BIOENERGY
ASSOCIATION

Guidance for the Consenting of Biomass Boiler Systems Using Different Solid Biofuels for Heat Production

Bioenergy Association Technical Guide 9

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ABOUT THIS GUIDE

1. The compilation of this Technical Guide has been facilitated by the Bioenergy Association[1].
2. It is an outcome of industry discussion and collaboration. It captures the collective technical knowledge of a range of leading bioenergy industry personnel. In addition, it benefits from the collective experience of the Members of the Bioenergy Association Solid Biofuels Steering Group.
3. This guide is provided in good faith as an addition to the ongoing body of knowledge relating to wood energy and the wood energy sector in New Zealand and Australia. However, none of those involved with its preparation accept any liability either for the information contained herein, or its application.
4. As with all Bioenergy Association technical guidance documents, this guide is a ‘living document’ and will be revised from time to time and reissued, as new information comes to our attention. If you have suggested additions to this guide please contact admin@bioenergy.org.nz
5. The Bioenergy Association takes all care with regard to the information contained in this guide but users are advised to obtain professional advice on specific matters as there may be aspects which are particular to their application where alternative solutions should be adopted.
6. Preparation and maintenance of Bioenergy Association Technical Guides are overseen by association Interest Groups to ensure that current best practice is always being included however the bioenergy association cannot take responsibility for any decisions that are made as a result of following this Guide.

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[1] Bioenergy Association of New Zealand Inc

GLOSSARY

$m_{arsenic}$ = mass of arsenic
$m_{arsenic,volitised}$ = mass of arsenic volatised
$m_{air,100\%\ excess}$ = mass of air for 100% excess
$C_{m,arsenic}$ = mass concentration of arsenic
$C_{arsenic}$ = concentration of arsenic
$\dot{v}_{air}$ = specific volume of air
μg = micrograms
m_{H1} = mass of H1 wood
Dry basis moisture content = $\frac{M_{water}}{M_{dry\ wood}} \times 100$
CCA = chromated copper arsenate
NESAQ = national environmental standards for air quality
LOSP = light organic solvent preservatives
RMA = resource management act
CO = carbon monoxide
SO_2 = sulphur dioxide
NO_2 = nitrogen dioxide
O_3 = ozone
MDF = medium density fibreboard
WHO = world health organisation
μ = 10^{-6}
EU = European Union
PM_{10} = Particulate matter with a diameter less than 10 micrometres
$PM_{2.5}$ = Particulate matter with a diameter less than 2.5 micrometres
SCNR = selective non-catalytic reduction
SCR = selective catalytic reduction

1. EXECUTIVE SUMMARY

This guide provides an introduction to the (often) fraught world of using unusual materials as fuels. Such materials are all around us, be they agricultural or forestry wastes, industrial by-products, products of recycling and so on. In many cases, these unusual fuels can be a disposal or environmental problem in their own right; MFD offcuts, municipal sludge, demolition wastes, come readily to mind. Being able to dispose of such materials in a useful and environmentally more responsible manner than landfilling (or perhaps even ignoring them) has a lot of attraction.

The Guide looks at the nature of combustion, of different fuel types, and the difficulties which arise from the combustion of those fuels. Mostly the difficulties relate to the airborne products of combustion, some of which in sufficient quantity may be harmful to the environment or to health. However, there are other difficulties which can relate to the handling and storage of the fuel or to the disposal of the solid residues of combustion, which may also contain environmentally harmful materials.

Having looked at fuels and combustion, the Guide provides an overview of the regulatory environment is which we operate. It seeks to explain where one finds the rules which might apply, the basis for those rules, and the regional variations which exist in their interpretation and application.

The Guide goes on to describe a logical process by which one can gain an understanding of the fuel which it is proposed to use, how to establish the quantities, properties, and variabilities of that fuel, and how to understand the use to which the combustion of that fuel is to be put (in terms of size, variability, and other parameters).

Having equated the available fuel to the proposed use, it then lays out a rational path to establish whether it might be possible to gain a resource consent for its use, and then to create the documentation required to apply for a resource consent, (as will almost always be necessary).

The Guide finishes with a small group of illustrative case studies.

2. INTRODUCTION

This Technical Guide is intended to provide guidance to those applying for, and those who have to approve, Air Discharge and other Resource Consents for solid biofuels which, for whatever reason, may be regarded as contaminated, are treated wood, are unusual, or are otherwise problematic.

Given good system design, operation, and maintenance, most biofuels can be combusted cleanly and safely. The ideal is to construct combustion systems which burn any given biofuel cleanly with the minimum of pre or post combustion treatment. A process which is inherently simple and which with normal care combusts a fuel cleanly is preferable to one which relies on pre-or post "clean-up" processes or treatments, it being much less prone to malfunction or operator error. The ideal however is not always achievable.

Today, both wood pellet and wood chip from untreated wood are seen as "conventional" biofuels. There is a growing familiarity with them, their characteristics, needs, and limitations. It makes the consenting process for their use if not easy, then at least defined (although there is considerable variation between Regional Councils in their interpretation of the National Environmental Standards for Air Quality (NESAQ) and their administration of the consenting process.)

There is the potential for a wide range of other biofuels also, fuels the use of which is not generally approved by consenting authorities. Without being exhaustive, those fuels range from MDF and other wood wastes from production operations, demolition timbers which might be contaminated with paint residues, agricultural wastes such as straw, to plants being specifically grown as biofuels, like miscanthus.

Between them, such fuels represent a considerable renewable and generally "green" energy resource which is under-utilised and capable of making a useful contribution to the reduction of New Zealand's carbon footprint. Not only that, in some cases the use of such materials as a fuel is a safer and more environmentally responsible solution to their disposal than dumping, or perhaps in some cases, simply ignoring them.

This document looks at a number of fuels. It:

- Looks at the issue of possible environmental contaminants or other environmental issues for each fuel in the pre-combustion stage.
- It looks at the likely environmental contaminants in the combustion gasses.
- It seeks to quantify the expected levels of contaminants and to compare them with the NESAQ to identify those which might require particular attention to ensure environmentally safe use of the fuel.
- Identifies for each fuel, the types of equipment that will likely produce acceptable combustion results, and where necessary, such additional pre or post use treatments or systems as might be required to meet the NESAQ and related legislation emission requirements.

This guide is for consenting so only aspects relevant to consenting are addressed. Some contaminants etc may affect the life of equipment and performance but they are not the subject of this document.

Liquid and gaseous biofuels are not covered by this document although there will be many aspects which will be relevant to their use in combustion systems to produce heat.

3. BIOMASS TYPES

3.1. HERBACEOUS

Plants with a non-woody stem are considered herbaceous biomass. While likely not contaminated chemically, there may be some attributes which requires combustion of herbaceous biomass to require specific equipment design or operation. Herbaceous biomass may also have a higher moisture content compared to woody biomass. This will primarily focus on herbaceous agricultural waste, such as oat husks, miscanthus (right), and straw.

3.2. HIGH MOISTURE

Most boilers can burn biomass up to approximately 35% moisture content (on a dry basis). The moisture of biomass itself does not make it a difficult fuel regarding New Zealand's emissions regulations. Biomass with a dry basis moisture content above 35% but below 50%, such as wet wood chip will be referred to as a standard wet fuel in this technical guide. Standard wet fuels are fuels which are plant based, and aside from high moisture (which can be relatively easily addressed by good boiler/dryer design), have no other contaminants that would pollute the environment above the regulations. However, biomass with moisture content above 50% may have trouble combusting fully (if not combusted in equipment specifically designed for higher moisture content fuels), resulting in more emissions compared to its dry counterpart. High moisture biomass may also contain contaminants which may require further analysis of possible flue composition. An example of a non-standard wet fuel is sludge or manure.

3.3. CHEMICALLY CONTAMINATED

Chemically contaminated biomass is biomass that contains chemicals harmful to people or biological ecosystems. Chemically contaminated biomass is not uncommon to find in waste wood, primarily in the form of treated wood. Chemically treated wood may have boron, copper chrome arsenate, or light organic solvent preservatives (LOSP) impregnated as a form of preserving wood against its environment. Another possible chemical contamination is the resin adhesive found in medium density fibreboard (MDF), or wood that has been painted.

Typical waste demolition timber

3.4. PHYSICALLY CONTAMINATED

It is not uncommon for waste wood to be physically as well as chemically contaminated. Physical contaminants are components of waste wood that can potentially be separated by sorting or by using mechanical processes. Physical contamination may be in the form of metal or plastic items from construction or demolition. Possible physical contamination also includes (but not limited to) textiles, rubber, plastic, concrete, metals, and stone.

3.5. NOVEL FUELS

There is an almost endless list of other materials which might under some circumstances be burned, either as a means of disposing of them, as a fuel source, or perhaps both. Often enough they might arise as a waste product from some sort of commercial process. Without being exhaustive the list includes:

- Dry municipal sewage sludge
- Chicken or other animal litter
- Oil impregnated wood chip
- Forestry wastes (other than chipped slash or mill waste)
- Grape and other prunings

Forestry waste, fresh from processing.

Chicken litter

4. REGULATORY REQUIREMENTS

4.1. NZ REGULATIONS AND EMISSION LIMITS

The New Zealand Resource Management (National Environmental Standards for Air Quality) Regulations 2004 control the discharge of contaminants to air (Cartwright, 2011). Table 1 details the key contaminants identified by the Resource Management Act (RMA) and their corresponding threshold concentration that is not to be exceeded in an airshed.

Table 1: New Zealand ambient air quality standards for contaminants

Pollutant	Averaging period	Maximum concentration	Maximum allowable exceedances (goal)
Carbon monoxide	8 hours	10 mg/ m^3	1 in a 12-month period
Nitrogen dioxide	1 hour	200 µg/m^3	9 in a 12-month period
PM$_{10}$	24 hours	50 µg/m^3	1 exceedance/year
Ozone	1 hours	150 µg/m^3	None
Sulphur dioxide	1 hour 1 hour	350 µg/m^3 570 µg/m^3	9 in a 12-month period None

There is no clear definition of what constitutes an “airshed”. Typically they are boundary lines drawn by Regional Councils around various conurbations large or small. Within an “Airshed” certain air contaminant limits apply, and outside, other looser limits (or sometimes none at all.) The example of the Christchurch airshed is shown in Figure 1 on the preceding page, and the much smaller Roxborough airshed in Figure 2.

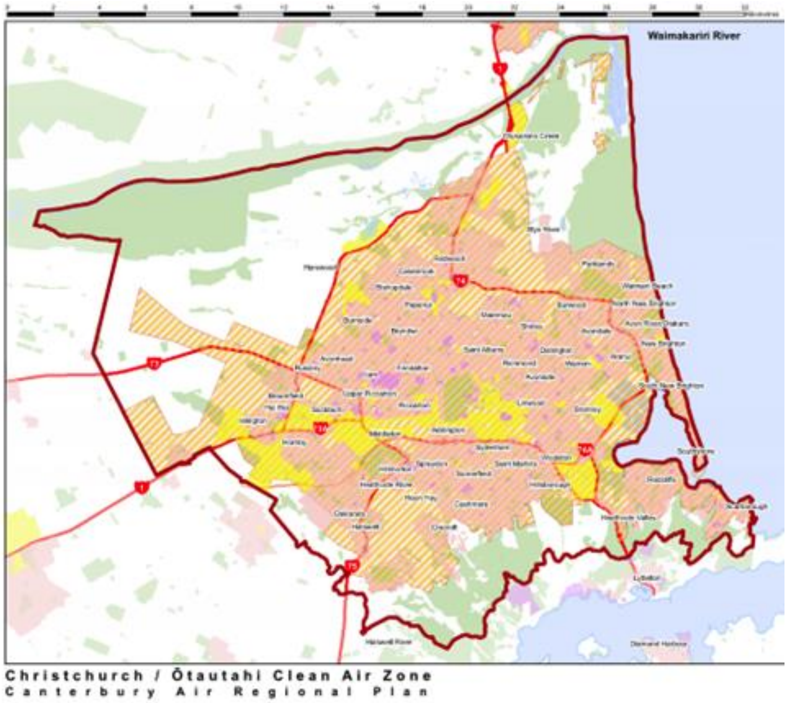


Figure 1: Christchurch Clean Air Zone

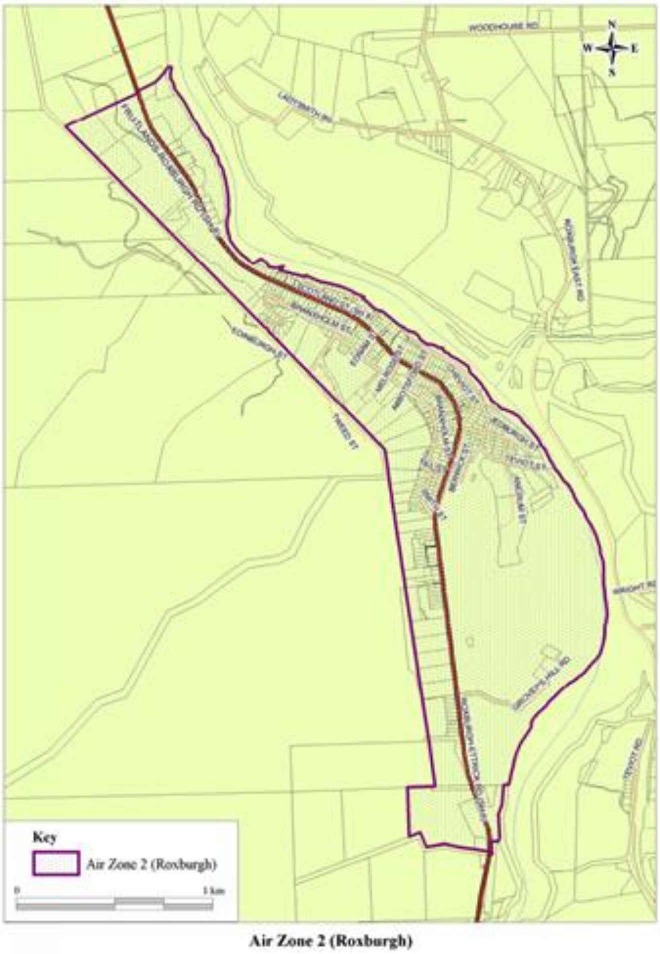


Figure 2: Roxburgh Air Zone 2

Under Section 30 of the RMA, regional councils and unitary authorities are responsible for managing the quality of air. This includes controlling the discharge of air contaminants and gathering information about the air quality. Regional councils may prepare regional policies or plans that help with managing air quality in the environment.

The 2002 Ambient Air Quality Guidelines set guideline values of air contaminants to reduce the emissions of air pollutants in New Zealand (New Zealand. Ministry for the Environment., 2002). These guidelines aid councils, industries, and communities involved in monitoring air quality. However, these values are not legislative requirements under the RMA. (Refer to

Table 2 over page for the guideline values for air contaminants.)

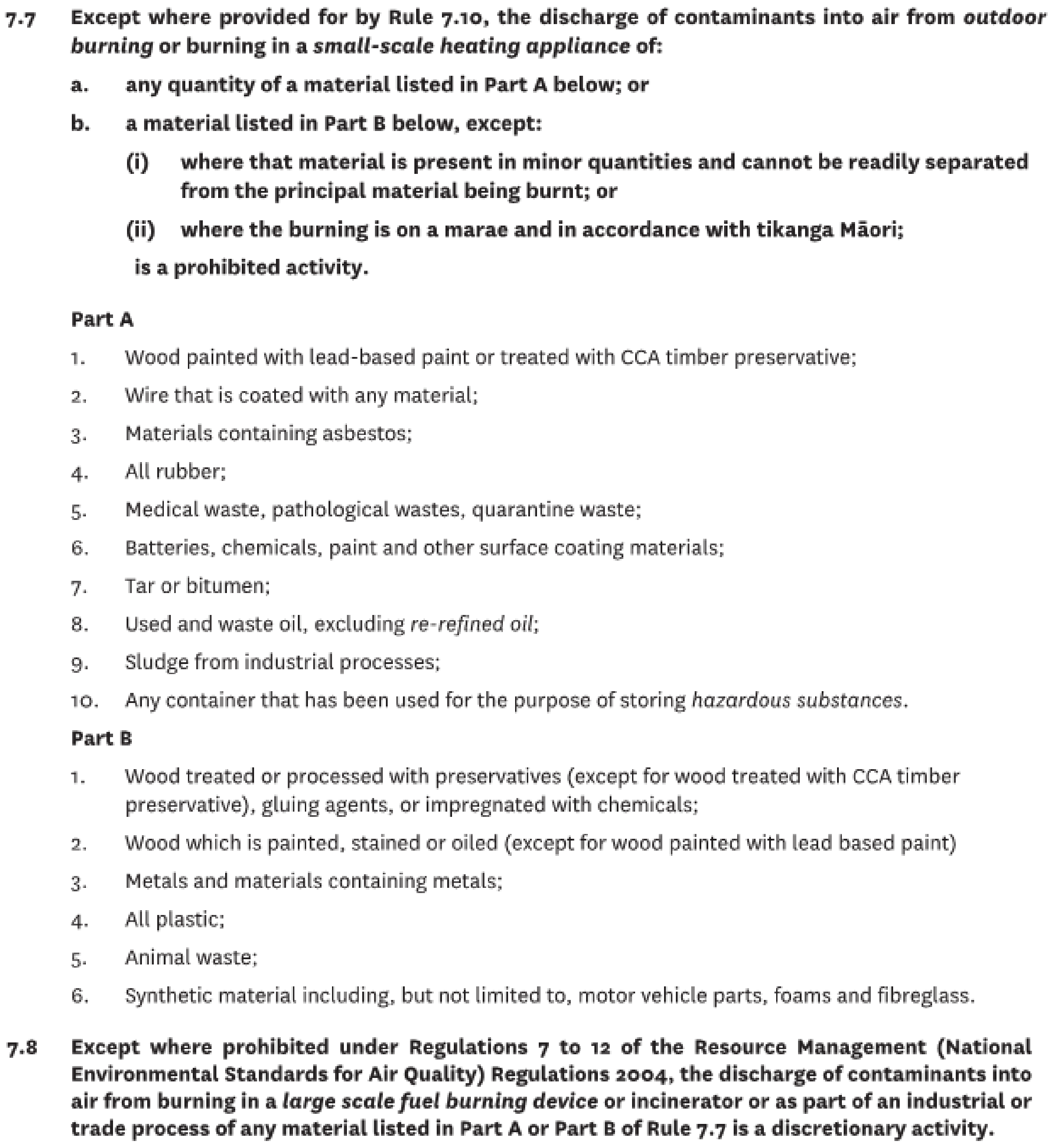
Table 2: New Zealand Guideline values for air contaminants

Contaminant	Averaging period	Maximum concentration
Carbon monoxide	1-hour	30 mg/m^3
	8-hour	10 mg/m^3
PM_{10}	24-hour	50 µg/m^3
	Annual	20 µg/m^3
Nitrogen dioxide	1-hour	200 µg/m^3
	24-hour	100 µg/m^3
Sulphur dioxide	1-hour	350 µg/m^3
	24-hour	120 µg/m^3
Ozone	1-hour	150 µg/m^3
	8-hour	100 µg/m^3
Hydrogen sulphide	1-hour	7 µg/m^3
Lead	3-month moving average	0.2 µg/m^3
Benzene	Annual	10 µg/m^3
	Annual	3.6 µg/m^3
1,3 -Butadiene	Annual	2.4 µg/m^3
Formaldehyde	30 minutes	100 µg/m^3
Acetaldehyde	Annual	30 µg/m^3
Benzo(a)pyrene	Annual	0.0003 µg/m^3
Mercury (inorganic)	Annual	0.33 µg/m^3
Mercury (organic)	Annual	0.13 µg/m^3
Chromium VI	Annual	0.0011 µg/m^3
Chromium metal and chromium III	Annual	0.11 µg/m^3
Arsenic (inorganic)	Annual	0.0055 µg/m^3
Arsine	Annual	0.055 µg/m^3

When reading an airplan, activities are broken into three categories; Permitted, Discretionary, and Prohibited.

- A “Permitted” activity within an airplan is one for which no resource consent is required, provided all of the conditions stated in the applicable rules are met.
- A “Discretionary” activity is one for which a resource consent is required. The Regional Council has reserved the right to decide if it will grant a resource consent or not and should be guided in considering any application for a resource consent by the policies and rules contained within its airplan, its Regional Policy Statement, and the applicable requirements of the Resource Management Act.
- A “Prohibited” activity is one which is expressly forbidden and for which no resource consent will be granted.

An excerpt from the Canterbury Regional Airplan (Figure 3) is informative.



7.7 Except where provided for by Rule 7.10, the discharge of contaminants into air from *outdoor burning* or burning in a *small-scale heating appliance* of:

a. any quantity of a material listed in Part A below; or

b. a material listed in Part B below, except:

  (i) where that material is present in minor quantities and cannot be readily separated from the principal material being burnt; or

  (ii) where the burning is on a marae and in accordance with tikanga Māori;

is a prohibited activity.

Part A

1. Wood painted with lead-based paint or treated with CCA timber preservative;
2. Wire that is coated with any material;
3. Materials containing asbestos;
4. All rubber;
5. Medical waste, pathological wastes, quarantine waste;
6. Batteries, chemicals, paint and other surface coating materials;
7. Tar or bitumen;
8. Used and waste oil, excluding *re-refined oil*;
9. Sludge from industrial processes;
10. Any container that has been used for the purpose of storing *hazardous substances*.

Part B

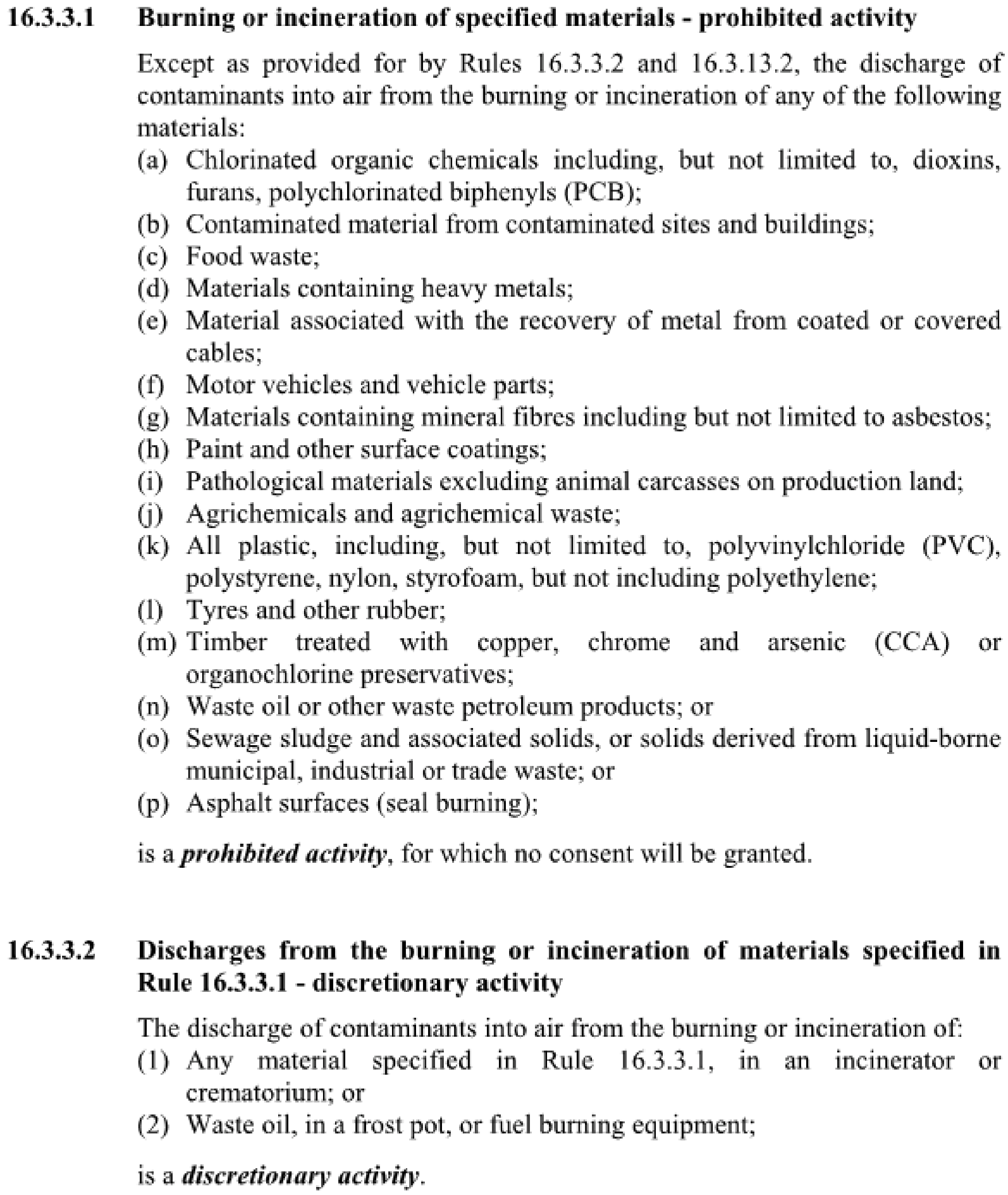
1. Wood treated or processed with preservatives (except for wood treated with CCA timber preservative), gluing agents, or impregnated with chemicals;
2. Wood which is painted, stained or oiled (except for wood painted with lead based paint)
3. Metals and materials containing metals;
4. All plastic;
5. Animal waste;
6. Synthetic material including, but not limited to, motor vehicle parts, foams and fibreglass.

7.8 Except where prohibited under Regulations 7 to 12 of the Resource Management (National Environmental Standards for Air Quality) Regulations 2004, the discharge of contaminants into air from burning in a *large scale fuel burning device* or incinerator or as part of an industrial or trade process of any material listed in Part A or Part B of Rule 7.7 is a discretionary activity.

Figure 3: Canterbury Regional Airplan

Within the Canterbury Regional Airplan a small-scale heating appliance is anything of less than 40kW output, in other words, a domestic log burner or the like. A large-scale device is anything above 40kW. What the airplan is saying, is that the combustion of many materials which might be considered as objectionable in some way, are discretionary activities. In short, in principle there is nothing prohibiting their use provided an adequate plan to do so is put forward and then adhered to.

A similar excerpt from the Otago Regional Airplan is a useful comparison, detailed in Figure 4. What it says is:



16.3.3.1 Burning or incineration of specified materials - prohibited activity

Except as provided for by Rules 16.3.3.2 and 16.3.13.2, the discharge of contaminants into air from the burning or incineration of any of the following materials:

(a) Chlorinated organic chemicals including, but not limited to, dioxins, furans, polychlorinated biphenyls (PCB);
(b) Contaminated material from contaminated sites and buildings;
(c) Food waste;
(d) Materials containing heavy metals;
(e) Material associated with the recovery of metal from coated or covered cables;
(f) Motor vehicles and vehicle parts;
(g) Materials containing mineral fibres including but not limited to asbestos;
(h) Paint and other surface coatings;
(i) Pathological materials excluding animal carcasses on production land;
(j) Agrichemicals and agrichemical waste;
(k) All plastic, including, but not limited to, polyvinylchloride (PVC), polystyrene, nylon, styrofoam, but not including polyethylene;
(l) Tyres and other rubber;
(m) Timber treated with copper, chrome and arsenic (CCA) or organochlorine preservatives;
(n) Waste oil or other waste petroleum products; or
(o) Sewage sludge and associated solids, or solids derived from liquid-borne municipal, industrial or trade waste; or
(p) Asphalt surfaces (seal burning);

is a ***prohibited activity***, for which no consent will be granted.

16.3.3.2 Discharges from the burning or incineration of materials specified in Rule 16.3.3.1 - discretionary activity

The discharge of contaminants into air from the burning or incineration of:

(1) Any material specified in Rule 16.3.3.1, in an incinerator or crematorium; or
(2) Waste oil, in a frost pot, or fuel burning equipment;

is a ***discretionary activity***.

Figure 4: Otago Regional Airplan

The ORC list is generally similar to Canterbury's, but it has blanket prohibition on the combustion of any of the listed materials unless, as it says in 16.3.3.2 (1) they are burned in an incinerator or crematorium.

In short, whilst in principle it is possible to get a resource consent to use many fuels which are regarded as difficult or contaminated for an industrial or commercial reason "In a large scale burning device or incinerator" in Canterbury, ORC does not permit their use at all, only their incineration.

A major barrier to combusting different fuels is the differences the Rules set out in each Regional Air Plan. This is summarised in this report https://www.usewoodfuel.org.nz/documents/resource/OP21-air-quality-report-180507.pdf

4.2. NZ VS OVERSEAS REGULATIONS

Appendix A details the ambient air quality standards for Australia, Europe, United States of America, and Canada compared to New Zealand. It also highlights the World Health Organisation (WHO) guidelines for the five major pollutants: carbon monoxide, nitrogen dioxide, PM_{10}, ozone, sulphur dioxide and $PM_{2.5}$.

The World Health Organisation recommended maximum concentration of **carbon monoxide** is 10 mg/m^3 in an 8-hour period. New Zealand, Australia, United States of America, Canada, and Europe, all have regulations that fall below or at that concentration.

For **nitrogen dioxide**, WHO recommend a maximum concentration of 200 $\mu g/m^3$ within a 1-hour average period, and a maximum concentration of 200 $\mu g/m^3$ within an annual averaging period. Australia is the only country within this analysis that exceeds this guideline in their regulations and allows for 226 $\mu g/m^3$ in a 1-hour average period. New Zealand, USA, Europe, and Canada all follow the WHO guidelines for the 1-hour average period. Both Australia and USA exceed the annual recommended concentration of 40 $\mu g/m^3$ with values of 56 $\mu g/m^3$ and 139 $\mu g/m^3$ respectively.

For **particulate matter less than 10 µm (PM_{10})**, the WHO recommend 50 $\mu g/m^3$ and 20 $\mu g/m^3$ for a 24-hour period and an annual averaging period respectively. It should be understood that the ambient particulate concentration limits include particulates from ALL sources, natural (dust, salt particles), mineral extraction, motor vehicles, agricultural processing, industrial processing, industrial, commercial and domestic combustion and the like. Because the background particulate concentrations (from natural or other non-combustion sources and from sources such as motor vehicles over which the Regional Authorities have no authority) vary from airshed to air shed, the limits imposed by each Regional Authority in relation to any given situation may differ widely, depending upon the location.

Australia, Europe, and Canada maximum PM_{10} concentrations are all below the WHO recommendation for a 24-hour period, while New Zealand is at the 50$\mu g/m^3$ limit. The USA allows for three times this concentration, but only allows one exceedance of this in a three-year period. New Zealand is the only country to pass the WHO recommendations into national law as fixed limits within the annual particulate matter concentration, although Australia does come close with 25 $\mu g/m^3$. Europe and Canada both exceed this guideline with a regulation of 40 $\mu g/m^3$ per annual averaging period.

New Zealand periods of exceedance (eg hourly, annual) differ to that of WHO for both **ozone** and **sulphur dioxide**, but it does have tighter regulations compared to Australia for a 1-hour averaging period of ozone emission. Australia and the USA have the same maximum concentration of ozone allowed for a 4-hour averaging period. Similarly, the USA regulation for an 8-hour averaging period exceeds the WHO maximum concentration of 100 $\mu g/m^3$ by 37 $\mu g/m^3$.

New Zealand has two regulations for a 1-hour averaging period of sulphur dioxide emissions - 350 $\mu g/m^3$ with 9 exceedances allowed in a 12-month period, and 570 $\mu g/m^3$ with no exceedances allowed. The latter is most comparable to the regulations of Australia and the United States of America. Both countries have a 524 $\mu g/m^{3-}$ limit with a maximum allowable exceedance of one in a twelve-month period. Australia also has an annual limit of 39 $\mu g/m^3$ of sulphur dioxide, which is almost double that of the World Health Organisation's annual limit of 20 $\mu g/m^3$. New Zealand's first 1-hour averaging period of 350 μg/m^3 is comparable to Europe's 350 μg/m^3 regulation, however, Europe allows for a maximum of 24 exceedances of this per year.

Unlike all other countries identified in the above table, New Zealand has no regulatory limits on $PM_{2.5}$ exposure.

4.3. OVERSEAS COMBUSTION PRACTICES AND COMPLIANCE

Comparatively, the EU and NZ have relatively similar emissions regulations, thus EU practices might be used to help outline what could be achieved in NZ.

Herbaceous biomass is permitted to be burned widely in other countries around the world. Notably, in 2009 Denmark set a biomass target which encourages the use of herbaceous biomass as fuel as an alternative to fossil fuels. A biomass target of 1 million tonne of straw was set to be used for Denmark's energy annually (Bentsen et al., 2016). Denmark is an active member of the EU, and therefore must abide by the EU's emission regulations. As above, the emission regulations of the European Union are similar to New Zealand's emission regulations, particularly particulate matter which is the emission of concern with herbaceous biomass. The EU goes a step further than New Zealand by also including regulations for PM2.5 – one of the biggest concerns with herbaceous biomass.

Sweden permits the incineration of physically and chemically contaminated waste wood in municipal incineration plants. Sweden's incinerators typically operate around 1000 °C, allowing for possible pollutants to be broken down at higher temperatures. Despite introduction of waste incineration in Sweden, SOx and NOx have decreased by 94.2% and 38.2% respectively and heavy metal emissions have reduced by over 90%.

The South East London Combined Heat and Power (SELCHP) refuse incinerator in Lewisham, London

A contributing factor to Sweden's decline in emissions is flue gas cleaning after incineration, a feature of all municipal incineration plants. Control methods used in waste-to-energy systems in Sweden include electrostatic precipitator, scrubbers, and catalytic converters or Selective Non-Catalytic Reduction (SNCR). Water from the scrubbers also undergoes cleaning treatment to remove heavy metals and other contaminants prior to draining (Avfall Sverige A, 2016).

Municipal incinerators (or waste-to-energy plants) have been in growing use in Europe, Japan, North America and elsewhere since the 1950's and have gone through several generations of development from the initial installations which were often based on coal burning plant. For the most part the incineration heat is used through steam boilers to generate electricity, and in many cases use the remaining waste heat used for district heating.

Today municipal incinerators are highly developed, closely controlled combustion devices that are capable of safely incinerating virtually any form of refuse which may arise from municipal and commercial collections, no matter what, including contaminated wood wastes. However, because of the great cost and specialist nature of municipal incineration plant, it is outside of the scope of this guide, despite its ability to burn virtually any biomass cleanly and safely.

Figure 5 is a diagram of a typical waste incineration plant. Of particular note is the large combustion space which is intended to hold the combustion gasses at very high temperatures for at least two seconds to ensure the burn out of most contaminants before the gasses are cooled as they pass through the boiler sections of the plant.

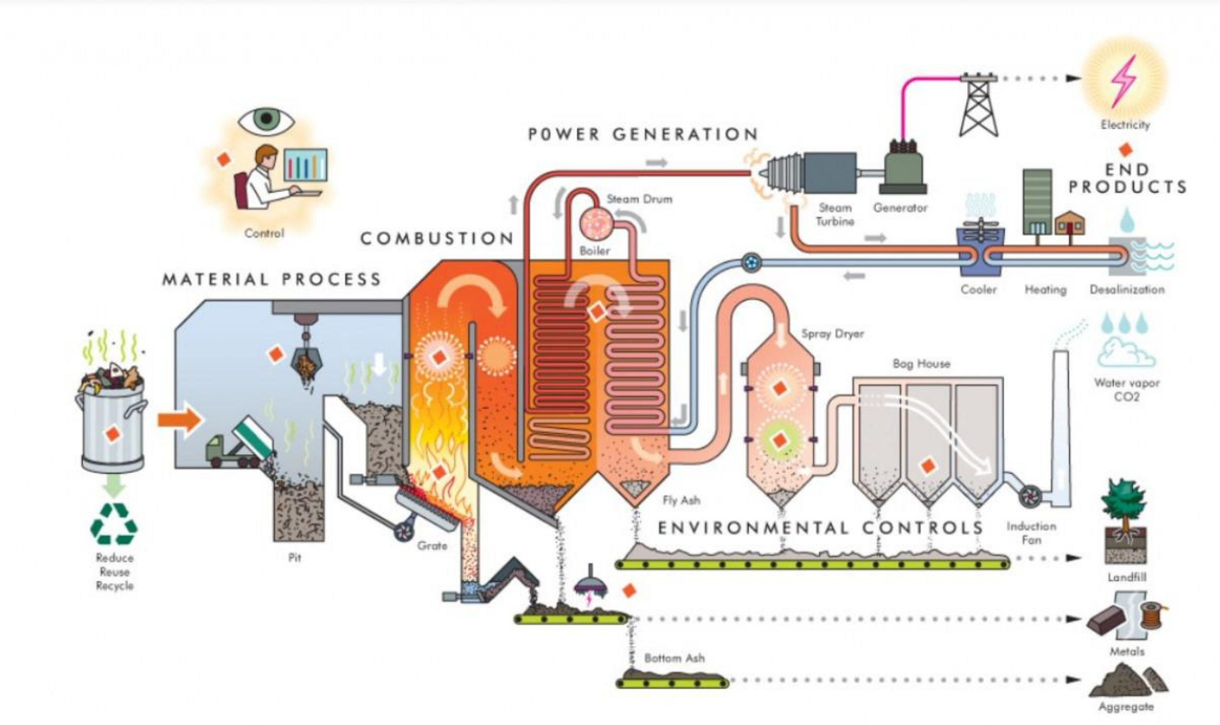


Figure 5: Municipal incinerator set-up

The second point of note is the extensive post-combustion contaminant treatment equipment to cool the gasses, often inject lime, and then to collect the particulates in (in this example) large scale bag houses.

4.4. FUEL HANDLING, PRE-COMBUSTION

The regulations which might relate to solid biofuel handling are not usually specific to biofuels. They are those which might apply to many other situations where a site is to be used for a new purpose, and for which resource or building consents might be required. They may have significant difficulties or costs associated, and so must be identified at an early stage in any project. Without being exhaustive, they might include:

- Vehicle movements in and out of the site and the impact of those movements on the local roading network and the areas surrounding the plant.
- Dust nuisance. If the yard area where fuels are handled or stored is unpaved, it can present a significant dust nuisance and be the subject of specific dust suppression measures.
- The fuel itself may have the potential to be a specific dust or other nuisance (such as smell) which requires some form of control.
- Storm water run-off from outside yard areas must be dealt with in any building consent application, but consideration should be given to specific measures to prevent any fuel materials from entering and blocking drains. Such measures must be easily accessible and cleanable.
- The storage of significant quantities of combustible fuel may present a fire risk which must be considered and possibly controlled.
- Access by emergency service vehicles.
- Site barriers to prevent public access.
- Noise and noise effects on neighbouring properties.

Depending upon the nature of the issues identified, the services of several other professions may be required beyond those of the air consenting specialists directly involved.

5. METHODOLOGY OF COMPLIANCE

5.1. BACKGROUND

The NESAQ requires Regional Councils to manage the air quality in defined airsheds. Predominantly the issue is particulate emissions. The NESAQ also requires that each Regional Council create an Airplan which sets the background to the air contamination issues faced by each airshed and the rules which are to be followed within the airshed to deal with those issues so as not to exceed the regulatory limits.

Regional Councils set up local monitoring stations in each airshed which continuously sample the surrounding air for a range of contaminants. The monitoring stations are required to be located in the place of worst contamination. Being able to show that air contamination at that spot meets the regulatory limits means by implication that the air quality of rest of the airshed will be at least as good, and often considerably better.

Data from each monitoring site tells the Regional Council how much capacity a given airshed has for additional contaminants. As previously stated, the contaminant which almost always predominates is particulates.

Figure 6: The airborne contaminant monitoring station, Garlands Road, Woolston, Christchurch

Figure 7 shows what a typical year's monitoring for particulates might look like. It is the NES 24 hour exposure limit of 50 µg/m^3 that the Regional Council must work to.

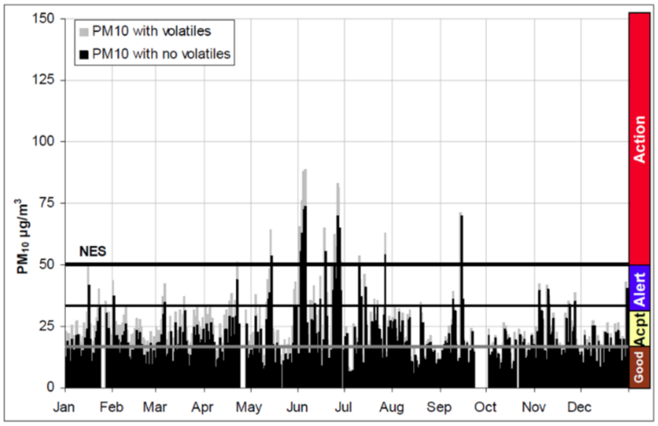
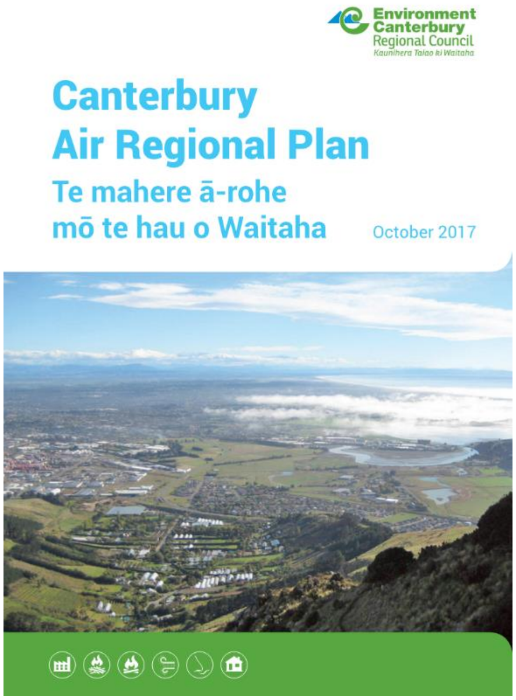


Figure 7: Christchurch Woolston 24-hour PM_{10} concentrations in 2009

In this case the airshed exceeded its 50 µg/m^3 limit on several occasions, so the Regional Council is not permitted to grant any air discharge resource consents which might add to the PM_{10} loading of that particular airshed, and any new consent application must be able to demonstrate this. Indeed, it is incumbent upon the Council to actively take measures to reduce the airshed particulate loadings to meet the "no more than one exceedance of 50 µg/m^3 a year" rule.

Other airsheds may not presently exceed the 50 µg/m^3 limit at all, making the granting of a resource consent for the same activity considerably easier at higher levels of emission than might be permitted elsewhere.


Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Canterbury
Air Regional Plan
Te mahere ā-rohe
mō te hau o Waitaha
October 2017

Very early in any project which requires an air discharge resource consent, it is essential to read the local Regional Council's Airplan to understand the planning rules which apply. It is also wise to establish the current emissions into the airshed where the site is located, as that will give an immediate indication of the complexity that might surround the granting of a resource consent, and the likely cost and complexity of the equipment to achieve it. This applies to all new projects regardless of the fuel.

If one is fortunate, it might be that the planned discharge can be shown to meet the various planning rules directly. However, if the discharge is larger, more complicated, or if the airshed is at its regulatory limit, then a more thorough approach is required. The information provided to support an application also must be site specific and refer to recent data.

In the case of particulates, in an airshed which is at its particulate limit or where the proposed activity is defined as a "Discretionary", one must demonstrate that the new discharge for which a consent is being sought when measured at ground level at the property boundary will be no more than 2 µg/m^2.

To do this usually requires environmental modelling, a service provided by some environmental consultants and which involves the creation of a computer model of the site, its size, shape, location, and expected stack emissions, which is then combined with real local weather data over a long period to demonstrate that under all reasonably foreseeable circumstances that the 2 $\mu g/m^2$ rule will be met.

One can layer onto that model data for contaminants other than particulates which might be present in a fuel to demonstrate that the NESAQ limits for those will also be met.

If any contaminant limit cannot be met, it leads one to other control measures that might be required.

It is likely some the pollutants of concern listed in the regulatory requirements will be formed from the combustion of biomass, but the concentration of the pollutant is determined by the composition of the fuel. The amount of pollutant emitted might be reduced by pre-treatment of the fuel and mitigation methods on the boiler.

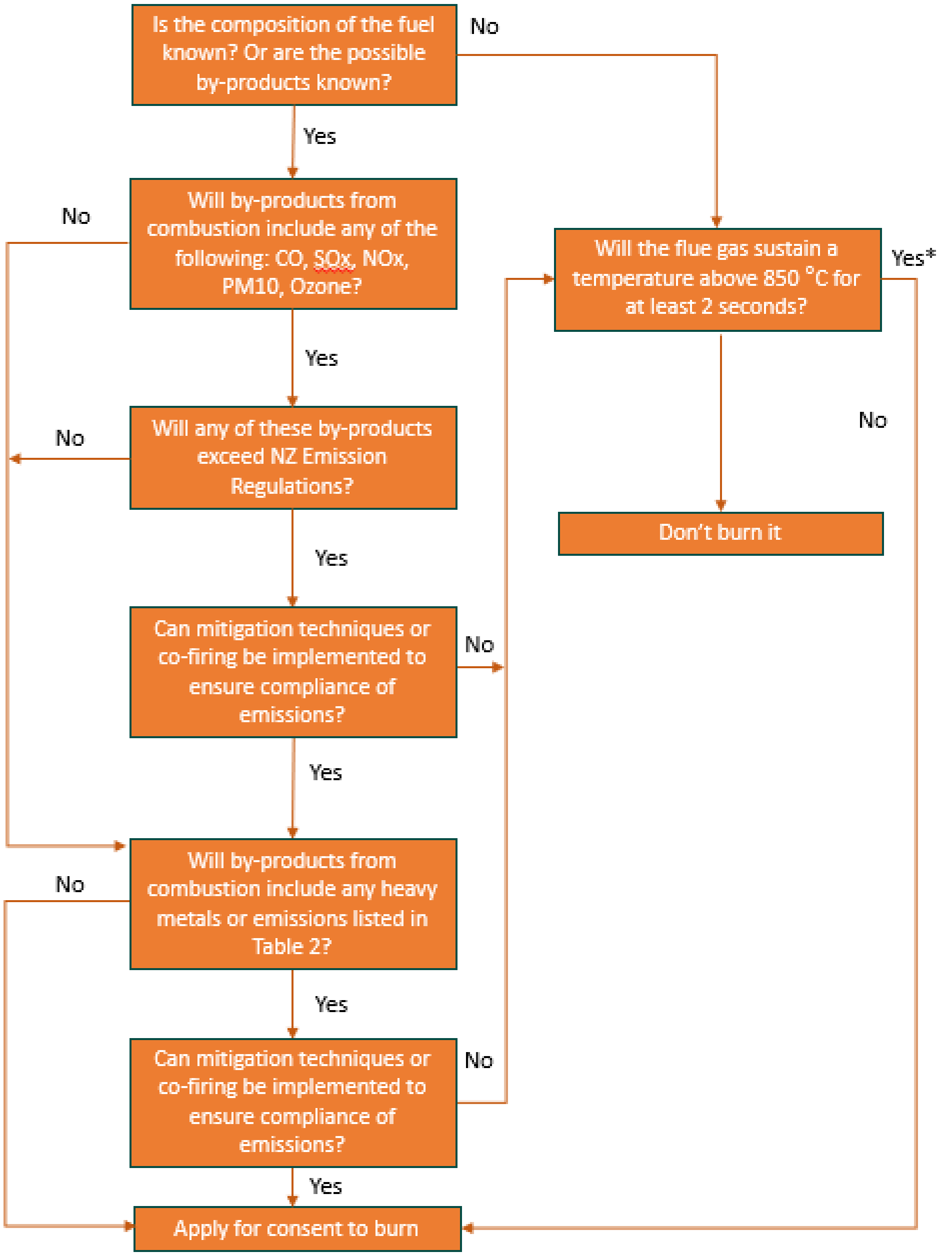
For permitted or discretionary applications, the methodology of compliance is mostly the same process, regardless of fuel. Figure 8 below provides a rough outline of the various aspects that need to be considered before applying for consent to burn.

To begin with, it is crucial to identify potential by-products resulting from combustion. If the fuel's composition cannot be approximated or possible contaminants cannot be determined, it is advisable to rely on data derived from actual incineration. The boiler supplier may be able to provide relevant information in this regard. In this situation, the flue gas must maintain a temperature above 850 °C for a minimum of 2 seconds (Fernández Rodríguez et al., 2014). This ensures the breakdown of the majority of by-products. However, it is probable that additional flue gas control methods will be necessary to mitigate SO2, NO2, CO, ozone, particulate matter, and any metals (if they are present in the fuel). Operators should avoid burning fuels with an unknown composition to protect the boiler's lifespan and ensure compliance with discharge regulations.

If any of the identified by-products are SO_2, NO_2, CO, ozone, or particulate matter, a mass balance needs to be done to determine the maximum amount of by-product produced from combustion. It is important to consider the effect boiler conditions may have on the formation of these by-products (namely temperature, excess air, boiler type). If the concentration of pollutants exceeds the New Zealand emission regulations, post combustion mitigation techniques (as outlined in 5.1) or co-firing should be considered to ensure compliance to regulations. The same process needs to be repeated if any of the possible by-products are listed in Table 2.

Disposal of ash also needs to be considered. Ash from difficult fuels may contain higher levels of heavy metals and possible dioxins. Heavy metals from fuel combustion usually remain in the bottom ash or are contained inside fly-ash particles. An ash composition for each specific fuel and any potential environmental hazards that may arise from disposal will need to be identified.

Methodology of Emission Compliance for Discretionary and Prohibited Activities



*Exceptions to this include any metals that will be emitted from the flue gas and cannot be controlled within the regulation limits from mitigation techniques.

Figure 8: Methodology for emission compliance

5.2. MITIGATION FOR SOx, NOx, OZONE, PM$_{10}$, AND CO

The ideal is to use a combustion system which inherently produces low contaminant emissions. It is better to use a more sophisticated means of combustion than to try to clean up the results of a less effective process with post-combustion treatment.

There are many reasons, amongst which are:

- If combustion is inherently clean, then ensuring and demonstrating regulatory compliance is usually easier than it might be otherwise.
- If combustion is inherently clean, then the likelihood of equipment malfunction or operator error leading to excess emissions is much reduced.
- Post combustion equipment is often costly to install, operate and maintain, and reduces the overall reliability of the plant) It can also have an impact on overall plant efficiency.

Sometimes this is possible for a new-build plant, sometimes not. Often enough one is dealing with a retro-fit to enable existing plant to continue to meet regulatory limits.

For fuels that cannot be changed with pre-treatment, post combustion control methods can be implemented. For each main pollutant, there are several control methods that might be used. However, the combination of control methods must be evaluated on a case-by-case basis depending on boiler type, fuel, and economic feasibility. The following methods outlined are based for each pollutant of concern. For pollutants outside of the New Zealand Ambient Air Quality Standards, further research will be required for mitigation techniques specific to the substance.

PM$_{10}$ emissions can be mitigated easily using cyclones, electrostatic precipitators, fabric filters (bag houses), ceramic filters, or wet scrubbers. For higher particulate matter control, a baghouse or electrostatic precipitator is recommended as they have a 98% and 90% removal effectiveness respectively for both PM$_{10}$ and PM$_{2.5}$ (AEA Technology Environment, 2001). These techniques can have a higher capital cost associated with them, so should only be used when necessary.

Control methods for NO$_2$ might involve reducing combustion temperatures, reducing the peak residence time to ensure majority of nitrogen available is not ionised, removing nitrogen from combustion, and replacing air with oxygen, or nitrogen abatement. NO$_2$ abatement techniques such as selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), or regenerative selective catalytic reduction (RSCR), all chemically reduce NOx to remove the oxygen from the nitrogen oxides in the flue gas. NO$_2$ abatement could involve the oxidation of NO$_2$ instead, raising the valence of the nitrogen ion so that water can absorb it. Removal efficiencies for these methods are heavily dependent on equipment and operating conditions but can range from 20-90% (United States Environmental Protection Agency, 1999).

It is rare for sulphur to be an issue with biomass fuels; however it is worthwhile being aware of the possible issues that could arise if it is present. One of the hidden benefits from conversion from coal to a biomass fuel is the elimination of sulphuric acid corrosion from the fire side of a boiler. Sulphur dioxide emissions arise from sulphur being present in the fuel. Flue gas desulphurisation (FGD) is used to reduce the sulphur dioxide emissions. Some possible FGD options are a venturi scrubber, packed bed scrubber, spray tower, or gas phase oxidation followed by reaction with ammonia. Reduction efficiencies for scrubbers is in the range of 50% to 98%, with wet scrubbers achieving removal efficiencies of over 90% and dry scrubbers typically achieving a removal efficiency of less than 80% (United States Environmental Protection Agency, n.d.).

A consideration when looking at sulphur dioxide control methods is the amount of chlorine in the fuel used. The concentration of chlorine in the flue gas can affect water evaporating. High chlorine content in the flue can improve sulphur dioxide removal but can also result in salt deposits on equipment (United States Environmental Protection Agency, n.d.).

Carbon monoxide is difficult to remove post combustion. The best control method to reduce CO emissions is to ensure complete combustion and optimise excess air percentages during combustion.

CO is the result of poor combustion conditions and is generally the result of either inadequate volumes of air being supplied to the combustion process, or a maldistribution of the combustion air to the combustion process. In properly designed and controlled combustion systems, CO generation should be minimal, and if not, close attention is required to the set-up of the plant to ensure the proper and even distribution and mixing of both fuel and air.

5.3. HERBACEOUS

The most harmful pollutants expected from lignocellulosic agriculture residues are nitrogen dioxide, hydrogen chloride, ammonia, sulphur dioxide, particulate matter, carbon monoxide, and volatile organic compounds. Compared to wood, agricultural residues tend to contain more sulphur, nitrogen, and chlorine. The emissions of these pollutants can be mitigated through primary methods (such as combustion regimes, organisational, and preparatory measures), and secondary methods (such as specialised gas cleaning equipment).

Herbaceous crops of especial interest are miscanthus and straw, as these are grown all around the world as a possible energy crops. Combustion of these crops must consider the chemical composition and its retrospective impact on the boiler, as well as the practicality of fuel supply to the boiler.

The Elean Power Station in Cambridgeshire, England, is a good example of accounting for the challenges that arise with herbaceous crop. Originally designed to combust 200,000 tonnes of straw, Elean mitigated fuel emissions by passing flue gas through an economiser and neutralised flue emissions with lime injection, prior to passing through a bag filter to remove particulates and acid gases. The plant also made use of high temperature above 850°C to ensure complete combustion and the destruction of any dioxins.

A particular challenge of agricultural biomass compared to wood are the lower ash fusion temperatures, around 850 °C. The main cause for low fusion temperature is due to the chlorins, sulphur, and metal contents of agricultural biomass fuels (Baxter et al., 2014). These can result in slag formation in the boiler, which in turn affects combustion, lowering the temperature, and therefore increase the concentration of carbon monoxide in the flue gas. As the concentration of carbon monoxide is a result of incomplete combustion, one way to combat this is to increase the excess oxygen into the boiler. However, if slag formation isa a problem, then an alternative is to reduce the boiler combustion temperature, co-firing with other fuels, using a specialist boiler. These are aspects to consider if carbon monoxide emissions exceed New Zealand regulations. There are no post combustion techniques for carbon monoxide reduction. If combustion is properly set up in the first place, CO emissions should be negligible. If they are not, something is wrong.

Particulate matter in the flue gas is also of concern for agricultural biomass combustion. In New Zealand, there is only regulation for PM_{10}, but it is beneficial to be aware of $PM_{2.5}$ emitted due to the concerning health effects. To mitigate PM_{10} emissions in the flue gas, a baghouse or electrostatic precipitator is recommended.

5.4. HIGH MOISTURE

At the most basic level, any moisture in a fuel reduces its calorific value, in that the moisture must be converted from liquid to vapour during combustion. Energy used for evaporation is not available for any useful purpose, so that to achieve any given plant output, more fuel must be burned, with more emissions, more ash to dispose of, more plant wear and tear and so on.

One of the biggest challenges with a standard wet fuel is reducing moisture content so that it can ignite at the desired temperature in the boiler. The presence of excessive moisture reduces the combustion temperature which increases the likelihood of incomplete combustion of some components of the fuel, resulting in greater emissions. For biomass within the range of 35% to 50% dry basis moisture content, it is possible to pass the biomass through a precombustion dryer (typically heated with flue gas) to evaporate the moisture. For biomass above this moisture content, it is likely further drying options will need to be considered. Drying methods for high moisture fuels include but not limited to screw pressing, centrifuging, air drying, kiln drying and tunnel drying.

It is worth noting that high moisture biomass that is not a standard fuel in industry currently may have specific contaminants of concern. For instance, municipal sludge, a semi-solid material produced from wastewater treatment, has a high moisture content between 55-60% dry basis. As a result of wastewater treatment, it may also have a significant concentration of heavy metals, or poorly biodegradable organic compounds. This is of particular importance with NO_2 emissions as the high nitrogen content from organic compounds may mean more NO_2 is formed compared to a biomass with less nitrogen. High moisture can also increase oxygen concentration, which can promote volatile N to convert to NO in the initial volatile combustion zone (Tan et al., 2017). The amount of NO2 that could potentially form from combustion should be analysed. This can be done by evaluating how much nitrogen is in the fuel prior to combustion, and assuming all nitrogen will form nitrogen dioxide. This pessimistic assumption will give the worst-case scenario for combustion and allow for control methods to be considered prior to use.

Another point of concern with high moisture biomass that also has high amounts of biological organic compounds is possible sulphur content of the fuel. Sulphur is of particular concern as it contributes to SO_2 pollution, one of the regulated pollutant emissions in New Zealand. A high sulphur content in fuel will mean that there is a higher concentration of SO_2 in emissions. Like nitrogen, the sulphur content in fuel should be analysed and assumed that all available sulphur will form sulphur dioxide. This will provide the worst-case scenario of sulphur dioxide emissions, and it can be evaluated if the fuel will meet emission regulations. The sulphur content found in these biomass fuels may by minute, but it is still an aspect to consider if there is any sulphur present. Most biomasses do not have enough sulphur to be of concern, however it is imperative to be aware what the possible implications might be if sulphur were present.

As previously stated, a hidden benefit of conversion to biomass is the elimination of sulphuric acid corrosion, which is the result of burning some fuels, particularly coal. Sulphur dioxide is a product of combustion from the sulphur content of some fuels. So long as it is in a gaseous form, it is relatively harmless, but as the combustion gasses cool and the water of combustion begins to condense, the SO2 dissolves in that moisture to form sulphuric acid. The acid attacks the cooler "back end" of the boiler and the chimney.

5.5. CHEMICALLY CONTAMINATED

Emissions from chemically contaminated biomass can be difficult to evaluate and control due to the possible unknown chemicals contaminating the biomass. For example, construction and demolition waste composes of a variety of chemical contaminants - with not all contaminants known, let alone the amount of contaminant. If the type of chemical contamination is known, the process for compliance is easier.

A good example of known chemical contamination is vineyard utility posts as there is one known product to analyse – CCA treated wood. CCA treated wood is made from Pinus radiata impregnated with chromated copper arsenate (or another preservative). As untreated chipped Pinus radiata typically complies with New Zealand emissions when burned, the main cause for concern is CCA. The chemicals involved in CCA treated timber are known, and the maximum amount of chemical contamination can be determined based on treated wood standards.

The composition of the fuel can then be used to identify possible by products from combustion. As outlined in the methodology of compliance, the maximum concentration of by-products which are of concern based on Table 1 and 2 needs to be determined. The best way to do this is with a mass balance. If the maximum concentration exceeds the New Zealand regulation for a specific pollutant, mitigation techniques to control the pollutant emissions will need to be implemented. The removal effectiveness of a control method can be used to determine if a mitigation method will be successful in bringing the emissions down to the accepted value.

When the fuel composition or potential combustion by-products are not reliably known, the fuel should not be burned in standard temperature boiler. For fuel that is contaminated with a variety of chemicals, or for fuel with a large amount of uncertainty on what by-products will be produced, a high temperature boiler is one of the possible options. Boilers for burning of chemically contaminated fuel must include a high temperature zone, where the temperature of the flue gas is sustained above 850 °C for at least 2 seconds (Fernández Rodríguez et al., 2014). This is particularly important if there is any plastic contamination to ensure dioxins produced are broken down and not emitted to the environment. High temperature boilers will not breakdown any metals in the fuel, however the higher temperature may result in a change of metals volatised in the fuel. For any metal present in the fuel, it is important to further research how temperature affects its presence in the flue gas.

While New Zealand may not currently have any high temperature boilers currently, places such as lime kilns may meet the high temperature criteria and be a possible opportunity to explore. There are various pathways outside of high temperature boilers that can combust chemically contaminated fuel, such as pyrolysis or gasification. However, these are outside of the scope.

Boilers also can use various mitigation techniques to clean the flue gas prior to emission. Particulate matter emissions are controlled with electrostatic precipitators and/or baghouse filters. Particulate matter control is extremely important with high temperature combustion processes, as more volatile heavy metals like lead or mercury often vaporise and recondense on fine particles (Nzihou & Stanmore, 2013). The flue is also scrubbed of any acid gases, typically through a packed bed absorber. Acid gases that are soluble (such as HCl) are collected in the first stage with an acidic scrubber liquid. Acid gases that aren't very water soluble (such as SO_2) are collected in the second stage with an alkaline scrubber liquid. NO_2 emissions are typically controlled using SCR, SCNR, or flue gas denitrification. Lastly, carbon adsorption is used as dioxins and mercury removal (Staff et al., 2000).

5.6. PHYSICALLY CONTAMINATED

The biggest challenge with physically contaminated fuel, such as demolition or construction waste, is sorting or separating the fuel from the contamination. In the case of demolition or construction waste, there is likely to be physical contamination in the form of nails, PVC wire, glass, or even bathroom ceramics. These contaminants can be physically removed from the fuel through mechanical sorting. However, if they are not removed, some of the physical contaminants may result in chemical contamination once combusted.

If physical contamination (such as plastic wrapped wood can be removed from the fuel, this is the preferred option as it will have less of an effect on the boiler and possible emissions. However, separation of some physical contamination may not be practical. For cases such as this, it is important to consider if the fuel is contaminated with something that is inert or reactive.

Fuel that is physically contaminated with an inert substance will require a boiler that is capable of handling possible issues that may arise from the non-combustibles, such as blockages. Fuel that is physically contaminated with a reactive substance – wood wrapped in plastic, for instance- should be treated as above, with additional consideration given to possible chemical contamination and its corresponding emissions. The process outlined in chemical contamination above will need to be followed.

As a final note on physical contamination, it is very important that the fuel handling process from source to final delivery to combustion is clean does not add any further contamination. All areas where fuel may be dumped for blending, storage or handling must be paved and kept swept of stones, sand, and dusts. Only a small stone or such like can cause enormous damage if it happens to wedge in the wrong place during handling or combustion.

5.7. NOVEL FUELS

Novel fuels, by definition, are unusual, one-off types of material. Often enough they can be wastes from some commercial, industrial, or agricultural process or activity which may (or may not) present a disposal problem as well.

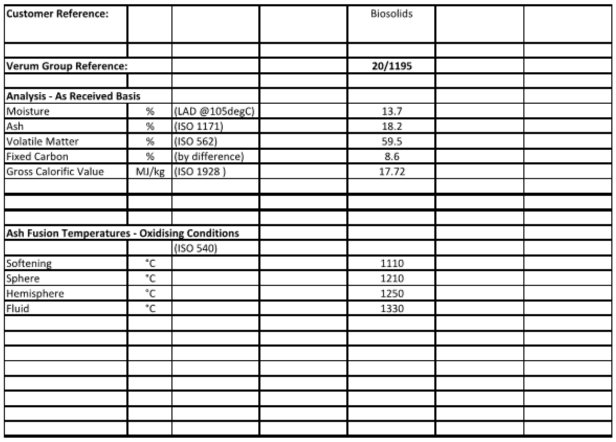
As they are novel, a standard combustion solution is probably not available, although it is quite likely that a standard solution might be the adaptable.

What follows are some general guidance notes as to a path to follow from the time at which one thinks that one might have a useful fuel, to the point at which there is a viable project ready to go. Before even starting to consider a fuel, one should read the local Regional Airplan to establish that there is not already an outright prohibition on its use. Assuming that this first hurdle has been cleared successfully, then:

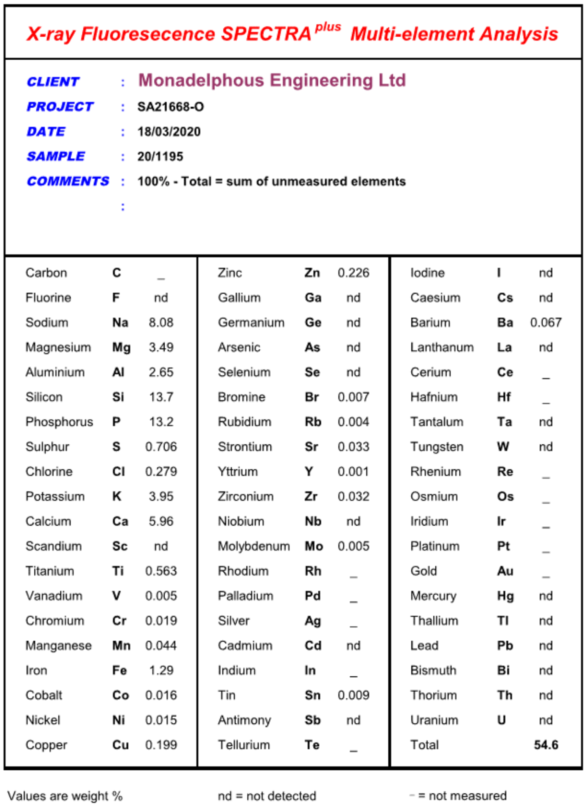
- What is the fuel?
- How much is there?
- Is it seasonal or is its availability relatively steady?

If one can satisfy oneself that on the face of it there is enough fuel and the supply is sufficiently reliable, the next matter is to get a fuel analysis carried out. Normally one would send a sample of a kilogramme or more off to a fuel analysis laboratory. There are a few characteristics that we need to know (see below). Without being exhaustive:

- Its calorific value (right).
- Its moisture content.
- An elemental analysis (below). We need to know what the fuel is made of and if there are any components which might create some sort of emission problem when burned, either as an air emission or something that might be a residual component of the ash, which may require some form of special arrangement for its disposal (typically, disposal in a controlled landfill).



Customer Reference:				Biosolids		
Verum Group Reference:				**20/1195**		
Analysis - As Received Basis						
Moisture	%	(LAD @105degC)		13.7		
Ash	%	(ISO 1171)		18.2		
Volatile Matter	%	(ISO 562)		59.5		
Fixed Carbon	%	(by difference)		8.6		
Gross Calorific Value	MJ/kg	(ISO 1928)		17.72		
Ash Fusion Temperatures - Oxidising Conditions						
		(ISO 540)				
Softening	°C			1110		
Sphere	°C			1210		
Hemisphere	°C			1250		
Fluid	°C			1330		



X-ray Fluoresecence SPECTRA plus Multi-element Analysis

CLIENT : Monadelphous Engineering Ltd
PROJECT : SA21668-O
DATE : 18/03/2020
SAMPLE : 20/1195
COMMENTS : 100% - Total = sum of unmeasured elements
:

Carbon	**C**	_	Zinc	**Zn**	0.226	Iodine	**I**	nd
Fluorine	**F**	nd	Gallium	**Ga**	nd	Caesium	**Cs**	nd
Sodium	**Na**	8.08	Germanium	**Ge**	nd	Barium	**Ba**	0.067
Magnesium	**Mg**	3.49	Arsenic	**As**	nd	Lanthanum	**La**	nd
Aluminium	**Al**	2.65	Selenium	**Se**	nd	Cerium	**Ce**	_
Silicon	**Si**	13.7	Bromine	**Br**	0.007	Hafnium	**Hf**	_
Phosphorus	**P**	13.2	Rubidium	**Rb**	0.004	Tantalum	**Ta**	nd
Sulphur	**S**	0.706	Strontium	**Sr**	0.033	Tungsten	**W**	nd
Chlorine	**Cl**	0.279	Yttrium	**Y**	0.001	Rhenium	**Re**	_
Potassium	**K**	3.95	Zirconium	**Zr**	0.032	Osmium	**Os**	_
Calcium	**Ca**	5.96	Niobium	**Nb**	nd	Iridium	**Ir**	_
Scandium	**Sc**	nd	Molybdenum	**Mo**	0.005	Platinum	**Pt**	_
Titanium	**Ti**	0.563	Rhodium	**Rh**	_	Gold	**Au**	_
Vanadium	**V**	0.005	Palladium	**Pd**	_	Mercury	**Hg**	nd
Chromium	**Cr**	0.019	Silver	**Ag**	_	Thallium	**Tl**	nd
Manganese	**Mn**	0.044	Cadmium	**Cd**	nd	Lead	**Pb**	nd
Iron	**Fe**	1.29	Indium	**In**	_	Bismuth	**Bi**	nd
Cobalt	**Co**	0.016	Tin	**Sn**	0.009	Thorium	**Th**	nd
Nickel	**Ni**	0.015	Antimony	**Sb**	nd	Uranium	**U**	nd
Copper	**Cu**	0.199	Tellurium	**Te**	_	Total		**54.6**

Values are weight %　　nd = not detected　　_ = not measured

- The amount of ash present and the ash fusion temperature. The ash fusion temperature and its importance is discussed in the next section. The percentage of ash in the fuel is also important as that will define the likely requirements for ash removal and ash handling for a future equipment supplier.

If there is any reason to believe that the nature of the fuel might vary over time, then it would be wise to take a series of samples and have them analysed to establish the degree of variability.

At this point, having satisfied oneself that there is enough fuel and that there is nothing in its properties which might be regarded as a “show-stopper” the fuel needs to be matched to the use.

The next step (if this is something not already known) is to define the heat load that the fuel will be expected to support. What we are aiming to do is to define the likely operating envelope of the combustion plant. Again, without being exhaustive we need to define:

- The peak heat load.
- The mean heat load, by hour, over an operating day, or perhaps a 24-hour day if the load is continuous.
- How rapidly the load changes over time? Are load changes almost instant or do they ramp up and down gently?

With this information the heat load can be matched to the fuel and estimates of the burn rate can be made.

Unless what is proposed is a known “Permitted” activity (which is unlikely with a novel fuel) then at this juncture there is enough information to engage an environmental consultant. The environmental consultant should be asked to create an air discharge computer model to convert the properties of the fuel and its burn rates into estimated stack emissions and to predict the likely effect of those emissions into the surrounding airshed.

There are two possible outcomes; that there is not likely to be a problem and one can carry on with the design of a plant, or that there is a problem with one (or more) of the components of the likely air emissions.

The environmental consultant should be able to provide guidance on the degree of “clean-up” of the air emissions which might be necessary to make the use of the fuel acceptable. At one end of the scale, it may be no more than ensuring that the fuel is well graded and that the moisture content is limited. At the other it might require air filtration, chemical injection into the flue gasses, or the like.

The important thing is that when one goes to a potential equipment supplier, all the information is there.

- This is the heat load and its characteristics.
- This is the fuel and here are its characteristics.
- These are the stack emission rates that you must achieve.

From this point on, it is a standard process of establishing the economic viability (or otherwise) of the project. Assuming that the project is viable, then all the information is available to apply for an air discharge resource consent with a reasonable expectation that it will be granted without undue difficulty.

Using a Novel Fuel in an Existing Plant

In principle, using a novel fuel in an existing installation follows much the same process as for a new plant. All the same hurdles must be cleared from inception to implementation. However, there is one opportunity that should be taken - that of running a real combustion trial (or trials) as soon as practicable in the process.

Any trial must be designed and planned specific to the fuel and the installation concerned. At the most basic level, it needs to be confirmed that the fuel will burn reasonably and that the fuel feeding equipment can adequately handle it. Beyond that one needs to:

- Set up the equipment combustion properly with a combustion test kit to ensure that it is adjusted to achieve the most efficient combustion of the fuel. (Equipment set to operate at its most efficient point is almost always operating at its cleanest point as well.)
- Operate for a sufficient time period to be sure that there are no fuel feed problems such as blockages or bridging.
- Ensure that the stack emissions are clear, or at least appear no more than when operating on the normal fuel.
- Ensure that there is no apparent formation of clinker across the burning fuel bed, or if there is, it is no worse that when operating on the normal fuel.

If a short trial suggests that the fuel can be used successfully, or if it indicates that the plant needs modifications to do so, but that those modifications are practicable, then the next step would be to contract an environmental monitoring company to come to site and carry out real-time stack emission monitoring.

The results of that monitoring can be passed to the environmental consultant to model the effects on the local airshed, and again there can be two possible outcomes; there the fuel is safe to use in the plant as-is, or some kind of additional treatment may be necessary.

6. EQUIPMENT CONFIGURATIONS

For each fuel, an effective equipment configuration, with indications of the expected emission levels from each possible configuration for each fuel, is required to ascertain overall compliance. Note that there are likely more than one configuration, and configurations need to change with complexity in proportion to the expected fuel burn. Consideration should be given to:

- Pre-treatment, such as drying, size optimisation (such as chipping or pelletising).
- Fuel Storage
- Boiler feed systems
- Combustion systems (ie the boiler itself)
- Post combustion mitigations (ash handling and flu gas treatment)

It is critical before committing to burn any fuel (and this applies to all fuels) that a full fuel analysis is made which defines all of the fuel parameters (density, particle size ranges, moisture content, calorific value, chemical composition, and the like, and which also defines the ash fusion temperatures) as this will drive what equipment is required to enable satisfactory combustion. If there is any possibility of significant variability of the fuel properties over time or source, then several analyses are required to ensure that the likely properties of the fuel are fully understood.

In the case of new equipment, the fuel analyses must be provided to the supplier and assurances received that their equipment will be capable of burning it without issue.

If the fuel is to be used in existing equipment (if at all possible) it is wise to arrange for a trial operation period where the plant is properly set up by competent technicians with adequate combustion analysis equipment to prove (or otherwise) that the equipment can handle the fuel effectively, before any commitment is made for permanent operation on that fuel.

6.1. ASH FUSION

Ash fusion temperature is a consideration with most solid fuels. It depends on the nature and composition of the ash, which in turn depends upon the ground that the fuel was grown on (for solid fuels), so it varies place to place for the same fuel. (By way of example, wood pellets from the central North Island have a lower ash fusion temperature than those out of Nelson, entirely down to the different minerals present in the soil where the wood from which they were made was grown.)

To confuse matters further, some of the ash components can interact to form “eutectics”, or molten mixtures which melt at temperatures significantly below any of the constituents.

All but the most minor of clinkering must be avoided in any combustion situation as it restricts the free flow of combustion air and gasses and will damage grates and refractories.

Clinkering occurs when the combustion temperature exceeds the ash fusion temperature. Sometimes it is down to the poor set-up of the combustion equipment, sometimes that the equipment is too crude to ensure uniform combustion temperatures across a fuel bed, and sometimes that the inherent design leads to high combustion temperatures.

6.2. POST COMBUSTION CLEAN-UP

This section is presented to provide an overview of the sorts of technologies which might be applicable to a flue-gas clean-up operation, and which might be offered to a plant operator by a designer or supplier. It is not a definitive list of the available possibilities.

The environment of a boiler exhaust is a tough one for filters and materials to survive in. Typically, it is hotter than 160^0C, humid, and contains potentially corrosive NO_x, SO_x and CO_x materials, not to mention particulates or other combustion products some of which can (depending on what they are) be quite cohesive.

Although considerable research and development has been undertaken around the world over a long period into cleaning up emissions, much has been directed to burning on an industrial / power generation scale. There are a limited number of technologies available which are potentially applicable to small / medium sized boilers.

A quote from a 2006 report by the Finnish Funding Agency for Technology (TEKES)

"Overall, the FINE programme confirms that there is a clear window of opportunity for innovation in combating particulate emissions in energy generation and industry given the ongoing requirement for more efficient boilers and better filter technology, resulting both from the introduction of ever tougher emission limits and the limitations of existing solutions.

This is particularly clear in respect of small plants rated below 10MW for which no cost-efficient fine particulate control technology exists as yet - something that is highlighted by the fact that fine particulate emissions from larger energy generating facilities are low compared with those from small scale wood combustion."

Nonetheless, technically, the following particulate reduction “add-ons” may be applicable.

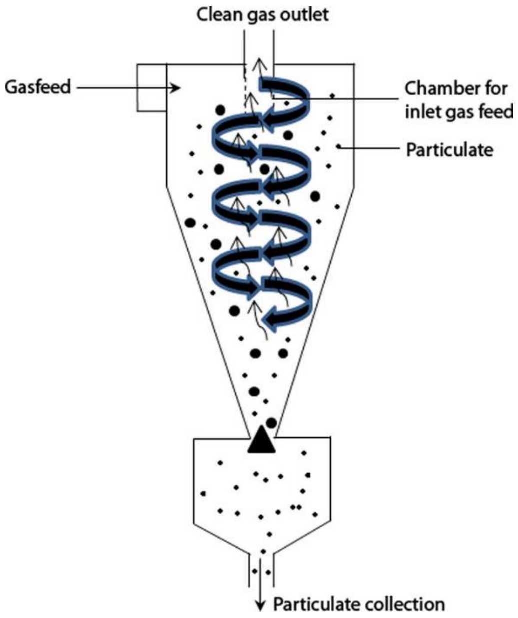
Cyclones

A cyclone is a device that causes the exhaust gasses to move in a tightly circular path and in so doing causes entrained particles to be thrown to the sides of the cyclone and fall to the bottom, from where they may be removed.

The principle of operation is well illustrated by the adjacent diagram.

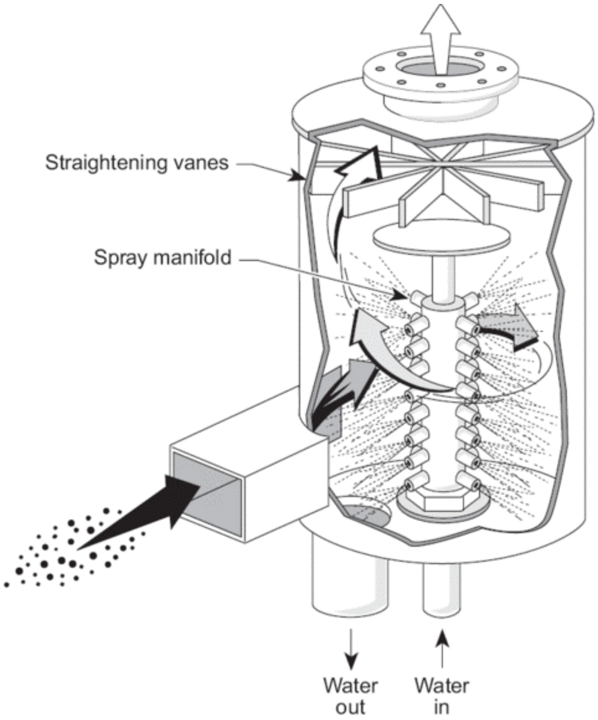
To improve the collection efficiency, a number of cyclones may be placed in series, creating the so-called multi-cyclone, a device commonly used in drop tube boilers.

Cyclones of this pattern are a simple and reliable way of reducing emissions.



Cyclones are effective at removing the larger sizes of particles, but are relatively ineffective at removing particles of 10 micron (PM10) or less.

Wet Scrubbing



Wet scrubbers force flue gasses to pass through fine water sprays. The particulates, along with a significant proportion of any soluble gasses such as SO_2 are entrained in the water. The wet gasses then pass through a cyclone separator to remove the particle containing water droplets.

A proportion of the water is then passed through a clean-up process before it is discharged as waste.

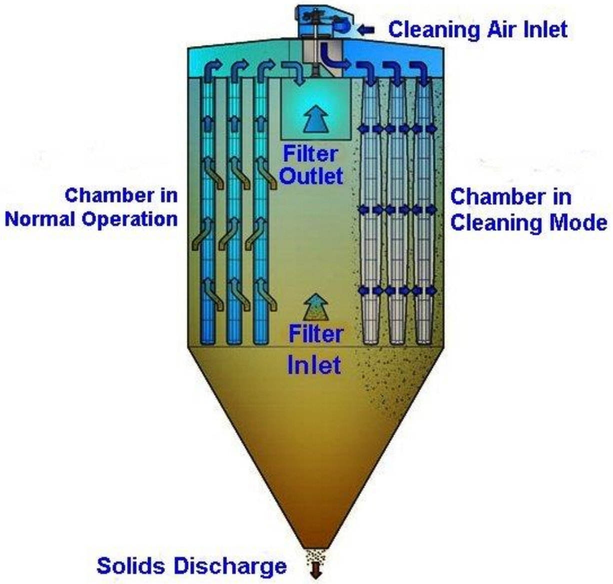
Typical emissions from coal combustion plant using wet scrubbers

Bag Filters

Bag filters are made from a variety of fabrics, normally nylon, polyethylene, or polypropylene. Typically. they will operate at temperatures up to 240^{0}C, or 280^{0}C with teflon or glass fibre bags.

The flue gasses pass from the outside of the bags to the inside. When the pressure drop between the inside and outside of the bag becomes too great, the bag is shaken, either mechanically or by injecting a pulse of compressed air inside the bag. The collected particulates are collected from the bottom of the baghouse for disposal.It will be noted when data that is presented for bag filters in real operation that the actual measured particulate levels may vary considerably. There are two reasons for this.

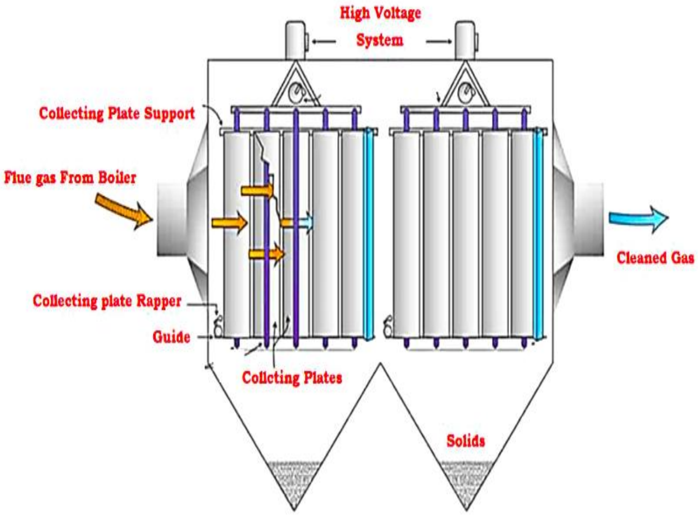
First, in some cases the bag filters are arranged to filter only a percentage of the total gas flow. This is a commonplace arrangement in many installations around the world.



Second, is that if bags and baghouses are not well maintained their performance deteriorates. There is no guarantee that those installations which have been monitored for particulate performance were working at their best efficiency.

It is clear from a number of sources that where bag filters are installed so as to filter the entire gas stream, particulate emission rates of the order of 5mg/m^3 are achievable .

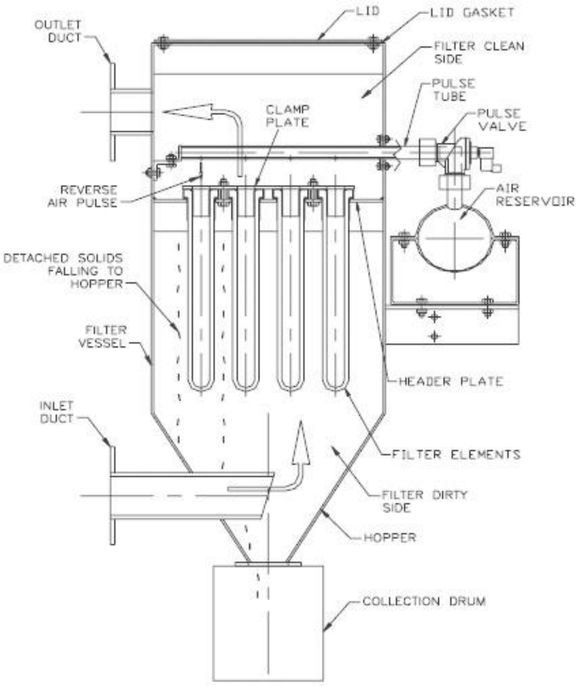
Electrostatic Precipitators



Electrostatic precipitators pass the boiler flue gasses through very high voltage electrostatic fields causing the particulates to precipitate out on the electrostatic plates, from which they are removed either mechanically, or by a water spray.

Water spray precipitators are much easier in operation but can only be used at temperatures of 180^{0}C maximum, rendering them inappropriate for many combustion related applications. At temperatures above 180^{0}C dry precipitators are used.

Electrostatic precipitators are the device of choice at very large sizes (power stations), but are comparatively expensive at smaller sizes. The costs are falling over time, and they are seeing use now in NZ in cleaning up kitchen extract exhaust steams.



Achievable emission rates are around 20mg/m3 although data from their use in industrial / commercial installations is limited.

Ceramic Filters.

Ceramic filters in operation are very similar to bag filters saving that they use a hollow ceramic tube as a filtration device.

In a typical installation, large numbers of ceramic filter elements are arranged to operate in parallel. Gasses pass from the outside to the inside of the element, with the particulates adhering to the outside.

When the differential pressure across a group of elements reaches a pre-determined maximum, a pulse of compressed air is injected into the hollow centre of each element, knocking the accumulated particulates off to the bottom of the filter assembly from where they can be collected.

Ceramic filters are particularly suitable for hot corrosive environments, as high as 1000^0C.

The downside however is that, (apart from being costly), the elements are relatively fragile and prone to breakage. Should a single element in a ceramic filter assembly fail, the entire assembly ceases to function.

Achievable emission rates with ceramic filters are claimed to be around 5mg/m3. Additionally, manufacturers are offering catalyst coated filter elements which are capable of decomposing SO_x and NO_x compounds, as well as acids, heavy metals, furans and dioxins, not just particulates.

7. CCA CASE STUDY

Chromated copper arsenate (CCA) is used to treat timber to meet durability requirements for building materials and components. The appropriate treatment level for timber in different circumstances is detailed in NZS 3640. Timber that is treated to hazard class H1.2 is appropriate for structural framing. Timber that is treated to hazard class H3.2 is suitable for exposure to weather but not in-ground contact, such as decking. Timber that is treated to hazard class H4 is suitable for contact with the ground, such as fence posts. These are the three treated timber classes that are most common in construction and demolition waste and have therefore been selected as a case study.

Chromate copper arsenate is produced by dissolving copper, chromium and arsenic salts or oxides in water to give a solution with a composition detailed below. Table 3 specifies the percentage of Cu + Cr + As component retained in each class of CCA treated wood on a mass/mass oven dry weight of wood basis as per the NZS 360:2003 standard.

Table 3: CCA Solution for Treated Wood Composition

Copper %	Chromium %	Arsenic %
23 - 25	38 - 45	30- 37

When wood treated with CCA is combusted, the elements mentioned are distributed between bottom ash, fly ash and flue gas emissions, depending on the degree of volatilization and to which extent they are physically and chemically bound to the carbon matrix of wood (Lundholm & Larsson tr.), 2007).

The main pollutant of concern is the arsenic, as this tends to be the most abundant pollutant found in the flue gases. A study conducted trials with simulated open burning of CCA treated timber. It was observed that between 11% and 14% of arsenic in the wood was emitted to the air, while over 99% of the chromium and copper remained in the bottom ash (Wasson et al. (2005)). Further studies have estimate concentrations of arsenic much higher in the flue gas, estimating anywhere from 8-95%, depending on the degree of volatilisation due to residence time of the wood, and ashes and the temperature of the combustion (Sipilä et al., n.d.).

Table 4 below shows the varying concentrations of the different elements present in the different types of CCA treated timber.

Table 4: Concentration of CCA in Treated Wood

	%m/m oven dry weight of wood			
	CCA	Copper 24%	Chromium 42%	Arsenic 34%
H1.2	0.12	0.03	0.05	0.04
H3.2	0.37	0.09	0.16	0.12
H4	0.72	0.17	0.31	0.24
H5	0.95	0.23	0.41	0.32

Using the above quantities of CCA in various classes of CCA treated wood and the ideal stoichiometric equation (Equation 1) for the combustion of wood, the amount of air required to burn a kg of wood can be found at various levels of excess air. An example calculation for arsenic emissions from combustion of 1 kg of H1.2 in 100% excess air is below.

$$1\ kg\ dry\ wood + 6.4\ kg\ air\ \rightarrow 1.83\ kg\ CO_2 + 0.52\ kg\ H_2O + 5.05\ \ kg\ of\ N_2 \qquad (1)$$

$$\frac{m_{arsenic}}{m_{H1}} = \frac{0.04\% \times 1\ kg \times 1000}{1\ kg} = \ 0.4\ mg$$

$$\frac{m_{arsenic,volitised}}{m_{H1}} = \frac{10\% \times 0.4}{1} \ = 0.04\ mg$$

$$m_{air,100\%\ excess} = 6.64 + 100\% \times 6.64 = 12.8\ kg$$

$$C_{m,arsenic} = \frac{m_{arsenic,volitised}}{m_{air,100\%\ excess}} = \frac{0.04\ mg}{12.8\ kg} = \ 3.13\frac{\mu g}{kg\ \ air}$$

$$C_{arsenic} = \frac{C_{m,arsenic}}{\dot{v}_{air}} = \frac{3.13}{1.2929} = 2.42\ \frac{\mu g}{m^3}$$

This can then be used to estimate the concentration of the pollutants in the flue gases. Best case scenario, if H1 class timber is burnt with only 10% of the arsenic present being volatilised and emitted via the flue gasses, with an excess of air of 100%, the concentration of arsenic in the flue gasses would be approximately 400 times higher than the allowable annual limit of 0.0055 µg/m^3

This is also the case for chromium, although as mentioned previously the level to which chromium is found in the flue gases is much lower than that of arsenic, however the levels in the flue gases would still be higher than the allowable limited of 0.11 µg/m^3.

Research has found that most of the arsenic vapour generated from combustion is captured by the fly ash and will often accumulate on the surface on particles with a diameter less than 10 µm (Wang et al., 2018). There have been varying conclusions on the removal effectiveness of arsenic removal from an ESP, ranging from 83% to as high as 97%. Wet limestone flue gas desulfurization (WFGD) is another viable control method, although like ESP, effective removal is varied in case studies, ranging from 75% to 96%.

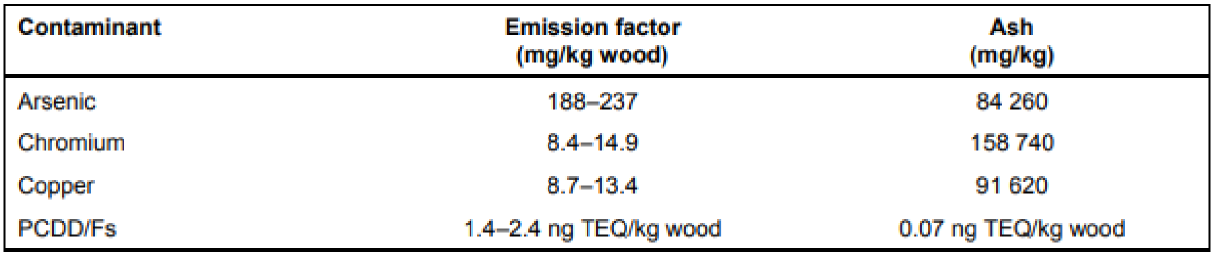
If an ESP was added to the best-case scenario of only H1 class timber burnt with 10% of the arsenic present being volatilised and emitted via the flue gasses, and an excess of air of 100%, arsenic emissions in the flue would still be almost 75 times more than the allowable annual limit for just 1 kg of CCA timber burned. With co-firing and an ESP, emissions would be below the annual limit if CCA timber made up 1.3% of the overall fuel, as an even blend throughout. If an additional control method was added, such as WFGD, CCA timber could make up 3.5% of the overall fuel. This does assume that the effective removal of arsenic from ESP and WFGD are independent of each other.

While co-firing with 3.5% CCA timber may seem like a small percentage, this could reduce a decent amount of wood waste from landfills if used by big energy using sites. For example, a site with a 20 MW boiler may use 30,000 tonnes of wood pellets a year on average. Just over 1,000 tonnes of this could be replaced with CCA timber as part of a co-firing blend.

Anything that is not lost up the flue gas is therefore found in the bottom ash, approximately 99% of the copper and chromium and anywhere from 5-92% of the arsenic can be found here. Bottom ash disposal can be harmful to the environment if not done correctly. Harmful elements in the ash can leach into the soil or groundwater. Correct disposal of ash is of even more importance when arsenic is present, as it is more leachable that other heavy metals (Wang et al., 2018).

Table 5 below gives indicative emissions factor for the various components of CCA treated timber and ash levels (WASSON, 2005).

Table 5: Indicative Emission Factors for CCA Timber and Ash Levels



Contaminant	Emission factor (mg/kg wood)	Ash (mg/kg)
Arsenic	188–237	84 260
Chromium	8.4–14.9	158 740
Copper	8.7–13.4	91 620
PCDD/Fs	1.4–2.4 ng TEQ/kg wood	0.07 ng TEQ/kg wood

8. MDF CASE STUDY

This was an analysis carried out for Taymac, the boiler manufacturers in Christchurch to establish air emissions data for their “Heatpack” boiler and Taylors underfeed stoker when operated on MDF, melamine, sawdust, and associated wood wastes which might arise from the operation of a typical joinery shop.

The fuel is reasonably typical of that found in similar manufacturers’ facilities all over NZ and elsewhere. The analysis was carried out over 2 days.

Taymac had a potential Australian customer with a large joinery shop and with a need to both dispose of their wood waste and to provide space heating in winter. They were able to demonstrate to the satisfaction of the Australian consenting authorities that their boiler plant when operated correctly was capable of reliably meeting the local Australian emission rules, without any particular pre-treatment of the fuel or post treatment of the flue gasses.

The “Heatpack” boiler is a sectional welded steel design which has been in operation for more than 60 years. It was originally designed for coal firing, but in the early 2000’s proved capable of being updated to fire efficiently and reliably on wood pellets, and more recently on wood wastes.

Since the initial installation Taymac have sold several other sets of plant into Australian joinery firms for both space heating and as a means of reliably disposing of MDF and related wastes.

As an example of the detail which sometimes one must go to, to prove that combustion is safe and effective, the tabulated data is provided as Appendix C.

9. OAT HUSK CASE STUDY

Oat hulls (husks) represent the largest volume of by-product from an oat-milling operation and can add significant cost and complexity to a processor to dispose of. However, the husks are typically dry and can be burned in order to generate heat for a processor, offsetting fossil fuel use.

While they can be burned in specialist boilers, existing equipment can be utilized to minimize capital investment required.

A NZ producer had a stream of oat husks and wanted to burn these in existing standard coal boilers to minimize costs and carbon output. Physically and chemically the husks are different to coal and are smaller, lighter, dryer, and changes were needed to the boiler to facilitate the combustion, including to the:

Feed system
Burners
Fire box
Air flow

The changes and combustion were successfully implemented.

The primary resource consent condition limited the PM_{10} emissions to 250 mg/dsm³. Actual emissions of 197 mg/dsm³ were measured, for a successful project.

At the conclusion of the initial resource consent, standard particulate discharge rates had been reduced in order to improve overall air quality. As such, PM_{10} discharges were now limited to 50 mg/dsm³, well below current operating levels.

A range of options to reduce particulate emissions were reviewed, and it was decided to install a bag house filter system. Post installation, particulate emissions measurements were performed, and PM_{10} emissions were reduced to 16 mg/dsm³ - a reduction of over 90%.

The new system has met the requirements of the much more stringent resource consent, indicating that the mitigation techniques implemented were exceedingly effective at removing particulate matter from the flue gas stream.

10. PROCESS RESIDUE

A New Zealand forest owner and timber producer recognised that there was a possible market for some forest residues which might otherwise go to waste. After some years of investigation, they established that they could extract specialist chemicals from foliage wastes in sufficient quantity and of a quality as to (potentially) be an economic proposition.

They constructed a “benchtop” sized extraction plant and operated it to establish the parameters within which a full-sized plant would need to operate, and from that were able to create a plant specification to enable potential boiler and process plant providers to offer equipment.

The essential process involves steaming forest residues to drive out the, condensing the resultant vapours, and separating the economic components.

In principle any steam boiler could do the job, indeed it could have been done quickly, simply, and comparatively inexpensively using a packaged oil or gas boiler. However, this neither matched the Company’s aspirations, not the aspirations of many of their future customers for a product

produced with a high degree of environmental and sustainable responsibility.

The choice therefore had to be a biomass boiler which was to be operated on chipped forestry slash, (of which they had an abundant supply). The boiler type chosen was from Hurst of the USA, a hybrid design especially suited to using wood chip, and with a reasonable ability to burn chip of variable moisture content and size. The intent was to stockpile material suitable for chipping and allow it to air-dry for some months before use, so whilst not a raw, green, as-cut fuel as is often used in sawmills, it would nonetheless be moister and more variable than might be used in many commercial or industrial applications.

Part way through the detailed design of the steam and processing plant, it was realised that the residue from the extraction process might well make a useful fuel. At the end of processing the cell structure had been well broken down by heat (in order to extract the volatile components), and although still damp it was relatively fine in nature. If stored under cover for a short period and turned regularly to dry, there was (apparently) no reason why it should not be fed back to the boiler as its fuel.

The boiler manufacturer had no experience of this variation in the application of their products, and so the design and construction of the plant proceeded on the assumption that it would be fuelled with wood chip, but that at the earliest opportunity process waste (in whole or in part), would be substituted for chip.

In practice, the boiler has operated with little difficulty on the process waste, which has had three additional benefits for the operation. First, it has much reduced the need to operate a tractor PTO driven woodchipper, second it has reduced the need to recover and store timber specific for chipping, and third it usefully disposes of a process waste which otherwise would need to be spread back into the surrounding forest.

11. SEWAGE WASTE

A local authority has a municipal waste-water treatment plant which uses a solar drying process for the de-watered sludge. It is essential to dry the sludge before disposal, both to reduce the transported weight, and to reduce the disposal cost (which is charged by the tonne).

Whilst much of the time the solar process works well, in winter or prolonged overcast periods it works less well, as it does during periods of plant overload (which can occasionally happen.).

Initially, the notion was to add underfloor heating to the solar drying halls to provide additional drying heat when the sun was inadequate. However, it rapidly became apparent that as the sludge might lose moisture against the floor, it would become an increasingly better insulator, preventing heat flowing to the sludge layers above.

It was realised that the correct approach was not to heat the floor, but to do exactly what the sun does; heat the sludge from above and the warm the surrounding air to allow the air to carry away the moisture driven out of the sludge.

The heat source was to be hot water, heated either from a solar collection array or from a biomass boiler. A solar array would still have the same limitation as the solar driers themselves; when there is no sun there is no heat, albeit the effect could be moderated by incorporating large amounts of thermal storage. Nonetheless it was not going to provide a totally reliable operating solution, so it was settled upon that a biomass was likely the better alternative.

However, what made that alternative doubly attractive was the recognition that properly dry, municipal sewage sludge was potentially a fuel in it own right with a similar calorific value to a wood chip at around a 10% moisture content.

A literature search on the internet provided plenty of examples of municipal sludge being incinerated in the de-watered form by burning it with another fuel as a means of disposal, but no examples of it being used as a fuel in its own right.

Sludge samples have been analysed, and as previously mentioned, the calorific value as established at about 17.7MJ/kg. The ash content is comparatively high at 18.2%, but the various ash-fusion temperatures are between 1100 and 1300^{0}C. Unless there are any eutectics present, then clinkering during combustion should not be a difficulty (although it will be tested for). A range of other components of the fuel (metals and the like) have been identified.

Whist no boiler plant has yet been selected, the project is proceeding on three fronts.

- Regular sampling to establish the consistency of the sludge over time.
- Emissions modelling to provide data for a resource consent, particularly in relation to any issues which might arise from metals contamination.
- To create a specification for the limits on stack emissions which will need to be provided to any boiler manufacturer and (if necessary) to any provider of post-combustion clean-up equipment.

12. MONITORING

In all cases where a resource consent has been required to burn a fuel, there will be conditions attached to that consent.

Normally a draft of the consent will be provided to the applicant before it is formally granted. The draft consent document must be read carefully, particularly the "Conditions". A typical consent may attach conditions relating to:

- Maximum fuel burn, hourly, daily, or annually.
- Type of fuel and limitations on its composition.
- Plant operating hours.
- The keeping of operating and / or maintenance records.
- Requirements specifying the routine measurement of emissions. In most cases they will require particulate monitoring, but there is no reason why the emission of any component of the flue gasses may not be a part of a monitoring regime.
- Emission monitoring intervals. How often? Most consents would require at least an annual emissions monitoring report, but in principle there is no reason why shorter (or longer) intervals should not be set.
- It is possible that there may be a requirement for continuous logging and record keeping. If there is a requirement for continuous logging, then it will be necessary to contact a specialist instrumentation supplier to recommend appropriate instruments for the particular application. It is worth talking to more than just one, as (in some cases) there are a number of different ways in which a parameter might be measured, some more costly than others.

  If continuous measurement and logging is to be installed it is important to understand the likely life (and cost) of the consumable parts of instruments and their calibration procedures and intervals (and again any associated costs).
- If the requirement is for periodic measurement and reporting, then there are a number of specialist environmental monitoring companies with portable instrumentation who are available for such work. A short look on the internet or in the Yellow Pages will usually be all that is required. Again, it is worth discussing in detail the monitoring requirement with them before final commitment to a project to establish likely costs and difficulties associated with any particular monitoring and reporting regime.

Whatever the conditions set in the draft consent document it is important to read them carefully and understand their implications, technically, operationally, and financially. If any appear to be unduly onerous or the reason for the requirement is unclear, then push back and talk with the consenting authority. It is important to arrive at a set of conditions appropriate to the situation, which are workable, achievable, and affordable, and it is important to have this clear before a final commitment is made to a project.

As a final point, whatever the emissions monitoring requirement might be which is laid down by the consenting authority, it is prudent to have one's own combustion monitoring and regime in place. The simple routine combustion checks and adjustments which can be made using a set of portable flue gas analysis equipment can keep a plant operating at peak efficiency more reliably than the most experienced eye. What is more, plant which is operating as efficiently as it can is usually operating very close to as cleanly as it can.

Appendix A. GLOBAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Averaging period	Maximum concentration	Maximum allowable exceedances (goal)	Maximum concentration	Maximum allowable exceedances (goal)	Maximum concentration	Maximum allowable exceedances (goal)
		USA		EU		Canada	
Carbon monoxide	1 hour	40 mg/m^3	1 in a 12-month period				
	8 hours	10 mg/m^3	1 in a 12-month period	10 mg/m^3	n/a	10 mg/m^3	n/a
Nitrogen dioxide	1 hour	188 µg/m3	98th percentile of 1 hour daily maximum concentrations, averaged over 3 years	200 µg/m^3	18 per year	113 µg/m^3	The 3-year average of the annual 98th percentile of the daily maximum 1-hour average concentrations
	Annual	139 µg/m3	Annual mean	40 µg/m^3	None	31 µg/m^3	The average over a single calendar year of all 1-hour average concentrations
PM$_{10}$	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over three years	50 µg/m^3	35	50 µg/m^3	35
	1 year			40 µg/m^3	None	40 µg/m^3	None
Ozone	1 hours		1 in a 12-month period				
	4 hours	157 µg/m3					
	8 hours	137 µg/m3	Annual forth-highest daily maximum 8 hour concentration, averaged over 3 years	120 µg/m^3	25 days per year averaged over 3 years	121 µg/m^3	The 3-year average of the annual average of the daily maximum 8-hourr average concentrations
Sulphur dioxide	1 hour	524 µg/m3	1 in a 12-month period	350 µg/m^3	24 per year	183 µg/m^3	The average over a single calendar year of all 1-hour average concentrations
	1 hour	210 µg/m3	1 in a 12-month period				
	24 hours	52 µg/m3	None	125 µg/m^3	3 per year		
	Annual					13 µg/m^3	The average over a single calendar year of all 1-hour average concentrations
PM$_{2.5}$	24 hours	35 µg/m^3	Not to be exceeded more than once per year on average over three years	35 µg/m^3	Not to be exceeded more than once per year on average over three years	27 µg/m^3	The 3-year average of the annual average of the daily 24-hour average concentrations
	Annual	12 µg/m^3		12 µg/m^3		8.8 µg/m^3	The 3-year average of the annual average of the daily 24-hour average concentrations
Lead	1 year			0.5 µg/m^3	None	0.5 µg/m^3	None
	3 month rolling average	0.15 µg/m^3	None				
Arsenic	1 year			6 ng/m^3	None		
Cadmium	1 year			5 ng/m^3	None		
Nickel	1 year			20 ng/m^3	None		
Benzo(a)pyrene	1 year			1 ng/m^3	None		

Appendix B. LITERATURE REVIEW

Introduction

Documentation has been reviewed from around the world to help identify where NZ sits in terms of our comparative emissions standards, and what fuels other countries are combusting. The bulk of this review has been restricted to regions with similar (or better) requirements to NZ.

The sections below briefly outline the findings, with more specific information being able to be found in the sources referenced in Appendix D.

Australia

Australia developed the National Environmental Protection Measure for Ambient Air Quality (Air NEPM) in 1998, which identified 7 key air pollutants to the environment: carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter (PM_{10} and $PM_{2.5}$) and sulphur dioxide. The Australia Air NEPM has very similar exposure limits as New Zealand, with the exceptions of sulphur dioxide being twice the New Zealand annual limit, a $PM_{2.5}$ limit, and a lead exposure limit.

Australia relies on individual states to determine how burning is controlled and the regulations required to protect the environment. For example, in New South Wales Protection of the Environment Operations (Control of Burning) Regulation 2000 outlines the obligations one has when burning within the state. Most importantly is the general obligation to prevent or minimise air pollution, and prohibition of burning certain articles. Prohibited articles within the New South Wales state include tyres, coated wire, paint containers and residues, solvent containers and residues, and timber treated with CCA or PCP. It is also stated that local government areas specified in Part 1 of Schedule 1 are not allowed to burn anything unless with prior approval, Part 2 of Schedule 1 are not allowed to burn any vegetation unless given prior approval, and local government areas specified in Part 3 of Schedule 1 are not allowed to burn anything other than vegetation without prior approval.

Canada

The Canadian Ambient Air Quality Standards (CAAQS) identified four key air pollutants to the environment: PM2.5, ozone, sulphur dioxide, and nitrogen oxide. The maximum concentration of these pollutants is similar to the New Zealand regulations. However, it should be noted maximum concentration for carbon monoxide and PM10 are recommended objectives.

Following hydroelectricity, biomass is currently Canada’s second largest course of renewable energy. The main sources of biomass for Canada include forestry, agriculture, food-processing residues, and industrial wastes. The paper industry is the largest consumer of biomass in Canada, as well as forest industries which burn wood waste to provide energy for lumber drying (W. H. Cruickshank, 2022).

European Union

Directive 2008/50/EC on Aimbient Air Quality and Cleaner Air for Europe sets reduction commitments for the following air pollutants within the European Union- sulphur dioxide, nitrogen oxides, carbon monoxide, ozone, benzene, lead, and particulate matter (PM10/PM2.5). These limits are all below the corresponding pollutant’s maximum concentration allowed in New Zealand.

Herbaceous biomass as fuel as an alternative to fossil fuels is often used within the EU. For example, A biomass target of 1 million tonne of straw was set to be used for Denmark's energy annually (Bentsen et al., 2016). There are other countries within the EU who utilise agriculture waste and residue for fuel, as long as it not sourced from highly biodiverse forests (European Commission, 2022).

Sweden permits the incineration of physically and chemically contaminated waste wood in municipal incineration plants. Sweden's incinerators typically operate around 1000 °C, allowing for possible pollutants to be broken down in the high temperature. Despite introduction of waste incineration in Sweden, SOx and NOx have decreased by 94.2% and 38.2% respectively and heavy metal emissions have reduced by over 90%. A contributing factor to Sweden's decline in emissions is their flue gas cleaning after incineration. Control methods used in waste-to-energy systems in Sweden include electrostatic precipitator, scrubbers, and catalytic converters or Selective Non-Catalytic Reduction (SNCR). Water from the scrubbers also undergoes cleaning treatment to remove heavy metals and other contaminants prior to draining (Avfall Sverige A, 2016).

USA

The USA has multiple power plants that utilise some of the difficult fuels outlined in this report. The USA restrictions allow for some prohibited fuels to be burned with specific permission. Some of these fuels burned include municipal waste, plant hulls or shells (such as pecan shells, rice or peanut hulls), urban wood waste, logging residue, and woody biomass. As of January 2022, there were a total of 163 power plants, with a total capacity of 5,851 MW (Biomass Magazine, 2022).

It is of note, however, that the USA national ambient air quality standards have a higher allowance for some pollutant's emitted into the environment compared to New Zealand. This is true for sulphur dioxide, with the USA allowing a maximum concentration of 524 µg/m^3 in a one hour averaging period, compared to New Zealand's concentration of 350 µg/m^3. The USA also allows for more PM_{10} to be emitted in a 24-hour averaging period, with 150 µg/m^3 permitted – three times as much as New Zealand's 50 µg/m^3.

Findings

In general, it was found that the above regions base their emissions regulations on the WHO standards, have similar emissions requirements to NZ and burn the same kind of fuels. However, where the regions differ is that more conversations are had around the burning of difficult fuels and the larger countries have incinerators to combust a wide range of contaminated fuels. These incinerators are typically very large and are used to generate steam to feed turbines for electricity generation.

Appendix C. MDF / LAMINATE COMBUSTION TEST RESULTS EXAMPLE

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1 INTRODUCTION

1.1 Summary of Results

The following table summarises the results for sampling at XXXXXXXXX

Table 1 Summary of Results

Analyte		Concentration (mg/m^3,dry, 0°C, 1 Atm, 12%CO_2)	Mass Emissions (g/hr)
Particulate	Filterable	150	61
	Condensable	53	23
	Total	200	85
Cyanide		1.1	0.38
Ammonia		3.0	1.2
Aldehydes and Ketones	Formaldehyde DNPH	0.40	0.11
	Formaldehyde NCASI	0.63	0.27
	Glutaraldehyde	2.5	0.73
	Acetaldehyde	<0.056	<0.016
	Propionaldehyde	<0.056	<0.016
	Total	15	4.3

Volatile Organic Compounds – no organic compounds were above the individual detection limit of the method used.

1.2 Purpose of Sampling

Sampling was performed to determine the concentration and mass emission of contaminants being released into the atmosphere. The process involves burning waste MDF and melamine from the production of kitchen cabinetry and bench tops.

1.3 Sampling Performed

On the 2nd and 3rd of August 2011 samples were collected from the incinerator discharge to determine the concentration and mass emission of the following analytes present in the gases released to the atmosphere. These are:

- Total Particulate ○ Filterable Particulate ○ Condensable Particulate

- Aldehydes ○ Formaldehyde ○ Glutaraldehyde ○ Acetaldehyde ○ Propionaldehyde
- Cyanide
- Volatile Organic Compounds (VOC)
- Ammonia

Other parameters measured were:

- Carbon dioxide (CO_2)
- Oxide of Nitrogen (NO_x)
- Stack temperature
- Stack gas flow
- Stack gas moisture

K2 Environmental is accredited for the following methods used in this report:

- Determination of Total Suspended Particulate (USEPA[2] Method 5)
- Determination of Condensable Particulate (USEPA Method 202)
- Determination of Ammonia Emissions (USEPA CTM 027)
- Determination of Cyanide (USEPA Method 029)
- Determination of Total Aldehydes (USEPA Method 11)
- Determination of Formaldehyde (NCASI[3] CI/WP – 98.01)
- Determination of Volatile Organic Compounds (BS:EN[4] 13649:2002)
- Combustion Gases (USEPA Method 10, 3, 7e and 3a)
- Sampling Location (USEPA Method 1)
- Measurement of Velocity (USEPA Method 2)
- Molecular Weight (USEPA Method 3)

Moisture was determined by using the wet/dry bulb humidity method.

1.4 PM_{10} Sampling

It was stated in the proposal that PM_{10} sampling was to be carried out. The diameter of the stack is 200mm and it is difficult to install a 4 inch port. A 4 inch port is required to sample PM_{10}. Condensable sampling was carried out and generally the particle size is less than 1µm in size

2 SAMPLING DETAIL

2.1 Incinerator Details

Process Description

XXXX manufacture kitchen bench tops and cabinetry. They use a melamine laminate which is set onto particle board. When sanding or cutting takes place any sawdust/shavings are extracted from the factory into a storage bin. A baghouse is used to capture the saw dust.

---

[2] USEPA: United States Environmental Protection Agency

[3] NCASI: National Council for Air and Stream Improvement

[4] BS:EN: British European Standard

The sawdust and melamine are used as a fuel in the incinerator and the heat produced from the incinerator is used to heat the water in the under floor heating system.

2.2 Sample Point Information

Location and description

The sampling position is located approximately 7.5 stack diameters downstream from a flow disturbance and approximately 15 stack diameters upstream from a flow disturbance.

0.20 meter diameter circular duct.

Sample Date and Times

Sample	Date	Start	Finish
Particulate	2 Aug 2011	12:12	13:12
Ammonia		13:43	14:43
Cyanide		15:20	16:20
Aldehydes	3 Aug 2011	09:50	11:00
Formaldehyde		11:43	12:43
VOC Sample 1		10:29	10:39
VOC Sample 2		10:55	11:15

Sample Point Requirements

USEPA 1a requires 1 point on 1 traverse (a total of 1 point). Sampling complied with requirements.

Table 2 Sampling Information

Sample	Max Impinger Temp (°C)	Max Vacuum (kPa)	Leak Check Before		Leak Check After	
			(L/min)	Vacuum (kPa)	(L/min)	Vacuum (kPa)
Particulate	13.6	-10 -	<0.2	-35	<0.2	-30
Ammonia		5	<0.2	-30	<0.1	-20
Cyanide		-7	<0.2	-25	<0.2	-30
Aldehydes		0	<0.1	-10	<0.1	-10

3 RESULTS

3.1 Particulate

A brief description of the sampling procedures used during the programme is given in Appendix B. Results are shown in Tables 3 to 10. A copy of the calculation spreadsheet is included in Appendix C.

Table 3 Filterable Particulate Emissions

Sample	Filter Colour	Filter Weight (mg)	Concentration[5]	Concentration CO_2 Corrected[6]	Mass Emission (g/hr)
1	Grey	38	63	140	62
2[7]	Brown	33	54	140	55
3[8]	Grey	41	65	180	66
Average			**61**	**150**	**61**

Table 4 Total Particulate Results

Particulate	Concentration[4]	Concentration CO_2 Corrected[5]	Mass Emission (g/hr)
Filterable	63	140	62
Condensable	23	53	23
Total	86	200	85

A lab blank filter was run. This had a sample mass of 2.66 mg, if an average sample volume was used this would correspond to a concentration of 9.9 mg/m^3, dry, 0°C, 1 Atm.

3.2 Ammonia and Cyanide

Table 5 Ammonia and Cyanide Emissions

Sample	Concentration[8]	Concentration CO_2 Corrected[9]	Mass Emission (g/hr)
Ammonia	1.2	3.0	1.2
Cyanide	0.38	1.1	0.38

---

[5] mg/m^3, dry ,0°C, 1Atm

[6] mg/m^3, dry, 0 °C, 1 Atm, 12% CO_2

[7] Results taken from ammonia sample

[8] Results taken from cyanide sample

3.3 Aldehydes

Table 6 Total Aldehyde Emissions

Sample		Concentration[9]	Concentration CO_2 Corrected[10]	Mass Emission (g/hr)
Formaldehyde	**DNPH**	0.098	0.40	0.11
	NCASI	0.23	0.63	0.27
Glutaraldehyde		0.63	2.5	0.73
Acetaldehyde		<0.014	<0.056	<0.016
Propionaldehyde		<0.014	<0.056	<0.016

A full aldehyde scan was done of the samples supplied. The results for acrolein are indicative only, as the acrolein is not stable and the reference method says it is not suitable for acrolein.

Table 7 Results from the full scan of Aldehydes and Ketones (Blank Corrected)

Sample	Concentration[11]	Concentration CO_2 Corrected[12]	Mass Emission (g/hr)
Acrolein	0.90	3.6	1.0
Acetone	0.11	0.46	0.13
Crotonaldehyde	0.20	0.80	0.23
Buteraldehyde	<0.013	<0.056	<0.016
Benzaldehyde	0.21	0.86	0.25
Cyclohexanone	0.17	0.70	0.20
Isovaleraldehyde	0.19	0.77	0.22
Pentanal	<0.013	<0.056	<0.016

---

[9] mg/m^3, dry ,0°C, 1Atm

[10] mg/m^3, dry, 0 °C, 1 Atm, 12% CO_2

[11] mg/m^3, dry ,0°C, 1Atm

[12] mg/m^3, dry, 0 °C, 1 Atm, 12% CO_2

0-tolualdehyde	0.19	0.77	0.22
m-tolualdehyde	0.18	0.73	0.21
p-tolualdehyde	<0.013	<0.056	<0.016
Hexanal	<0.013	<0.056	<0.016
2,5- Dimethylbenzaldehyde	0.19	0.77	0.22
Heptanal	<0.013	<0.056	<0.016
Octanal	0.19	0.77	0.22
Nonanal	0.14	0.56	0.16
Decanal	0.20	0.81	0.23
Total Aldehydes[13]	**3.7**	**15**	**4.3**

---

[13] Includes formaldehyde and gluteraldehyde

3.4 Volatile Organic Compounds

Table 8 VOC Results (Sample 1)

Sample 1	Concentration[13]	Concentration CO_2 Corrected[14]	Mass Emissions (g/hr)
Ethanol	<23	<64	<24
Isopropyl Alcohol	<12	<32	<12
Acetone	<12	<32	<12
Pentane	<12	<32	<12
Dichloromethane	<12	<32	<12
Butan-2-one	<12	<32	<12
Hexane	<2.3	<6.4	<2.4
Ethyl acetate	<2.3	<6.4	<2.4
Chloroform	<2.3	<6.4	<2.4
1,1,1- trichloroethane	<2.3	<6.4	<2.4
n-Butanol	<12	<32	<12
Benzene	<2.3	<6.4	<2.4
2-methylhexane	<2.3	<6.4	<2.4
2,3-dimethylpentane	<2.3	<6.4	<2.4
Cyclohexane	<12	<32	<12
3-methylhexane	<2.3	<6.4	<2.4
heptane	<2.3	<6.4	<2.4
trichloroethene	<2.3	<6.4	<2.4
Propyl acetate	<2.3	<6.4	<2.4
methylcyclohexane	<2.3	<6.4	<2.4
4-methyl-2-pentanone	<2.3	<6.4	<2.4
octane	<2.3	<6.4	<2.4
tetrachloroethene	<2.3	<6.4	<2.4
butyl acetate	<2.3	<6.4	<2.4
ethylbenzene	<2.3	<6.4	<2.4
m+p-xylene	<2.3	<6.4	<2.4
stryene	<2.3	<6.4	<2.4
o-xylene	<2.3	<6.4	<2.4
nonane	<2.3	<6.4	<2.4
alpha-pinene	<2.3	<6.4	<2.4
propylbenzene	<2.3	<6.4	<2.4
1,3,5 - trimethylbenzene	<2.3	<6.4	<2.4

---

[14] mg/m

beta-pinene	<2.3	<6.4	<2.4
decane	<2.3	<6.4	<2.4
1,2,4 trimethylbenzene	<2.3	<6.4	<2.4
limonene	<2.3	<6.4	<2.4
undecane	<2.3	<6.4	<2.4
dodecane	<2.3	<6.4	<2.4
tetradecane	<2.3	<6.4	<2.4

13 mg/m3

Table 9 VOC Results (Sample 2)

Sample 2	Concentration[15]	Concentration CO_2 Corrected[15]	Mass Emissions (g/hr)
Ethanol	<11	<30	<11
Isopropyl Alcohol	<5.3	<15	<5.6
Acetone	<5.3	<15	<5.6
Pentane	<5.3	<15	<5.6
Dichloromethane	<5.3	<15	<5.6
Butan-2-one	<5.3	<15	<5.6
Hexane	<1.1	<3.0	<1.1
Ethyl acetate	<1.1	<3.0	<1.1
Chloroform	<1.1	<3.0	<1.1
1,1,1- trichloroethane	<1.1	<3.0	<1.1
n-Butanol	<5.3	<15	<5.6
Benzene	<1.1	<3.0	<1.1
2-methylhexane	<1.1	<3.0	<1.1
2,3-dimethylpentane	<1.1	<3.0	<1.1
Cyclohexane	<5.3	<15	<5.6
3-methylhexane	<1.1	<3.0	<1.1
heptane	<1.1	<3.0	<1.1
trichloroethene	<1.1	<3.0	<1.1
Propyl acetate	<1.1	<3.0	<1.1
methylcyclohexane	<1.1	<3.0	<1.1
4-methyl-2-pentanone	<1.1	<3.0	<1.1
octane	<1.1	<3.0	<1.1
tetrachloroethene	<1.1	<3.0	<1.1
butyl acetate	<1.1	<3.0	<1.1
ethylbenzene	<1.1	<3.0	<1.1
m+p-xylene	<1.1	<3.0	<1.1

---

[15] mg/m

stryene	<1.1	<3.0	<1.1
o-xylene	<1.1	<3.0	<1.1
nonane	<1.1	<3.0	<1.1
alpha-pinene	<1.1	<3.0	<1.1
propylbenzene	<1.1	<3.0	<1.1
1,3,5 - trimethylbenzene	<1.1	<3.0	<1.1
beta-pinene	<1.1	<3.0	<1.1
decane	<1.1	<3.0	<1.1
1,2,4 trimethylbenzene	<1.1	<3.0	<1.1
limonene	<1.1	<3.0	<1.1
undecane	<1.1	<3.0	<1.1
dodecane	<1.1	<3.0	<1.1
tetradecane	<1.1	<3.0	<1.1

15 mg/m$_3$

Table 10 Average VOC Results

Average	**Concentration**[17]	**Concentration CO$_2$ Corrected**[16]	**Mass Emissions (g/hr)**
Ethanol	<17	<47	<17
Isopropyl Alcohol	<8.4	<23	<8.7
Acetone	<8.4	<23	<8.7
Pentane	<8.4	<23	<8.7
Dichloromethane	<8.4	<23	<8.7
Butan-2-one	<8.4	<23	<8.7
Hexane	<1.7	<4.7	<1.8
Ethyl acetate	<1.7	<4.7	<1.8
Chloroform	<1.7	<4.7	<1.8
1,1,1- trichloroethane	<1.7	<4.7	<1.8
n-Butanol	<8.4	<23	<8.7
Benzene	<1.7	<4.7	<1.8
2-methylhexane	<1.7	<4.7	<1.8
2,3-dimethylpentane	<1.7	<4.7	<1.8
Cyclohexane	<8.4	<23	<8.7
3-methylhexane	<1.7	<4.7	<1.8

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[16] mg/m

heptane	<1.7	<4.7	<1.8
trichloroethene	<1.7	<4.7	<1.8
Propyl acetate	<1.7	<4.7	<1.8
methylcyclohexane	<1.7	<4.7	<1.8
4-methyl-2-pentanone	<1.7	<4.7	<1.8
octane	<1.7	<4.7	<1.8
tetrachloroethene	<1.7	<4.7	<1.8
butyl acetate	<1.7	<4.7	<1.8
ethylbenzene	<1.7	<4.7	<1.8
m+p-xylene	<1.7	<4.7	<1.8
stryene	<1.7	<4.7	<1.8
o-xylene	<1.7	<4.7	<1.8
nonane	<1.7	<4.7	<1.8
alpha-pinene	<1.7	<4.7	<1.8
propylbenzene	<1.7	<4.7	<1.8
1,3,5 - trimethylbenzene	<1.7	<4.7	<1.8
beta-pinene	<1.7	<4.7	<1.8
decane	<1.7	<4.7	<1.8
1,2,4 trimethylbenzene	<1.7	<4.7	<1.8
limonene	<1.7	<4.7	<1.8
undecane	<1.7	<4.7	<1.8
dodecane	<1.7	<4.7	<1.8
tetradecane	<1.7	<4.7	<1.8

17 mg/m3

3.5 Combustion Gases

Table 11 Combustion Gases on 2 August 2011

Gas	CO	NO	NO2	O_2	CO_2
	mg/m3			%	
Average	**160**	**400**	**21**	**17**	**3.7**
Maximum	350	490	27	18	5.7
Minimum	3.0	310	5.0	13	2.1

Table 12 Combustion Gases on 3 August 2011

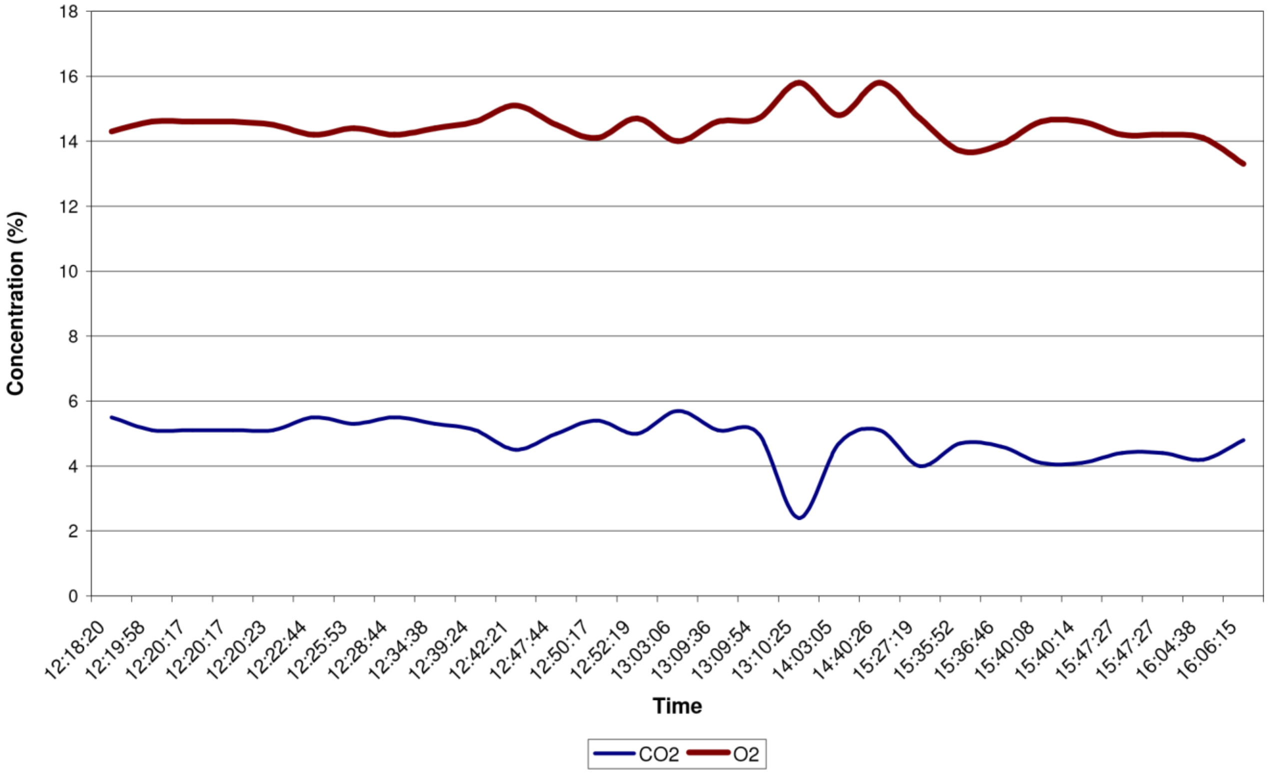
Gas	CO	NO	NO2	O_2	CO_2
	mg/m3			%	
Average	**200**	**290**	**21**	**18**	**3.2**
Maximum	350	340	27	18	3.7
Minimum	57	150	5.0	17	2.1

, dry ,0ºC, 1Atm

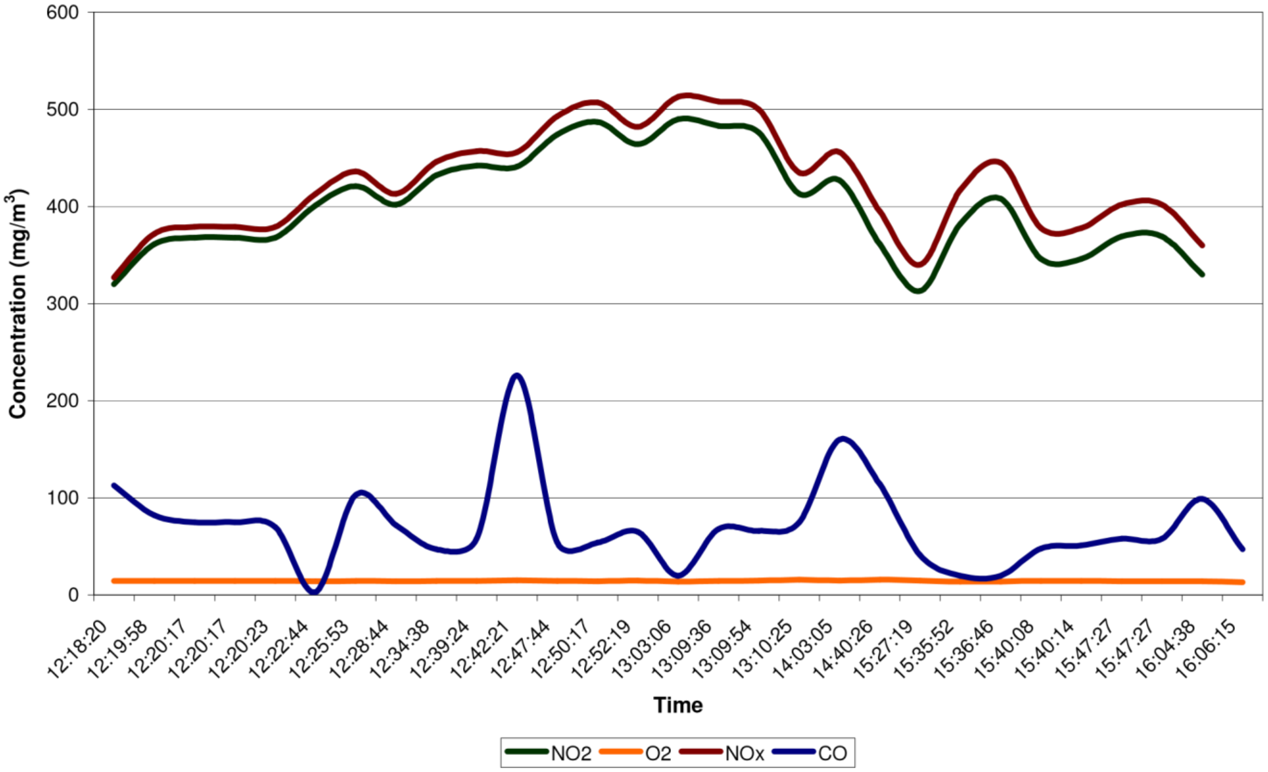
3

, dry, 0 °C, 1 Atm, 12% CO_2

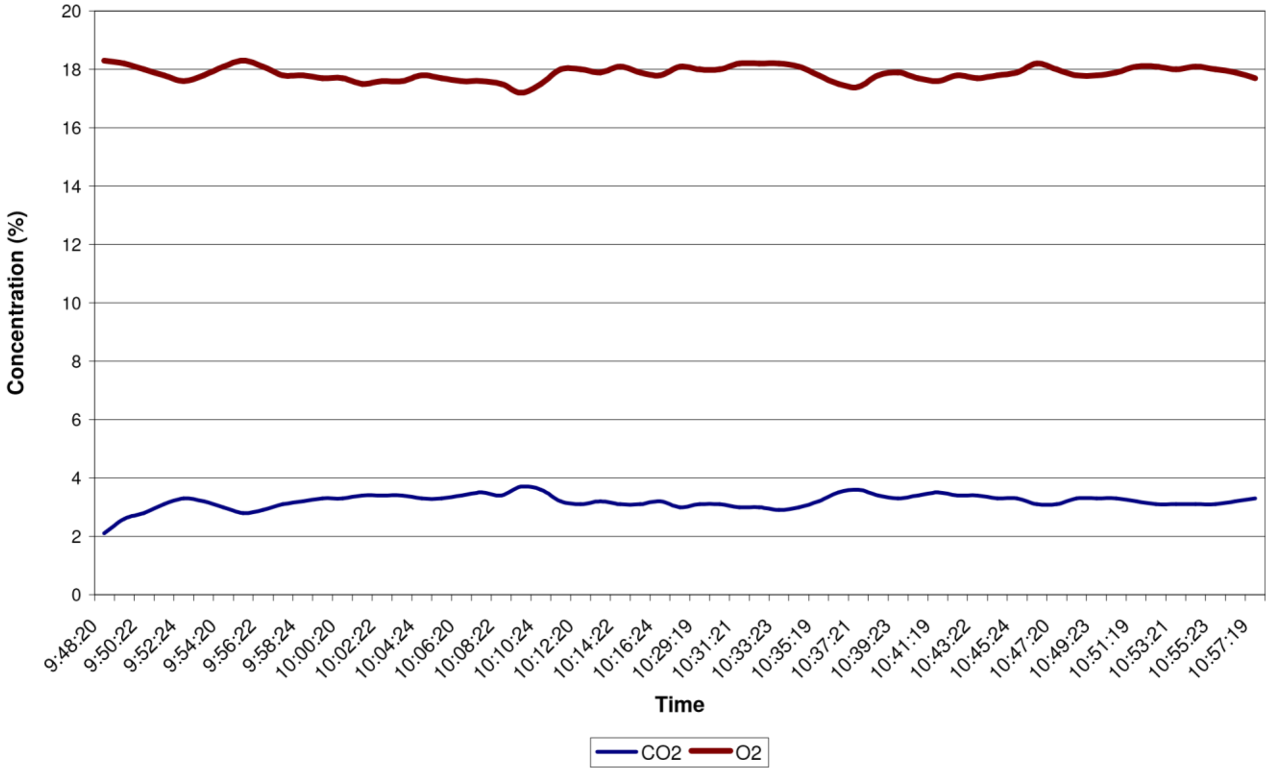
Graph 1 Combustion Gas Data 2 August 2011



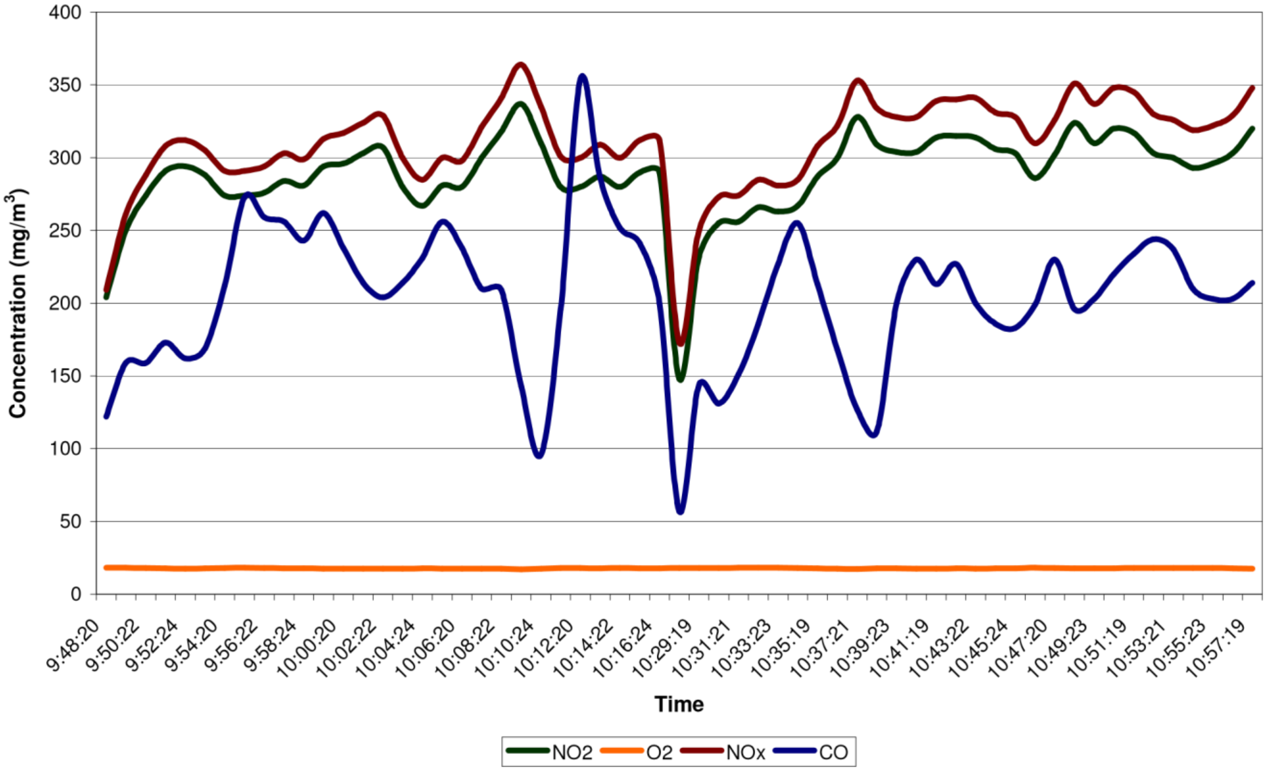
Graph 2 Combustion Gas Data 2 August 2011



Graph 3 Combustion Gas Data for 3 August 2011



Graph 4 Combustion Gas Data 3 August 2011



3.6 Gas Conditions

Table 13 Gas Conditions

Sample No.	CO_2		Temp (°C)	Moisture (%)	Velocity (m/s)	Isokinicity (%)	Flow Rate[17]
	%, wet	%, dry					
Particulate	4.8	5.3	150	9.0	15	98	0.27
Ammonia	4.5	4.7	150	4.5	15	96	0.29
Cyanide	3.9	4.3	150	8.8	15	98	0.28
Aldehyde	2.9	3.0	120	3.4	15	98	0.32
Average	**4.0**	**4.3**	**140**	**6.4**	**15**	**98**	**0.29**

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[17] m^3/s, 0°C, 1atm, dry

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