NOVEMBER 2020

PREPARED FOR
Otago Regional Council

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Evaluation of technologies for reducing particulate emissions in Otago Airsheds

EXECUTIVE SUMMARY

The main air quality concern in urban towns in the Otago Region is concentrations of particles in the air (PM_{10} and $PM_{2.5}$). Concentrations exceed National Environmental Standards (PM_{10}) and proposed standards ($PM_{2.5}$) regularly during the winter months in many areas. Air emission inventories have identified domestic heating as the main source of anthropogenic PM_{10} emissions in towns where these studies have been carried out.

The use of technology targeting domestic scale wood burning has been a focus for management intervention over the last decade as traditional wood burner designs are likely ineffective in achieving further reductions beyond an emission limit of 1.5 g/kg. A number of technologies were identified in an early review (Wilton, 2012) including down draught burners, electrostatic precipitators, automated air flow burners and catalytic converters. However, was uncertain whether these would be effective, feasible or economically viable solutions.

Environment Canterbury introduced the ULEB criteria to provide a market for new technology in Canterbury and included regulations allowing only the installation of ULEB in some airsheds. At the time of introduction, it was unclear if any wood burners would be able to meet the specified emission limit.

The technologies now available for domestic scale solid fuel burning has advanced and many burners have been authorised as ULEB. Some are imported and others manufactured in New Zealand. Historical differentials with price are no longer significant with a number of new technology burners available at prices similar to traditional wood burners. The main limitations with burners currently on offer are heat output range, with lower cost models typically available only at higher heat outputs, and only a few models of insert appliances or wetbacks. A number of burners are marketed as being capable of an overnight burn and include technologies that support the potential for this.

A key limitation that requires addressing is the extent to which the new technology results in improvements in real life emissions. Some real-life emissions testing carried out on the early model down draught burners shows the burners to result in real life improvements in emissions. However, recent approved ULEB include burner designs with no significant technological features differentiating them from traditional burners. The extent to which these burners include sufficient technological advancements as to minimise the potential for significantly increased operational emissions, as seen with traditional burners, is unclear. Testing of the real-life emissions from other technologies such as the catalytic converters and automated airflows is also required.

A second information gap is the impact of ULEB for the different in Otago Airshed and how the technology could be best adopted to assist with airshed improvements. This gap could be addressed through projections modelling for airsheds that have air emission inventory data but requires knowledge of the real-life emissions from ULEB prior to assessments being carried out.

The adoption of ULEB technology in the Otago Region had the potential to significantly improve air quality in urban towns. Addressing the information gaps identified would assist the Otago Regional Council with effective air quality management and would contribute to the knowledge base around the impacts of technology.

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1 INTRODUCTION

Air quality is a concern in many urban towns in the Otago Region. In particular, concentrations of PM_{10} and $PM_{2.5}$ (particles in the air less than 10 microns and 2.5 microns in diameter respectively) exceed National Environmental Standards or proposed standards ($PM_{2.5}$) regularly during the winter months. Locations where exceedences have been measured include Alexandra, Arrowtown, Milton, Mosgiel, Clyde, Cromwell, Laurence, Oamaru and Balclutha.

Air emission inventories have identified domestic heating as the main source of anthropogenic PM_{10} emissions in Alexandra, Arrowtown, Milton, Mosgiel, Clyde and Cromwell. In Milton industrial emissions were also a significant contributor to PM_{10} contributing 16% of the daily winter concentrations on average.

The Otago Regional Council has gazetted three Air Zones for the management of air quality and in particular concentrations of PM_{10} in the Region. These are:

- Air Zone 1: Alexandra, Arrowtown, Clyde and Cromwell.
- Air Zone 2: Balclutha, Dunedin, Hawea, Kingston, Milton, Mosgiel, Naseby, Oamaru, Palmerston, Port Chalmers, Queenstown, Ranfurly, Roxburgh, Waikouaiti and Wanaka.
- Air Zone 3: The rest of Otago.

Measures have been adopted in the Otago Regional Air Plan to manage air quality within the Airsheds with Air Zone 1 implementing the most stringent measures because of the extent of air quality degradation historically. Despite these measures being adopted air quality in many urban areas remains in breach of the NES for PM_{10} and could also be in breach of the proposed NES for $PM_{2.5}$.

The Regional Council has developed an air quality strategy which aims to revisit the approach to air quality management to effectively address air quality issues and ensure that air is safe to breathe for everyone, and at any time in Otago. The strategy includes a range of measures including improving understanding of the connection between housing quality, air quality and human health and partner with central government and other regional councils to promote affordable clean heating technologies.

The purpose of this study is to identify information gaps which if addressed would provide opportunities in the clean heating technologies sphere for addressing air quality issues for the Otago Region. The focus of the technology review is on domestic heating as this is the main source of issues with particulate pollution in the Region. Emerging technologies in other areas are identified where these target particulate matter in a manner relevant to the Otago airsheds. It is noted that Council policy has resulted in improvements in industrial emissions through technology and fuel switching in many urban areas and the contribution of other sources to airshed emissions is not typically significant.

2 DOMESTIC SPACE HEATING TECHNOLOGY

2.1 Introduction

The adoption of low emission technology for wood burners as a result of the implementation of Air Plans or through the National Environment Standard specifications has resulted in improvements in emissions in many urban areas of New Zealand. Historically these relied on AS/NZS 4012 and 4013 which specify test methodology for emissions and efficiency from domestic scale solid fuel burners.

The National Environmental Design Standard for wood burners (1.5 g/kg particulate and 65% efficiency when tested to AS/NZS 4013/4012) was introduced with an aim to reduce particulate emissions from wood burners in urban areas of New Zealand through improved burner technology. The use of particulate emission limits and associated burner design characteristics has contributed to reductions in airshed PM_{10} in a number of locations in New Zealand. Ongoing real life improvements through use of older technology, and the 4013/4012 test method and criteria are unlikely, however, because of the impact of behavioural aspects of burner operation and potential variability in fuel quality.

To address this issue, Environment Canterbury introduced the Canterbury Test Method which aims to test burners under conditions closer to real life operation. In addition to the test method they specified that for a burner to be classified as an Ultra-Low Emission Burner it had to meet an emission limit of 0.5 g/kg of particulate. The objective of the method was to encourage technology that would be more effective in addressing real life emissions including the operational aspects resulting in higher emissions. Burners complying with this limit when tested to the Canterbury Method are referred to as ULEB.

The ULEB criteria was introduced following an evaluation of domestic scale wood burner technology and associated emissions (Wilton, 2012). The review identified a range of emerging domestic scale technologies with the potential for lower emissions. These included down draught burners, electrostatic precipitators, automated air flow burners, catalytic converters. At the time of that review, it was unclear if any of these technologies would meet the ULEB criteria or provide feasible domestic scale wood burning options for New Zealand.

2.2 How the standards relate to the Otago Airsheds

The emission limit set for Air Zone 1 is 0.7 g/kg of particulate for wood burners when tested to NZS 4013. This is lower than the NES design criteria for wood burners of 1.5 g/kg.

This setting of this emission limit has not been effective in reducing concentrations of PM_{10} in Air Zone 1 to meet the NES for PM_{10} (50 µg/m^3, 24-hour average)

In other Air Zones the NES design criteria for wood burners (1.5 g/kg emission limit and 65% efficiency) is the standard for new installations of wood burners.

2.3 Technology of ULEB – wood burners

2.3.1 Down Draught Burners

The first generation ULEB were authorised between 2014 and 2016 and included the Rias Bionic, Jayline Watherm, Xeoos and the TropicAir Duo. Prices ranged from around $7000 - $11,000 per unit excluding flue kits ($650-$800) and installation. These burners all utilised down draught technology with secondary combustion chambers. The Rias Bionic had the additional feature of automated switch to down draught mode.

Since these models were authorised additional down draught burners have been approved. These include the Masport Cromwell and Mystique, Jayline UL200, Tropicair Duo and Rua and the Harris Ferva Saturn. Two down draught burners are priced at around $4000 (excl flue and installation).

Down draught burners are suitable for installation in Otago Airsheds as they provide similar heating characteristics to existing burners but with lower emissions. The main drawback historically was cost but with a few models available at $4000 the price point differential is not as extreme but still in excess of $1000 more than the lower cost traditional burners.

2.3.2 Catalytic converters

A number of ULEB have been authorised based on catalytic converter technology. Several Blaze King models have been introduced to the New Zealand market and are priced from around $5000 to $5700 (excluding flue and installation). Blaze King has the addition of a thermostatically controlled air supply, based on the temperature of the room. This provides benefits to the user in terms of maintaining room comfort.

Masport New Zealand produces a range of ULEB which utilise catalytic converters to achieve low emissions. These range in price from around $2790 to $4500 (excluding flue and installation).

The catalytic burner technology options are both suitable for Otago Airsheds and available at reasonable prices for wood burners relatively.

It is unclear how the catalytic burner technology performs in real life, when operated by the householders.

2.3.3 Heat storage and release burners

Two heat storage and release burners, more commonly known as tile fires in Europe, have been authorised as ULEB. The T-Sky eco2 and T-Art eco 2 contain ceramic or natural stone which absorbs heat from the fire which is slowly released back into the room after combustion has ceased. The units burn around six kilograms of wood per burn cycle (around two hours), which produces heat for 6-9 hours. The heat output averages around 2.6-2.8 kW (19-20 kWh) including the heat release period, and around 10 kW during the burn cycle. The efficiency ranges from around 81-84%, meaning they are more cost effective to run than most wood burners in terms of cost per kWh.

The units weigh 300-400 kilograms compared with around 150 kilograms for a more conventional style burner. They are made in Switzerland and shipped to New Zealand following order, so there is a delay of around four months.

Historically heat storage fires (also known as tile fires) have been more suited to new builds where allowance in the house design caters for the additional space required for the heat storage mass. However, these units appear to spread the mass vertically and may therefore be more suited to retrofit scenarios. The units are feasible heating methods for Otago towns for households that can afford the capital cost of around $15,000 per unit. Cost is a likely limitation of uptake. They have the benefit of slow release of heat unattended, potentially overnight, which is a characteristic of value when temperatures are sub-zero, although the heat released post combustion (unoperated) is much lower than during the burn cycle. Thus, poorly insulated dwellings may not benefit sufficiently from the overnight heat release.

No real life testing of heat storage burners has been carried out in New Zealand.

2.3.4 Other authorised ULEB burners

A number of burners have been authorised as ULEB which appear to contain no substantive technology shifts, rather relying on optimisation of previous designs with variability in features such as air supplies to the combustion chamber.

These burners range in price from $2700 to $4300 and would be suitable for the Otago Airsheds.

A key concern with these burners is whether the design/ technology is adequate to minimise the impact of household operation, a key behavioural component influencing real life emissions and driving the introduction of the ULEB process.

2.3.5 Automated air control

The use of automated air supply to the firebox to optimise combustion conditions is the technology adopted in two Pyroclassic burners authorised as ULEB. These burners have heat outputs ranging from 10 to 16 kW and priced from $3200 to $3700 per unit excluding flue and installation costs. The technology is suitable to the Otago Region.

2.4 ULEB boilers

Two domestic scale wood boilers have also been authorised as ULEB providing a wood burning heat source for central heating systems. The two brands of boiler approved as ULEB are Fruling and ETA. A number of pellet-fuelled boilers have also been authorised as ULEB. Domestic scale boiler systems heat hot water for circulation throughout a house (via radiators) and are typically located outside of the main living areas (e.g., in a garage).

The authorised boilers come in a range of heat outputs for each brand (15kW – 60 kW) and have gasification systems and automated air flows to achieve low emissions. The benefits to users of boiler systems are load and leave, long burn times between refuelling, whole house heating and alternative space utilisation in living areas. The draw backs are cost of the whole system including boiler ($26,000 - $32,000), radiators and installation. Operational costs are also likely to be higher owing to the need to burn more fuel to provide heat to the whole house.

2.5 Pellet fires and boilers

Pellet fires meeting the NES and ULEB emissions standards have been available on the market in New Zealand for some time. The Environment Canterbury burner authorisation website (Environment Canterbury, 2016) identifies more than 40 pellet burners or boilers that meet the ULEB emission criteria.

The technology that results in lower emissions for pellet fires is both the fuel and the ability to automate the loading or supply of fuel to the combustion chamber.

Pellet fires are not a popular heating method in New Zealand with typically less than 4% of households using them. The cost of the pellets and reliance of pellet suppliers appears to be a key deterrent.

2.6 ULEB authorised secondary technology for domestic burners

Secondary technology refers to devices used to scrub emissions post combustion and in this instance is used to include secondary controls that may be applied to existing wood or coal burners to reduce particulate emissions.

The Oekotube is the only authorised ULEB secondary technology. It 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. Appendix C contains further technical details of the Oekotube including its estimated particle reduction efficiency based on New Zealand testing.

The cost is around $2800 + GST for an individual unit (plus installation if applicable) but discounts may be available for bulk purchases. Some maintenance is required.

The Oekotube can be applied to an existing NES compliant burner and be considered to have emissions equivalent of a ULEB under the Environment Canterbury authorisation process. Whilst this may suit certain applications it would seem likely that general uptake would be limited by the lack of price differential between the purchase of a new burner and the purchase of the Oekotube.

2.7 Summary - feasibility for Otago Airsheds

All the technologies authorised as ULEB would be feasible as home heating methods for the Otago Airsheds although cost may be a limiting factor in uptake for particular models. Overall, however, a good range is available in terms of heat output and cost and the availability of boiler systems provides for whole house solutions beneficial in cold climates. The range of appliances approved now includes a wetback and an inbuilt model. Whilst this is a step towards increasing versatility in the market at present homeowners wanting an inbuilt are limited in heat output (14 kW) and those wanting a wetback to 16 kW. It is likely that the list of ULEB authorised will continue to grow and with it the versatility and options for households should increase.

The practicalities of most technology are not significantly different to an older style burner, although additional measures such as switching on the catalytic converter may be required. A number of the ULEB are promoted on the basis of being able to achieve an overnight burn, which is a characteristic highly valued in many Otago towns because of sub-zero overnight temperatures.

A few ULEB (e.g., the Jayline Waltherm) require electricity to operate and this may be seen as an issue in areas where there are concerns around electricity supply and power cuts.

The two key uncertainties relating to the adoption of ULEB technology in the Otago Airsheds is the real-life emissions and the extent to which introducing them as emission limits for new installations with or without the regulatory phase out of non-complying burners might result in compliance with National Environment Standards in each Airshed.

The extent to which the various technologies will result in improvements in particulate emissions when operated by the householder in real life settings can be assessed through real life testing programmes which involve measuring emissions for a number of households operating these burners. Once the average emission levels for ULEB burners have been established, the impact of introducing the technology on PM_{10} and $PM_{2.5}$ concentrations for airsheds where air emission inventory data are available can be evaluated.

3 COMPARATIVE COSTS

3.1 Capital costs

The purchase of a domestic burner includes the purchase price of the burner, the flue kit and installation costs. Appendix A outlines the capital costs for ULEB on the market currently. Flue costs are typically around $800 - $1200. Installation costs will vary but could be around $1200.

In addition to burner costs, some of the heavier burner models such as heat storage and release and down draught burners may require floor strengthening to allow for their installation. These costs will vary depending on the strengthening required.

3.2 Operational costs

The operating costs for a wood burner depend on a number of variables including the operation, heat output, fuel type and quality and burner efficiency. The operation costs will in most instances be similar to a non-ULEB of a similar heat output. In a few instances the ULEB technology has associated efficiencies, for example the tile fires, which may reduce heating costs. Consumer New Zealand report a range for pinewood in a wood burner from 10 c/kWh to over 40 c/kWh nationally. In Otago the cost of wood typically is in the 11 – 18 c/kWh range depending on wood type.

Several pellet fires are authorised as ULEB. These typically have higher operational costs at around 20 - 30c/kWh in Otago.

Some ULEB may result in slightly higher maintenance costs because of the additional expertise and maintenance requirements.

Table 3.1 compares the cost of heating using different methods nationally.

Table 3-1: Operating costs for home heating fuels in New Zealand (Consumer, 2020 www.consumer.org.nz)

	National Median c/kWh	National Approximate range c/kWh
Wood	20	11-53
Flued gas (LPG)	30	27-34
Electricity – resistance	26	16-42
Electricity – heat pump	10	7-15

4 EMERGING AND OTHER TECHNOLOGIES

The range of combustion and secondary technologies available for reducing particulate emissions internationally does not appear to have evolved much in recent years. Previous evaluations of potential technology solutions for domestic scale devices have identified catalytic converters and electrostatic precipitator technologies (both now included with authorised ULEB). Wood gasification has been an emerging technology in the industrial sphere and has now been applied to domestic boilers as ULEB also. These technologies are now likely to be providing feasible options for emissions reductions for domestic scale devices.

Hydrogen and fuel cell technologies provide alternative non carbon-based options for heating but do not appear to be favoured for advancement in Europe. Existing fuel cells have built-in reformers that produce hydrogen from natural gas. Alternative fuels such as hydrogen produced from a low-carbon energy source could be used to power fuel cells in the future. Natural gas networks are not available in the Otago Region.

District heating schemes are not new or emerging technology but are an option used in overseas countries to achieve efficiencies. New technologies in the delivery of energy (minimising transmission energy loss) may assist with the feasibility of district energy schemes.

There are many emerging energy sources targeting electricity generation in the energy sector. These are outside of the scope of domestic scale heating as electricity is available in Otago and does not contribute to localised particulate issues.

5 KNOWLEDGE GAPS

Evaluation of knowledge gaps focuses on areas likely to provide benefits in terms of air quality rather than climate or energy related benefits.

In our view, the priority area for evaluation is the real life emissions from ULEB technologies other than down draught burners (assessed by Environment Canterbury and Bay of Plenty Regional Council). We recommend focusing on the catalytic converter technology, the automated airflow technology and the traditional burner design technologies that are now authorised as ULEB. Appendix B summarises the different burners authorised with these technologies.

An alternative information gap that is relevant to the Otago Airsheds is the impact of burner design and technology on emissions of hazardous air pollutants such as benzo(a)pyrene as this may be an emerging issue in wood smoke environments.

A further information gap is the extent to which improvements in Otago towns may occur as a result of the implementation of measures to transition households to ULEB. Measures could limit the installation of new burners to ULEB or limit the installation of new burners to ULEB and phase out older technology. Bridging this information gap robustly requires better information on the real life emissions from a range of ULEB burners. Thus the priority information gap in our view is the testing of real life emissions from ULEB.

APPENDIX A: HEAT OUTPUTS AND COSTS - ULEB

Fire	Reported kW rating	Indicative Price*	Technology
Bionic Fire Studio	4.6	$9,900	Down draught
RAIS Bionic Fire	8.5	$7,950	Down draught
T-ART	2.8	$14,944	Tile fire
T-SKY eco 2	2.8	$14,944	Tile fire
Masport Cromwell	13.3	$4,899	Down draught
Masport Mystique	16.2	$5,877	Down draught
Masport Rakaia	8.4	$4,499	Catalytic converter
Masport Rangitata Beveled (Inbuilt)	14	$2,699	Traditional burner
Masport Waimakariri ASH	Not reported	$3,284	Catalytic converter
Masport Waimakariri LEG	Not reported	$2,899	Catalytic converter
Masport Waimakariri PED	Not reported	$2,790	Catalytic converter
Firenzo Lady Kitchener Ultra (Drawer)	23		Traditional burner
Firenzo Lady Kitchener Ultra (Leg)	23	$4,337	Traditional burner
Firenzo Lady Kitchener Ultra (Pedestal)	23	$4,337	Traditional burner
Firenzo Lady Kitchener Ultra (Platform)	23	$4,337	Traditional burner (wetback option)
Blaze King Chinook CK20.NZ	9.7	$5,299	Catalytic converter and automatic thermostat - air controls
Blaze King Chinook CK30.NZ	9.2	$5,699	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC20L.NZ	9.7	$4,999	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC20P.NZ	9.7	$4,999	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC30L. NZ	9.2	$5,299	Catalytic converter and automatic thermostat - air controls
Blaze King Sirocco SC30P. NZ	9.2	$5,299	Catalytic converter and automatic thermostat - air controls
Metro Ultra Insert (Inbuilt)	15	$4,299	Traditional burner
Metro Ultra Tiny Rad	11		Traditional burner

Metro Ultra Xtreme Rad	20	$3,299	Traditional burner
Metro Wee Rad Ultra	15	$2,675	Traditional burner
Pyrclassic IV	15	$3,699	Automated air control
Pyroclassic Mini	10	$3,199	Automated air control
Jayline UL200	13	$3,999	Down draught
Jayline Walltherm Air	14.9	$5,998	Down draught
Xeoos Twinfire X8	8	$6,950	Down draught
Tropicair Duo	18	$5,490	Down draught
Tropicair Duo Wet	18	$5,950	Down draught
Tropicair Rua	9.9	$3,990	Down draught
Harris Ferva Saturn	18.9	$5,299	Down draught
Woodsman Serene	16	$3,399	Traditional burner
Woodsman Serene WB	16	$3,698	Traditional burner

* excludes installation, flue kit and extras. In some case prices is base case price and additional charges may be incurred depending on options selected.

APPENDIX B: TECHNICAL DETAIL - OEKOTUBE

The Oekotube uses electrostatic precipitation to reduce particulate concentrations in the chimney and has been designed for use with small scale burning devices up to 40 kW heat output. It removes particles using a high voltage electrode which releases electrons into the chimney space containing the particles. The particulates become polarised and move towards, and accumulate into coarser material on, the chimney wall.

Accumulated material is removed 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) are 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 proportion 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, 2014). 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). Average burn cycle particle reduction efficiency of around 58% were indicated. The effectiveness was greatest when the fire was operated at a low burn setting and when emissions would otherwise have been greatest.

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