accordance with the test criteria would also result in lower emissions than other technologies when operated in real life, on average. However, ongoing reductions in the emission limits allowed under this method is unlikely to result in corresponding real life improvements owing to the impact of behavioural aspects of burner operation and potential variability in fuel quality. Emission factors used to assess real life emissions in inventories and air quality management evaluations were typically at least a factor of two higher than the test emission limit.

[1] This was carried over from the Clean Air Act requirements for the Christchurch "Clean Air Zone' through the "Transitional Regional Plan" (TRP). Under the TRP changes to this emission limit for solid fuel burners could be made by public notice.

2 REAL LIFE TESTING METHODS

2.1 New test regime in New Zealand – Canterbury Method

The Canterbury Method is a new approach to testing particulate emissions from small scale solid fuel burners developed by the Canterbury Regional Council. The method has been developed to encourage new technology in domestic wood burning that aims to reduce "real life" particulate emissions from wood burners. The term "real life" is intended to mean the actual emissions that occur when a burner is operated by a layperson in a home.

In contrast, the previous test method has focused on obtaining precision, so it can robustly compare one burner to the next, rather than on accuracy, (i.e., measuring the most relevant thing in terms of environmental outcome). While the move away from the AS/NZS 4012 and AS/NZS 4013 approach may seem logical in terms of assessing environmental outcomes, it is likely to come at the expense of precision of test results. An estimate of real life emissions is likely still required as is ongoing evaluation of the effectiveness of the test method and emission limits in terms of environmental benefits.

The Canterbury Method provides a testing regime for determining particulate emissions under a test that provides a closer simulation of "real life" emissions than the AS/NZS 4012 and 4013 test regime. Alternative test regimes are also allowed by the Canterbury Regional Council subject to their approval. An Ultra Low Emission Burner (ULEB) is classified as a burner that meets a particulate emission limit of 0.5 grams of particulate per kilogram of fuel burnt when tested to the Canterbury Method or Alternative Method and is a restricted discretionary activity under rules AQL9B, 81B and 92A of the Canterbury Natural Resources Regional Plan (NRRP). Under the Proposed Canterbury Air Regional Plan the limit is specified as 38 mg/MJ and the installation of a ULEB is a permitted activity. The 38 mg/MJ emission limit is equivalent of 0.5 g/kg at 65% efficiency but allows for a slightly higher emission level if the space heating efficiency is greater or requires a lower emission level if the efficiency does not meet 65%.

When authorising a ULEB Environment Canterbury (under schedule 8 of their proposed Air Plan) also require that:

- Ultra-low emissions must be sustainable.
- A burner cannot be operated in a way that bypasses the technology that results in ultra-low emissions.
- The burner cannot be tampered with to affect its performance.
- If maintenance (such as cleaning and filter changing) is required for the technology to be effective in reducing emissions, a process must be in place to ensure this happens (such as a condition of a resource consent).
- The technology for reducing PM_{10} emissions must be designed to be effective for the duration of the burner's life.

The main differences between the Canterbury Method test/ Alternative tests (and test philosophy) and the AS/NZS 4012 and 4013 test method is:

- The inclusion of start-up emissions and burn down phase.
- The wood fuel used for testing.
- The inclusion of tests with hardwood and unseasoned wood.

2.2 International progress with real life testing methods

At the time of the previous review into test methods and burner technology, Christoph Schmidl (BioEnergy 2020) was working on the development of a real life emissions testing regime. This has resulted in the funding on an EU-Project (FP7): Advanced Testing Methods for Better Real Life Performance of Biomass Room Heating Appliances, referred to as the "beReal" testing. The project commenced in October 2013 and concludes in September 2016. The basis for the project is outlined on their website:

Increasing environmental concerns due to the contribution of wood smoke to total PM concentration in ambient air pose a vital threat to the use and further diffusion of biomass room heaters in Europe. Existing test standards have supported technology development tremendously in the past decades. Due to today's changing and more demanding requirements, however, there is the obvious need for refined testing procedures and an improved assessment of the performance in order to differentiate between poor and excellent products. Such a differentiation should also take into account various operating conditions as they are found in real life installations. Offering such information to customers will create substantial competitive advantages to innovative SMEs providing high quality products and may provide a reliable guideline for future standards or regulations ("beReal," 2016).

The key objectives of beReal are: -

- Development of **advanced testing methods** for biomass room heating appliances (firewood & pellet stoves) to better reflect **real life operation.**
- Development of a **centralized standard evaluation tool** for quality assurance purposes.
- **Validation of methods** at an early stage of development.
- Proof of **real life impact** of advanced products by **field test demonstration.**
- Proof of **reliability** and **reproducibility** of testing methods and evaluation tools in a **Round Robin test.**
- Development and introduction of a **European quality label** based on the novel testing methods.
- Project results are accompanied by **dissemination activities** addressing standardization bodies, SME-members of participating SME-AGs and notified bodies, including training activities for the latter two groups. The introduction of the quality label addresses end users and general public (Christoph Schmidl, 2015).

The process for method development includes an evaluation of what type of operation constitutes "real life" and methods for evaluating this include literature reviews, surveys and long term field measurements.

The method is currently in draft form which includes the following:

- Eight successive batches are performed starting from cold conditions (Ignition & preheating batch included – since they always occur in real life operation).
    - Batch 1 to 5: Batch mass represent nominal load (100% batch mass).
    - Batch 6 to 8: Batch mass represent partial load (50% batch mass).
- Mode of ignition:
    - Mode of Ignition - Defined by the manufacturer (Quick User Guide):
    - Number of firewood pieces.
    - Mass of ignition batch (≥ 80% of the fuel mass representing nominal load).
    - Kindling material (max. 25% of total batch mass) & starting aids (only biobased firestarters allowed paper & liquids not allowed, max. 3% of total batch mass).
    - Mode of fuel placement of ignition batch in the combustion chamber.
- Fuel requirements:
    - Fuel: beech firewood (preferably) or birch firewood covered with bark.
    - Each wood log shall have at least one side covered with bark.
    - Covered is defined as >80% of surface area.

3 ULTRA LOW EMISSION BURNERS

3.1 Jayline Waltherm Wood Fire

The Jayline Waltherm was the first ULEB approved in New Zealand by Environment Canterbury. The burner is manufactured in Italy. The New Zealand supplier is Retail Links Limited of Nelson.

The burner is a batch fed down draught burner with twin combustion chambers. Kindling and fuel wood is loaded and ignited in the top chamber. Combustion gases generated during start up are emitted through holes in the top combustion chamber and exit via the flue. Once the temperature in the stack reaches 350 degrees C, the operator is required to close a bypass valve which diverts combustion gases generated in the top chamber to the bottom chamber where secondary combustion of gases takes place. This is referred to as downdraught mode. The exhaust from the lower chamber passes through ducts in the body of the appliance and exit via the flue. As the appliance heats up an internal convection fan activates (at 50 degrees) which pumps heated air from the internal ducts into the room through vents on the sides of the appliance. The device requires an electrical connection to drive the convection fan.

Figure 3.1 shows the double combustion chambers and location of the bypass lever, air ducts and flue.

Table 3-1: Jayline Waltherm Wood Fire

Canterbury Method test data indicate a heat output of 14.9 kW, a space heating efficiency of 66.6% and particulate emissions of 0.47 g/kg.

3.2 Rais Bionic (Bionic Fire)

The Rais Bionic fire has been authorised as a ULEB by Environment Canterbury and resource consent for installation of the burner into new dwellings and existing dwellings using other heating methods has been granted. The burner is imported and retailed by EnviroSolve.

The technology adopted is wood gasification and double combustion down draught burner (Figure 3.2). Wood is loaded into the upper combustion chamber and air flows are automated between chambers to achieve combustion of volatile gases in the lower combustion chamber.

The Rais Bionic has the down draught mode automatically controlled so there is no ability for the operator to bypass the technology. It also rates highly in terms of not being able to be readily tampered with.

Canterbury Method test data indicate a heat output of 4.1 kW, a space heating efficiency of 75.9% and emissions of 0.5 g/kg and 32 mg/MJ.

Table 3-2: Rias Bionic Fire

3.3 TropicAir Duo

The TropicAir Duo is the first New Zealand made ULEB authorised by Environment Canterbury. Resource consent has been granted for installation into new dwellings and existing dwellings using other heating methods. The burner is manufactured by TropicAir Heating Limited, Christchurch.

The technology adopted is a down draught burner with twin combustion chambers (Figure 3.3) and the aesthetics have been modified to be a closer fit with conventional burners commonly used in New Zealand. The Duo comes with two bases (woodbin and standard). The appliance was approved without automatic controls meaning the operator has to manually turn the appliance to downdraught mode. The instructions are for the down draught to be activated 15 minutes after lighting the fire (when the fire in the upper fire box is sufficiently well established). The control is located on the side of the appliance. However, the authorising report states that the client proposes to develop an automatic control for down draught and proposes the development of a wet back model of the burner. The fire has three temperature settings which are controlled with a damper level at the front of the appliance.

Unlike the Jayline Waltherm, the TropicAir does not have a fan for circulating air from the burner to the room.

Table 3-3: TropicAir Duo

Real life testing data indicate a space heating efficiency of 74%, emissions of 0.35 g/kg and 23 mg/MJ and a maximum heat output around 15 kW.

3.4 XEOOS Twin fire X8 Pur, Basic, Solo and Matten

The XEOOS twin fire (several models) have been authorised as ULEB by Environment Canterbury and resource consent for installation of the burner into new dwellings and existing dwellings using other heating methods has been granted. The burner is manufactured by Specht Modular Oven Systems (Germany) and is imported by Retrospective Designs Ltd.

The technology adopted is a down draught burner with twin combustion chambers (Figure 3.4). Like the Jayline Waltherm and TropicAir Duo and unlike the Bionic fire the Xeoos requires manually turning to downdraught mode when a predetermined temperature is displayed on a thermometer. This function is controlled by the door handle which has three settings. These are “Door Unlocked” which is used when loading fuel, “Heat Up” which is the setting for starting the fire when only the top combustion chamber is used and “Twinfire” which is the setting for down draught mode (when the second firebox is activated). The rate of combustion is also manually controlled by selection of a high or low burn rate in a similar way to a conventional wood burner.

Table 3-4: Xeoos X8 Solo

Real life testing data indicate a space heating efficiency of 69% and emissions of 0.45 g/kg and 33 mg/MJ. The heat outputs range from 4kw to 7.5 kW.

3.5 ULEB prices

Retail prices for ULEB burners at the time of writing this report were as follows:

- Rias Bionic - $7870 plus flue kit
- Jayline Watherm - $10,999 plus flue kit (approx. $799)
- Xeoos X8 - solo - $6950, madden $10950 both plus flue kit
- TropicAir Duo - $5490 plus flue kit (approx. $649)

Note that prices exclude installation costs which may be around $1200.

3.6 Uptake of ULEB in New Zealand

The main markets for ULEB in New Zealand currently are Christchurch, Kaiapoi and Rangiora and in Nelson where ULEB are the only appliances that can be currently installed in new dwellings or existing dwellings using other heating methods (note that the proposal to allow installations of ULEB was notified in January 2016 and is not operative in Nelson). Global consents have been issued for ULEB suppliers in Christchurch, Kaiapoi and Rangiora and in Nelson the proposed rule limits the number of new installations of ULEB to 1600.

Information provided by Environment Canterbury indicated that for the period up to mid January 2016 around 65 ULEB had been installed.

No ULEB had been installed under the proposed Nelson rules at the time of writing owing to the rule not being operative. However, it is possible that ULEB have been installed in Nelson as replacement heating methods as these burners are also authorised as NES compliant burners.

Environment Bay of Plenty implement an incentives programme to assist low income households in replacement methods for burners that do not comply with the NES design criteria for wood burners. The programme includes a fully funded insulation and heating option for low income households and a hotspot scheme which offers a 10 year loan for households replacing non-complying burners including financial incentives (no interest) for cleaner heating options. The Council is looking to purchase 40 ULEB wholesale from the supplier for the full subsidy incentives programme in 2016 and is expecting to purchase a further 90 units per year for the following four years. In addition it is considering incentivising towards ULEB installations for the hotspot scheme by offering no interest on the loans for households replacing with a ULEB (as it currently does for a heat pump).

No information is available on the installation of ULEB in areas other than where regulations favour the installations of ULEB over other burners. In these areas there is no incentive for households to install a ULEB over other burner types and installation numbers are likely to be relatively low owing to the price differential although this may change with the lower priced TropicAir Duo. One supplier indicated a ratio of one burner for an area outside of Christchurch to every two burners sold within Christchurch, Kaiapoi or Rangiora.

Data suggests limited uptake of ULEB throughout New Zealand to date with likely installations less than 300 throughout New Zealand. However, it is important to note that it is very early in the process and it is likely that uptake will increase during 2016, particularly in Christchurch, Kaiapoi and Rangiora, and in Nelson if the proposed rule change becomes operative.

3.7 ULEB summary

Table 3.1 summarises appliance information for the four ULEB technologies authorised by Environment Canterbury as at December 2015. In addition a TropicAir wetback has been authorised. A further appliance the Masport Mystique has obtained authorisation as a ULEB but was not available on the market by March 2016.

Table 3-5: Summary of ULEB authorised by Environment Canterbury as at 31 December 2015

	Jayline Waltherm	Rais Bionic	XEOOS	TropicAir Duo
Heat output	14.9	4.1 kW	4kW – 7.5 kW	15 kW
Emissions – Canterbury method	0.47	0.5	0.45	0.35
Efficiency – Canterbury method	67%	76%	69%	74%
Cost (excl flue and installation)	- $10,999	$7870	$6950 & $10950	$5490
Manual or automated switch to down draught	Manual	Automated	Manual	Manual
Requires electricity	Yes	No	No	No

3.8 Pellet fires

Low emission pellet burner and boilers have been available on the market in New Zealand for more than a decade. The Environment Canterbury burner authorisation website (Environment Canterbury, 2016) identifies more than 40 pellet burners or boilers that meet the ULEB emission criteria.

Pellet burners and boilers are more likely to produce low real life emissions than conventional wood burners because there is less ability for incorrect operation as the fuel feed is automated. The fuel in theory should also be more consistent although moisture can be absorbed into the pellets if they are not appropriately stored.

Although wood pellets provide a solid fuel alternative to wood burners they have a relatively low market share in most urban areas of New Zealand even locations such as Christchurch (3% of households) and Nelson (4% of households in Airshed A) where new wood burners are unable to be installed (Wilton, 2014b, 2014c). In the Otago region around 3% of households in the Air Zone 1 and 2% of households in other urban areas use pellet fired burners.

3.9 Other technologies

Emerging technologies include a ULEB that is able to be used as a wetback. A variation on the TropicAir Duo with wetback has been authorised by Environment Canterbury as ULEB.

The Oekotube could be classified as an emerging technology in terms of application in New Zealand as it has been tested over the last few years to evaluate its effectiveness using New Zealand required test methods. This technology is detailed in section five of this report. The Oekotube on its own could not be authorised as a ULEB but it could in theory be approved in conjunction with an existing low emission burner to further reduce emissions for ULEB compliance. Another application of the technology would be in conjunction with existing wood or coal burners to reduce emissions without replacing the heating device.

Other technologies that could be of value in the Otago Region include boilers (wood, coal and pellet) that can be used for central heating of dwellings. It is uncertain whether any solid fuel boilers (excluding pellet boilers) have been tested for compliance with the ULEB criteria. Several pellet boilers have been authorised as ULEB (Environment Canterbury, 2016).

4 INTERNATIONAL TECHNOLOGIES

Environment Canterbury carried out a review of international technologies for reducing particulate emissions from wood burners (Wilton, 2012a). That evaluation identified difficulties in comparing technologies owing to different methods of measuring and reporting particulate emissions in different countries, and even within the same country.

Low emission technologies identified in that report include tile fires, automated temperature and reloading technologies, down draft burners, small scale boilers or burners with secondary control technologies. The general response from experts in Europe was that the key to low particulate emissions (in the absence of secondary control equipment) is automation of the combustion process.

To understand advancements in technology since the 2012 review, experts were contacted to provide an update on the technologies being designed and tested. An internet search was also carried out. The following summary provides an overview of the findings with respect to international technologies.

4.1 Current issues for wood burning in Europe

In October 2015 there was a workshop on "Highly efficient and Clean Wood Log Stoves" held in Berlin as a side event to the IEA Bioenergy conference. A summary of the workshop is as follows:

"The workshop provided insight into the effectiveness of various technical measures that can help to further improve efficiency and emissions of typical woodstoves sold in Europe today. Wood stoves continue to be sold on the European market and provide significantly to renewable energy use, however, in case obsolete technologies are applied or the stove is not properly operated, there may be significant adverse effects on public health.

Good combustion starts with a properly designed combustion chamber. CFD[2] aided design tools are being developed to translate the improved fundamental understanding of the combustion process into better practical designs. The application of such tools however is relatively costly and it is doubtful whether smaller stove producers can afford this at the moment. For new stoves it is advised to start with a proper furnace design, and then design an attractive casing around it (currently the design process often takes place the other way around).

Very positive results have been achieved with stoves equipped with automatic combustion control, to optimise the combustion parameters through the various phases of the combustion process. For the validation of such improvements also new test procedures are required, which better reflect real life operational behavior, such methods are currently being developed.

Positive results have also been achieved for the application of catalysts in stoves, in Germany, stove catalysts are now commercialised. The effect of foam ceramic elements without catalyst, aimed at extending the reaction time and thereby reducing the emission of particles, seems only marginal.

Other major influencing factors on emissions are the use of wood with suitable moisture content, proper user behaviour and an adequate installation and integration of the stove into the building. These factors can be addressed by user trainings organized by stove suppliers and by quality certification schemes for installers."

4.2 Research and development in Europe

Areas of focus in international research into low emission wood burning technologies include:

- Computation fluid dynamics (CFD) as a tool for better understanding the combustion process and the design influences on combustion.

[2] Computational fluid dynamics

- Automating the primary air control to reduce the operator influence on combustion and including information to the user on when to add fuel.
- Improving combustion through stabilising the draught (Frank Kienle, 2015).

Emerging concepts in technologies include:

- Burners that can be operated through a combination of cord wood and pellets (presumably to enable some automation of fuel with pellets whilst still allowing the use of wood).
- Water heating exchange appliances (Frank Kienle, 2015)

4.3 Standardising of test methods and emission limits for Europe

One of the key issues identified in Wilton, 2012 in comparing burner technologies was different test methods for determining emissions, with one of the significant influencing factors being the inclusion or exclusion of a dilution tunnel to capture particulates that condense on contact with ambient temperatures. Across the European Union there are a range of test methods used as well as a range of emission limits applied. Table 4.1 outlines the emission limits that will apply in the EU from 2022.

Table 4-1: European Union emission limits for small scale burners

	Seasonal efficiency	PM_{10} (mg/m^3)	OGC (mgC/m^3)	CO (mg/m^3)	NOx (mg/m^3)
Closed fronted	65%	40	120	1500	200 300 fossil
Open fronted	30%	50	120	2000	200
Closed fronted pellets	79%	20	60	300	200
Cookers	65%	40	120	1500	200 300 fossil

4.4 Design recommendations for low emission burners in the EU

Characteristics of low emission burners are described in a presentation by Ingwald Obernberger, (2015). The following box provides an excerpt of low emission burner characteristics from that presentation:

LOW EMISSION BURNER CHARACTERISTICS

(from Ingwald Obernberger, 2015)

Adequate amount of combustion air

- Sufficient but not too high draught is needed
- Typical draught variations in chimneys and associated variations of the combustion air flows shall be considered during stove development or by appropriate measures

Enough residence time at high flue gas temperatures

- As high as possible temperatures are a pre-requisite for the oxidisation of products from logwood gasification.
- Therefore, the temperature in the main and the post combustion chamber should be kept as high as possible
- The temperatures are affected by:
    1. Refractory lining in the main combustion chamber
    2. The shape and size of the main combustion chamber
    3. Window material & size
    4. Location of air nozzles for secondary air injection
    5. Window purge air injection strategy

Mixing of the flue gases with the combustion air

- Is needed to achieve complete combustion
- Mixing is affected by
    1. The direction and geometry of the air nozzles
    2. The velocities of the flue gas and combustion air
    3. The distribution of different air flows, such as secondary air and window purge air (air staging)
    4. The geometry of the main combustion chamber
    5. The use of baffles in the post combustion chamber

Leakage air should be avoided by using appropriate materials for the door and sealing of the door

Short-circuiting of the flue gases should be avoided

- No gaps between the plate separating the main combustion chamber from the post combustion chamber
- Through such gaps unburned gases from the main combustion chamber could flow to the flue gas outlet without passing through the burnout zones in the main combustion chamber (2)

A logwood stove should consist at least of

- a main combustion chamber and
- a post combustion chamber

The combustion chamber should be hot enough but the fuel bed should be kept at moderate temperatures.

Insulation materials should be used around the main combustion chamber to keep the combustion temperatures high.

- for example refractory bricks with heat resistant wool and a small air volume between insulation and the outer stove casting

Radiation losses through the door shall be kept low

- window in moderate size
- glass qualities with low radiation coefficient
- double glazed windows (with an air gap)

The flue gas should have enough time to efficiently cool down downstream of the combustion chamber

- Sufficient heat exchanging surfaces to maximize the efficiency
  - should be associated mainly with the post combustion chamber
  - the heat exchange can be improved by introducing forced ventilation

A grate should be used:

- Simple de-ashing
- Controlled primary air supply through grate is possible
- However, air flow through the grate should be able to be shut down completely - only kept open during the first ignition phase and during the last batch after flame extinction

Firebox geometry:

- High and slim combustion chambers are preferable (compared to wide and low)
  - this shape improves flame dispersion
  - it leads to a more homogeneous residence pattern for the pyrolysis gases produced in the hot zones and therefore less danger of streak-formation (short circuit flows to the exhaust pipe)

Improvements to the authorisation process may also be possible through the use of Computational Fluid Dynamics. CFD may be used to reduce repeated prototype design and testing.

4.5 North America

In North America the Environmental Protection Agency's (EPA) New Source Performance Standards (NSPS) for residential wood heaters govern the manufacture and sale of new residential wood heating devices (USEPA, 2015).

The EPA is phasing in the new emission limits over a five year period to allow manufacturers time to adapt technologies to meet the more stringent limits. For woodstoves (wood burners), pellet stoves, and hydronic heaters (boilers), the final rule phases in emissions limits in two steps, with the first limit of 4.5 g/hr now in effect.

The second limit takes effect in 2020 and reduces to 2 g/hr or 2.5 g/hr if testing is carried out using cord wood (as is the requirement in New Zealand). The latter limit compares to around 1.25 g/kg for an average fuel burning rate of two kilograms per hour which compares with an emission limit of 1.5 g/kg as specified in the NES design criteria for wood burners. Comparability of emission limits are strongly influenced by the testing protocols and methods (Wilton, 2012b).

In America cord wood boilers and pellet boilers provide low emission options and several boilers have already demonstrated compliance with the 2020 emission limit. Boiler units that utilise full thermal storage tend to perform well as they are not designed to cycle and only operate on High (John Steinhart, pers comm, 2016). An example of a thermally insulated boiler that has low emission is the GARN wood boiler which is a wood gasification unit with thermal storage (www.garn.com). The emissions rating for this boiler when tested to EPA 28WHH is 1.69 g/hr (74% efficiency – noting that North America has different efficiency definitions).

Table 4-2: GARN wood gasification boiler

5 SECONDARY CONTROL EQUIPMENT

The 2012 review (Wilton, 2012b) of technology included a summary of the Biomass2020 report on secondary technology and progress with different issues associated with technologies. Since that time a number of secondary control equipment have been authorised for use in Germany (Table 5.1). The emission reductions requirements for authorisation require that the emission control technology be effective in removing 30% of the particulate.

Table 5-1: Secondary control equipment for domestic scale burners authorised for use in Germany (Lenz & Ulbricht, 2015)

System	Website
AIRJEKT 1“	http://www.kutzner-weber.de
OekoTube	http://www.oekosolve.ch
System „Future Refine	http://www.schraeder.com
System „AL-TOP“	http://www.schraeder.com
MAHLE Pure Heat“	http://www.dr-pley.com
ChimCat® RETRO	
CAROLA CCA-25, CCA-50, CCA-100 and CCA-200	www.carola-clean-air.com

One limitation with comparing overseas authorised appliances or secondary control technologies to New Zealand requirements is the different testing regimes and in particular the lack of requirement of the use of a dilution tunnel in many overseas standards. As outlined in Wilton, (2012b) methods for measuring particulate from wood burners in New Zealand include requirements for capturing gaseous phase organics that condense to particulate form when exposed to ambient temperatures. The methodology typically used for domestic scale burners in New Zealand is a dilution tunnel as detailed in Wilton & Smith, (2006) .

5.1 Oekotube

The Oekotube uses electrostatic precipitation to reduce particulate concentrations in the chimney and is manufactured by OekoSolve of Switzerland and available for purchase in New Zealand through EnviroSolve New Zealand Limited. It has been designed for use with small scale burning devices up to 40 kW heat output.

The OekoTube removes particles using a high voltage electrode which releases electrons into the chimney space containing the particles. The particulates become polarised and move towards the chimney wall and accumulate into coarser material on the chimney wall. The resulting particulate matter can be removed from the chimney wall by a chimney sweep or if the mass of material on the chimney wall reaches a critical point prior to cleaning, particles can they detach from the inner flue pipe wall and exit the flue system or may drop back down the chimney. Particles leaving the chimney will most likely be of sufficient size to settle on the dwellings roof or deposit within a short distance of the chimney.

Electrostatic precipitators (ESP) such as the OekoTube use an electronic charge to remove particulate emitted from the fire that is in particulate form in the chimney. It is unlikely to remove the volatiles that are in gaseous forms when passing the ESP that will condense out to form particulates at lower temperatures. The effectiveness of the OekoTube in reducing PM_{10} from domestic heating is therefore likely depend on the amount of volatiles in the air stream and the temperature of the flue at the point where the ESP is functioning.

A number of studies of the effectiveness of the Oekotube on wood or coal burners have been carried out in New Zealand in recent years (Spectrum Laboratories, 2015; Wilton, 2014a). These include initial testing of effectiveness on wood burners done by Environment Canterbury (unpublished), testing of effectiveness on coal burners, Wilton, (2014) and more recently additional testing of effectiveness on wood burners (Spectrum Laboratories, 2015).

Results of tests of effectiveness of the Oekotube in reducing emissions from coal burners indicated an average burn cycle particle reduction efficiency of around 58%. The effectiveness was greatest when the fire was operated at a low burn setting and when emissions would otherwise have been greatest.

Quantification of the effectiveness of the Oekotube in reducing emissions from wood burners is difficult owing to test design issues. The initial test design captured only limited data points (e.g., total burn cycle results only) which meant more detailed analysis of the effectiveness was limited. The more recent Spectrum Laboratory testing regime followed a different test protocol which required the assumption of a high degree of precision using the Canterbury test method on a conventional wood burner. It is not reasonable to assume a high degree of precision with the Canterbury Method and in the absence of validation tests to quantify precision it is not possible to derive a particle reduction efficiency from these tests. Notwithstanding this, a range of material from the test procedure including photographs, material scraped from the inside of the chimneys and the significant difference between test data all indicate that the Oekotube is very effective in reducing particulate from conventional wood burners.

Requiring the installation, operation and maintenance of Oekotubes fitted to existing NES compliant wood burners is likely to be a viable management option for reducing PM_{10} concentrations in urban areas of Otago. Systems would need to be implemented to ensure correct installation, operation and maintenance procedures are followed. The cost of the Oekotube is around $2800 +GST plus installation, which can vary depending on the ease of access to the chimney, for an individual unit but could be around $200-$300. However, a bulk purchase of 1000 or more units is likely to bring costs down to around $2100 + GST (plus installation). Annual sweeping and maintenance costs of around $200 are also likely.

New advancements in the OekoTube technology include OekoTube inside which is an ESP device which is located inside the dwelling. This is suitable for new dwellings but may not be possible in existing dwellings. The OekoTube inside will also be available with an automated self-cleaning option. The latter should be available from August 2016.

6 FUEL COSTS

Table 6.1 compares the operating costs for different fuels within the Otago Region. The range in prices reflects cheaper and more expensive suppliers, or different wood types, rather than differences in assumption (e.g., appliance energy efficiency). The methodology replicates that used by “Consumer” in their annual publication of fuel costs and data are therefore comparable to national data and other region information provided by consumer. The most notable difference is the lower cost for unflued gas as a result of Rockgas (Hillside Road, Dunedin) providing 9 kg gas refills for $22 a bottle. Electricity costs integrate daily and kWh rates based on an average use of 8730 kWh per year. All data include GST.

Table 6-1: Comparison of operating costs for fuels in Otago

	Otago Lower end c/kWh	Otago Upper end c/kWh	Consumer – national 2015 Lower end c/kWh	Consumer – national 2015 Upper end c/kWh
Wood	10	17	8	28
Coal	12	14		
Pellet burner	17	26		
Unflued gas (LPG)	21	40	31	41
Flued gas (LPG)	19	19	19	23
Electricity – heat pump Dunedin	8	10	6*	12*
Electricity – heat pump Otago	8	13		
Electricity Dunedin	23	29	16*	35*
Electricity Otago	25	40		

* national rather than area specific

7 ALTERNATIVE HEATING APPROACHES

7.1 Community heating schemes

Community heating schemes are typically referred to as "district heating" and are a system for distributing heat generated locally for space and potentially water heating of local dwellings. The heat is often obtained from burning fossil fuels or wood, although geothermal, heat pumps and central solar heating are also used. District heating plants can provide higher efficiencies and better pollution control than individual dwelling heating options.

District heating is common in many European countries. In Denmark district heating provides 60% of the residential heating (Biomass Energy Centre, 2016). The energy source is typically centrally located and from this there will be a network of highly insulated flow and return pipes distributing typically hot water or steam past all buildings which may be connected. A junction point for each building allows the water to be taken from the main pipes to a heat exchanger (heat substation) within each building. Temperature measurements and flow meters allow the heat usage within each building to be calculated and billed accordingly.

In 2004 district heating was not common in England, Wales and Northern Ireland with only 2% of housing stock connected to district heating systems. Of this, 89% of the dwellings connected were flats and the remaining 11% were houses. The latter statistic is a reflection of the greater suitability of the schemes to high density housing scenarios. Many areas of the United Kingdom have become more suitable for district heating because of the decrease in detached housing in favour of flats and maisonettes (Energy Savings Trust, 2015).

The low housing density in small towns in New Zealand has likely been a limitation with respect to effectiveness of district heating schemes historically as the cost of piping and the associated energy loss through the distribution lines reduces the feasibility. However, advances in insulating technology are likely to have reduced energy loss and improvements in household insulation likely to have reduced energy demand.

Use of the Clutha River for establishing a heat pump district heating scheme for Alexandra has been raised by Bodeker Scientific (http://www.bodekerscientific.com/other/clutha-heat-pump-project) as a project requiring further investigation. A case study below for the Drammen Heat Pump District Heating scheme in Norway provides an example of a heat pump district heating scheme. Other options for fuelling district heating in the Otago Region include wood chip as illustrated in two further case studies. One of the largest district heating schemes in the United Kingdom is fuelled by incineration of waste. This was not included as a case study as waste incineration is prohibited under the NES in New Zealand. However it was noted that the scheme (in Sheffield) covered a larger area than most, supplying 2800 houses and utilising 44 km of pipelines. It is probable that a wood boiler supplying energy to households via a district heating scheme would be lower emission overall than domestic scale wood burners. However, an assessment of the emissions would be required to determine the effectiveness of this option.

A key consideration for the introduction of a district heating scheme for urban areas of the Otago Region would be the costs associated with installation of the energy source, the pipe network and installing radiators to homes. Further investigations into the feasibility of a heat pump district heating scheme for Alexandra including indicative costs would provide a useful platform for assessing the viability of this option.

7.1.1 Case Study - Drammen Heat Pump District Heating (Norway)

The town of Drammen is located in Norway, 65 km from Oslo and operates a heat pump district heating scheme.

They operate a 45MW district heating system serving over 200 large buildings in the city. The heat was originally from a mixture of fossil fuel and biomass but a new system was designed to make a large heat pump the primary source. As a result they draw 75% of the network heat from the ammonia heat pumps at 90C with 15% from biomass and 10% from gas/oil (*European Heat Pump Association*, 2016).

The heat pump has three systems giving a combined capacity of 14 megawatts to central Drammen and provides 85% of hot water needed for the city. The district heating system is owned and operated by Drammen Fjernvarme who have the rights to the concession area given by the Drammen Municipality. All new buildings larger than 1000 m^2 are required to be built with a water-based heating system and connected to the district heating system.

The heat source is seawater that is taken in around 8 or 9°C from a depth of 18 m and is cooled to around 4°C by low pressure liquid refrigerant (ammonia). Using a vapor-compression refrigeration cycle, the system heats district water from 65 C to 90 C. The system has an average coefficient of performance (COP) of 3.0 which means 1 unit of electricity is combined with 2 units of heat from the seawater to provide 3 units of heat to the district heating circuit.

Because of the low cost of hydro-based electricity in Drammen, it is cheaper to run a heat pump than a gas or electric boiler. In addition, the compressor technology used in the Drammen heat pump is the single screw compressor from Vilter (Emerson). Its internal design allows for balanced forces allowing it to perform with a very long bearing life at more than 120,000 hours for normal refrigeration compressors (Hoffmann, Kenneth & Forbes Pearson, David, 2011).

The environmental benefits include a reduction in fossil fuels of 6700000 litres per year and 12663 tonnes of CO_2 per year (*European Heat Pump Association*, 2016).

7.1.1 Case Study – Barnsley Biomass District Heating (Yorkshire, UK)

In Barnsley, Yorkshire in the United Kingdom a district heating scheme using wood chip fired boilers was instigated in 2004 to provide heating to 166 flats in three buildings in the town. Two boilers (320 kW and 150 kW) replaced four coal fired boilers. A gas boiler was also installed as a back-up plant for use in an emergency. The programme also resulted in the creation of a 700 tonne store for drying tree waste, avoiding landfill disposal, and the establishment of a dedicated woodchip supply business (Forestry Commission England, 2009).

The scheme resulted in a 40% saving on heating costs and a reduction of 1,300 tonnes of CO_2 emissions. The boiler was cleaner in terms of discharges to air and was largely noise free (Forestry Commission England, 2009). The project was the first stage in a longer term plan to reduce coal burning based district heating in the town. Subsequent stages included a biomass fuelled boiler for to provide energy to schools and the conversion of a further 296 flats to a biomass fired district heating scheme. By 2010 the strategy had led to the installation of twelve biomass boilers with a total capacity of about 3 MW, covering a range of different uses and the programme had won the 2006 Ashden award for sustainable Energy (https://www.ashden.org/winners/barnsley).

The scheme demonstrated the potential to provide an estimated 15 jobs for every megawatt of biomass generated and provided diversification opportunities and extra income for farmers. It also provided the chance to utilise wood waste, which would otherwise be sent to landfill (Forestry Commission England, 2009).

7.1.2 Case Study - Hoathly Hill Community Wood Fired District Heating System

Hoathly Hill Community lies on the outskirts of West Hoathly village in West Sussex, England. The Community was established in 1972. The community comprises 27 units, ranging from single person flats to 4-bedroom detached family houses which are occupied by around 65 people of all ages and three main Community buildings which are used for a range of activities.

The district heating scheme is fuelled by a 300 kW wood chip fired boiler with high efficiency insulated flow and return pipes to all the houses. The pipework has a low heat loss design – less than 0.01^{o}C per 100 metres – and the insulation is bonded to the plastic pipe ensuring that no external water can be in contact with the pipe, leading to significant heat losses. There is approximately 1.4 km of pipework connecting the boiler to the interface units.

There are also two 4,000 litre buffer storage tanks designed to deliver peak output. The boiler uses around 300 tonnes of wood chips per year, which are supplied by a local sawmill (five miles from the town).

7.2 Passive solar heating

There are a number of ways to reduce the space heating requirements of a dwelling including insulation and house design features such as passive solar heating.

Passive solar heating refers to the design characteristics of a dwelling whereby the building design, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat during the summer. Guidance on passive solar design for New Zealand has been prepared by the Ministry for the Environment (Ministry for the Environment, 2008) as a method for reducing energy consumption. It describes techniques such as site, climate and building design, daylighting, shading, thermal mass, natural ventilation, window systems and computer simulation.

The adoption of methods that reduce energy requirements can provide a range of environmental benefits including improving air quality and increased household warmth. However, the benefits will be small in most areas in the short term because the techniques primarily impact on a new build.

8 KEY QUESTIONS

8.1 How does the current technology approved as ULEB in New Zealand compare with overseas technologies

All existing ULEB wood burners in New Zealand are down draft wood gasification burners with dual combustion chambers. While these meet many of the criteria outlined as important in Europe most recent technology focus appears to be on the issue of automation (automated airflows and reloading based on combustion conditions).

In addition tile fires, which absorb heat from the combustion process and slowly release it into the room are common in countries such as Austria. Low emission tile fire technologies are detailed in (Wilton, 2012b).

One burner noted in Wilton, (2012b) as European technology using automated controls was the Rika technology. No further developments of this technology were found in the literature review and it is unclear whether this burner or the automated control burner being developed in New Zealand by Paul Sintes is likely to meet the ULEB limits when tested according to the Canterbury Method.

In America cord wood boilers and pellet boilers provide low emission options. The EPA test methods require testing at low burn rates and not all boiler units can perform well in these ranges. Units that utilise full thermal storage tend to perform well as they are not designed to cycle and only operate on High. An example of a thermally insulated boiler that has low emission is the GARN wood boiler which is a wood gasification unit with thermal storage (www.garn.com). The emissions rating for this boiler when tested to EPA 28WHH is 1.69 g/hr (74% efficiency – noting that North America has different efficiency definitions).

8.2 Is it likely that the "real life" Canterbury test method emissions could be used as emission factors to represent real life emissions

The question of whether the real life test data collected using the Canterbury Method would be representative of real life was raised during the development of that method. The response at that time was that it was uncertain and would depend on the technology used and in particular to what extent the technology reduced operational aspects that influence emissions. For example, if reloading were automated and defined by combustion conditions then the test method is more likely to reflect real life emissions.

All burners authorised as ULEB at the time this report was prepared utilised down draught wood gasification using twin combustion chambers. One burner (Rais Bionic) had an automated down draught control but the other burners rely on manual switching to down draught mode. All burners are batch fed with cord wood. The user can therefore influence combustion conditions through the timing of the reload, the amount of the reload and the control settings for burn rates. The impact on emissions is uncertain for this technology however, as all discharges must pass through the secondary combustion chamber before release to the environment.

The impact of having a manually operated down draught mode means that it is possible for the operator to use the burner in such a way that bypasses the technology responsible for low emissions. To this end there is an inconsistency with one of the key parameters identified by Environment Canterbury as a consideration for authorising the burner and a criteria specified in schedule 8 of their proposed air plan. This specifies that

"The enclosed burner must be designed to achieve the efficiency and emissions standards when operated by a person in their own home. This means:

1. *The burner cannot be operated in such a way as to bypass the technology that results in ultra-low emissions and…… "*

It is unclear how these burners have been able to be authorised as they are clearly able to be operated in such a way as to bypass the technology that results in low emission. One manufacturer indicated concerns about the product warrantees on the bimetal strips used for automating the down draught transition.

In my view the Canterbury Method test results for the down draught burners are unlikely to represent real life emissions. Consideration should therefore be given to applying an adjustment factor when considering the discharges in scientific assessments such as emission inventories or when evaluating the effectiveness of management options.

8.3 Are the technology options approved as ULEB suitable for Otago conditions

One of the key issues for Otago is enabling adequate heating methods and cost effective fuels.

Common solid fuel heating appliances in Otago include wood burners, pellet burners, multi fuel burners (wood and coal) and central heating systems (various fuels but can include coal). Central heating systems provide whole house heating and have typically come at a high cost for households that have installed them.

The ULEBs approved to date include domestic scale burners with maximum heat outputs up to around 15 kW. They therefore could provide a reasonable alternative to existing wood burners although there is a price differential with the lowest cost high heat out burner being around $5700 (plus flue plus installation) compared with an average wood burner at around $3500.

The Canterbury Method provides an alternative testing regime to allow for the approval of wood fired boilers. No boilers have been authorised to date, however. It is unclear whether this is a demand issue (high cost of test procedures relative to low demand for boiler systems) or whether wood boilers are sufficiently low emission to be granted approval under the ULEB regime. Based on the GARN wood boiler tested to EPA 28WHH and a 24 hour operation the daily particulate emission may be around 41 g/day. This compares with around 110 g/day for an NES compliant burner on average.

Allowing provision for cord wood boilers or low emission coal fired boilers is reasonable consideration for central Otago owing to very cold winter temperatures. Environment Southland included a provision allowing for the use of existing coal fired boilers that could meet an emission limit of 300 mg/m^3 (approximately 2 g/kg) adjusted to 0°C, 12 percent carbon dioxide, 101.3 kPa on a dry gas basis, when tested to a method equivalent to ISO 9096:2003.

9 CONCLUSIONS

- The introduction of the ULEB and Canterbury Method for testing of real life sets a new technology standard that could be used throughout New Zealand to assist in air quality management.
- Further work is required to establish the precision of the Canterbury Method and to determine average real life emission for the purposes of evaluating the effectiveness of regulating for this method for air quality management purposes.
- Four ULEB have been approved in New Zealand and a wet back model based on one of these has been approved by Environment Canterbury and will be in stores in the near future. All models are down draught double combustion chamber technology.
- The cost of the burners range from $5490 to $10,000 and the heat outputs from 4 kW to 15 kW.
- Internationally there is also a move towards a real life emission testing regime with the development of the beReal test in Europe.
- Workshops promoting low emission burners for Europe focus more on technologies that control combustion conditions.
- Advancements in burner design internationally include the use of computational fluid dynamics for simulating combustion.
- A number of secondary technologies for reducing emissions have been authorised for use in Germany. Of these the Oekotube is available and has been tested in New Zealand. Results suggest it is likely to be an effective method of reducing PM_{10} emissions.
- An evaluation of energy costs for space heating in Otago suggests that heat pumps may be the most cost effective heating options and that wood burners were also very cost effective. The cost of unflued gas varied significantly depending on the supplier.

Introduction of the ULEB criteria and the authorisation process sets a new bar for low emission small scale wood burning technology and is likely to be an effective tool in managing air quality within urban areas of New Zealand. The standard is still very new, however, and additional tests should be carried out on the reliability/ precision of the test method and on the likely real life emissions from ULEB burners.

10 REFERENCES

beReal. (2016). Retrieved from http://www.bereal-project.eu/

Biomass Energy Centre. (2016). District Heating - Biomass Energy Centre. Retrieved from http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,97356&_dad=portal&_schema=PORTAL

Christoph Schmidl. (2015, October). *The beReal project. Real life stove testing for European label development*. Berlin. Retrieved from http://www.ieabcc.nl/workshops/task32_2015_Berlin/03%20Christoph%20Schmidl.pdf

Energy Savings Trust. (2015). *The applicability of district heating for new dwellings*. Retrieved from https://www.b2match.eu/system/low-carbon-heat-showcase-2014/files/District_Heating_for_New_Builds.pdf?1395756062

Environment Canterbury. (2016). Environment Canterbury Regional Council Authorised Solid Fuel Burners. Retrieved from http://ecan.govt.nz/services/online-services/pages/authorised-solid-fuel-burners.aspx

European Heat Pump Association. (2016). Retrieved from http://www.ehpa.org/technology/best-practices/large-heat-pumps/drammen-district-heating-norway/

Forestry Commission England. (2009). *Barnsley Biomass - working towards carbon emissions reductin in Yorkshire*. Retrieved from http://www.forestry.gov.uk/england

Frank Kienle. (2015, October). *Market developments and perspectives*. Presented at the IEA Expert Workshop on Clean Wood Log Stoves, Verlin. Retrieved from http://www.ieabcc.nl/workshops/task32_2015_Berlin/01%20Frank%20Kienle.pdf

Hoffmann, Kenneth, & Forbes Pearson, David. (2011). *Ammonia heat pumps for district heating in Norway - a case study*. The institute of Refrigeration.

Ingwald Obernberger. (2015, October). *Guidelines and relevant issues for stove development*. Presented at the Expert workshop on Clean Wood Log Stoves, Berlin. Retrieved from http://www.ieabcc.nl/workshops/task32_2015_Berlin/04%20Ingwald%20Obernberger.pdf

Lenz, V., & Ulbricht, T. (2015). *STAUBABSCHEIDER IN HÄUSLICHEN FEUERUNGEN*. DBFZ Deutsches Biomasseforschungszentrum. Retrieved from www.dbfz.de

Ministry for the Environment. (2008). *Passive solar design guidance*. Ministry for the Environment.

Spectrum Laboratories. (2015). *Draft Report 0407 Oekotube Testing*. Auckland: Spectrum Laboratories.

USEPA. (2015). United States Environmental Protection Authority. Retrieved from http://www2.epa.gov/residential-wood-heaters/regulatory-actions-residential-wood-heaters

Wilton, E. (2012a). International review of best technology for low emission wood burners. Environment Canterbury.

Wilton, E. (2012b). International review of best technology for low emission wood burners. Environment Canterbury.

Wilton, E. (2014a). *Evaluation of the effectiveness of the OekoTube ESP in the management of PM10 in Reefton*. West Coast Regional Council.

Wilton, E. (2014b). Heating and household data for rental and owner occupied dwellings in Christchurch 2013 update with 2013 census household numbers. Report Prepared for Environment Canterbury.

Wilton, E. (2014c). Nelson Air Emission Inventory - 2014. Nelson City Council Technical Report.

Wilton, E. (2014d). Nelson Air Quality Assessment – Meeting the NES for PM10 2014 update.

Wilton, E., & Smith, J. (2006). Real Life Emissions Testing of Pre 1994 Woodburners in New Zealand. . Environment Waikato technical report no. TR06/05.