

Best practice guidance for biomass boiler operation



Detailed guidance for
operators, maintenance and
service personnel

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The Department for Business, Energy & Industrial Strategy (BEIS), previously the Department for Energy and Climate Change (DECC), commissioned Kiwa to study the in-situ performance of solid biomass boilers in the UK under contract 1055/08/2015. This guide has been written to advise owners and operators of biomass boilers on ways to improve the performance (in terms of efficiency and emissions) of existing biomass systems, based on the knowledge gathered during the study.

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1 Preface

This document is about the biomass boiler system part of heating systems. The operation and maintenance of biomass systems has a major impact on their performance, both in terms of efficiency and atmospheric emissions. This detailed guidance document is written for operators, maintenance and service personnel, primarily within non-domestic sectors. A parallel, simple guidance document for owners and users of biomass systems, primarily within the domestic or small commercial sectors is also available.

- **Owners** are responsible for providing accurate and relevant information about their biomass systems. Owners influence biomass boiler performance by ensuring that they employ people competent to perform work on the biomass system. The owner of the system is also responsible for the health and safety of those who operate and maintain the installation.
- **Operators** run and may maintain the installation on a day-to-day basis. Boiler operators have a major influence over efficiency and gaseous pollutant emissions. The difference between 'good' and 'poor' boiler performance is often influenced by the presence (or absence) of a 'boiler champion'.

The owner is often also the operator of the biomass boiler for smaller systems.

Plant designers, installers, building services engineers and those practising as biomass specialists, for example as importers of biomass systems will also find the content relevant.

This document can be kept with the boiler operating manual and the procedure for operating the heating system. Operational considerations for biomass systems that are important for owners, operators or those involved in maintenance are summarised in the following chapters. The performance and efficiency of a biomass boiler system partly depends on the operation and the demand of the heating system it serves. This document does not cover the heat distribution part of the heating system.

Before making changes or adjustments to biomass boilers or connected heating systems ensure that the consequences of any changes are well understood. Changes made without full understanding of the operation of biomass systems may cause damage to both the boiler and connected heating system and can potentially lead to unsafe situations occurring within the boiler itself. Ensure that any changes made to the boiler do not go against the manufacturer's instructions.

2 Introduction

As a response to climate change and increasing fuel costs, the development of biomass systems in the UK continues to expand, supported by measures such as the Renewable Heat Incentive and the Renewables Obligation. The rapid development of this industry has had a positive global environmental impact by reducing fossil CO₂ emissions from heating systems. However, increasingly, there are concerns over local environmental impacts due to atmospheric emissions from biomass systems, which can adversely affect local air quality and human health.

Concerns have been raised over emissions of **particulates** (also called smoke or dust) and **oxides of nitrogen** (also called NO_x). Smoke contributes to the concentrations of PM₁₀ (particulate matter smaller than 10 microns in size) and NO_x contributes to concentrations of nitrogen dioxide (NO₂) in the air. Both of these pollutants have adverse effects on human health and are regulated by law. The concerns over PM₁₀ and NO₂ concentrations are greatest in areas where atmospheric pollutant concentrations are already high due to emissions from other sources, for example in large cities or in areas close to major roads where transport emissions are already affecting local air quality.

It is well known that the operating practices for biomass boilers have a strong impact on performance in terms of efficiency and emissions. Good operational practice will maximise boiler efficiency and minimise pollutant emissions. Operational practice influences component and plant life and how often maintenance interventions are needed.

In 2015, DECC¹ commissioned Kiwa to carry out a **field trial of biomass installations**, where performance (in terms of efficiency and emissions) was measured remotely. A wide range of biomass boilers from domestic to commercial scale were fitted with instruments and data was gathered over a period of a year (March 2016 to April 2017). This work was supplemented with laboratory and field testing of installed biomass boilers. The programme demonstrated that there was a **large spread of performance**, with some boilers operating very well, whilst others were operating at low efficiencies. Analysis of the reasons for these 'good' and 'bad' performers showed that operational factors were very important and that improvements at poor sites were possible, often at very low or zero cost. Interventions were made at selected sites and performance was then monitored for a further year (May 2017 to June 2018). This guidance document distils the lessons learned from the field trials and presents solutions to some of the operational problems commonly encountered.

The most effective biomass systems we observed were the result of a **close working partnership** between client, architect, mechanical and building services engineer where all aspects of design, management and operation were carefully considered and integrated, with an emphasis on **good operating practice**.

Biomass systems are subject to the same general health and safety principles, codes of practice, and design, installation and operation standards that apply to gas or oil-fired boiler systems. However, there are differences in the way that the boiler plant can respond to changes in demand for heat. As a result, different operational strategies are needed for biomass boilers compared with oil or gas boilers.

2.1 Conventions

This guide uses the following conventions when referring to:

Biomass system

A heating or combined heat and power (CHP)

system, using a boiler fired with biomass, including components such as the fuel storage and chimney.

Biomass fuel

Solid biofuel in the form of wood pellets, wood chips, logs, or plant material grown for fuel (e.g. miscanthus or short rotation coppice).

Fuel store

A bunker or containerised storage, below or above ground for the storage of biofuel.

Load Factor

The percentage of heat provided by the biomass boiler compared to the maximum amount of heat that could be provided

Accumulator

A water-storage tank which is integrated into the heating system. It collects and stores heat energy to allow its flexible use at all times and to smooth out daily demand profiles.

2.2 The biomass system

Burning wood for heat and cooking was largely replaced by the use of fossil fuels in the 19th and 20th centuries in the UK. In the past fifteen to twenty years, purpose-built biomass systems with equivalent functions to industrial sized gas or oil-fired plants have become real alternatives. This development has been driven by environmental motives and market incentives, following a trend already established for more than 25 years in some European countries. The Renewable Heat Incentive launched by the UK government in 2011 has stimulated further expansion of biomass use in the UK.

A commercial scale biomass system typically comprises the following components:

- **Fuel storage** and an area for fuel delivery
- **Fuel feed system** (such as augers) to deliver the fuel to the fire
- **Boiler** usually including a grate to support the fire bed in a combustion chamber, a hot air ignitor to light the fuel, fans to supply the

¹ Department of Energy & Climate Change, which became Department for Business, Energy & Industrial Strategy (BEIS) in June 2016

combustion air, and a system to collect and remove the ash

- **System controls** to set the hot water temperature output, monitor the combustion conditions and control combustion through the fuel feed rate and the combustion air flow
- **Heat exchanger** to transfer heat from the fire bed and flue gases to the working heat transfer fluid (usually water)
- Chimney and flue **gas clean-up system** (including fans)
- **Boiler house** (incorporating the boiler, chimney, controls etc)

The **biomass boiler system** is linked to and controlled by a **heating system** or **heat distribution system**. This is a system of pipes which takes a flow of hot water from the biomass boiler system and returns cooler water to it, after heat has been extracted from it for uses such as space heating and hot water. It is best practice for the heat distribution system and boiler system to be designed together to match the heat demand to the capacity of the boiler. Room thermostats are one of the ways in which the heating system signals demand to the boiler system.

Biomass is grown from plants and trees, and is mainly made of the elements carbon, hydrogen and oxygen, with smaller quantities of other elements. At a high enough temperature, it burns in the presence of air by combining with some of the oxygen to give off the gases carbon dioxide and water vapour, and relatively small amounts of unburnt material as soot or smoke, NO_x and carbon monoxide. It leaves behind around 1% ash, which is made of trace elements and compounds which cannot burn.

2.3 Comparison with gas and oil-fired systems

Commercial and industrial-scale biomass systems are a more recent development in the UK compared to gas or oil heating installations. Therefore:

- The UK does not have detailed biomass standards built up over the years.

- Owners, designers and operators do not currently have the depth of knowledge and understanding compared to gas or oil-fired systems.
- The familiarity to people of using wood fuel in their homes may lead them to underestimate the safety hazards of operating large-scale biomass boilers, which are significant, as with oil or gas boilers.
- The poor operation of a biomass system is more likely to cause a visible smoke plume, and an emissions nuisance or impact, than a similar oil or gas system.




Gas-fired systems

Natural gas is not stored on-site but delivered through pipe and metering, for which detailed design codes exist. Gas quality is defined and maintained by law, whereas biomass fuel quality can vary significantly, especially the moisture content which can have a considerable influence on efficiency and emissions.

Carbon monoxide (CO) concentrations in the flue gas from natural gas boilers are generally very low (<50ppm) compared to those from solid biomass (which can be up to 10,000ppm or 1%). The amount of unburned fuel in a gas boiler is very low and the time that the fuel spends in the boiler is less than a second. This compares with a biomass boiler which may contain large quantities of unburned fuel and have fuel residence times of 20 minutes or more.

Oil-fired systems

Oil is stored on-site and having an energy density as much as ten times higher than biomass fuels it takes less space and oil can be readily pumped. Oil burners are sophisticated devices with little risk of uncontrolled combustion. Most heating oils conform to European or International Standards, and fuel quality is generally consistent. As with gas boilers, the amount of unburned fuel in the boiler is very low and the residence time of fuel in the boiler is less than a second.

	<p>Gas fired boilers</p> <ul style="list-style-type: none"> • Startup period: 30 seconds – 5 minutes • Fuel present in boiler: 1 second • Shutdown period: 1 second or less
	<p>Oil fired boilers</p> <ul style="list-style-type: none"> • Startup period: 30 seconds – 1 minute • Fuel present in boiler: 1 second • Shutdown period: 1 second or less
	<p>Biomass boilers</p> <ul style="list-style-type: none"> • Startup period: 10 – 20 minutes • Fuel present in boiler: 20 minutes • Shutdown period: 20 minutes

3 Aims and objectives

This guide aims to make owners and operators of biomass boilers aware of the impact of different operational regimes on efficiency and emissions. The guide will offer practical advice on how to operate a biomass boiler in ways that minimise pollutant emissions and maximise boiler efficiency. The overall aim of this guide is to promote good operational practice.

The guide's objectives are to:

- Provide information about the operation of various components of biomass systems
- Bring together, in one publication, operational considerations for biomass systems
- Provide a guidance document educating biomass operators on:
 - Definition of performance (financial, environmental, component life)
 - Symptoms of poor performance and ways to identify these problems
 - How to solve these problems

Outside the scope of this guide is:

- Detailed design information as might be contained within a Design and Installation Guide²
- Detailed information that would apply to all boilers regardless of fuel and might be regarded as 'standard' boiler or pressure systems as governed by the Pressure Systems

Safety Regulations 2000 (PSSR) or the Pressure Equipment Regulations 1999 (PER)

- Installations where any fuel is pulverised. The hazard of dust explosions presented by such systems requires special design and operating criteria

This guide concentrates on the specific issues associated with the operation and maintenance of biomass boiler systems and can form the basis of an operation improvement plan.

3.1 Overview of chapters

In Chapter 4, there is a description of ideal biomass boiler operation. This is intended to educate owners and operators on what should be expected from their systems.

The following chapters address four main themes which have major impacts on biomass performance. The four themes are:

1. **Load factor** and the impact of cycling on performance and plant life.
2. The impact of **controls** on biomass performance.
3. The effects of **fuel characteristics** on the performance of biomass.
4. How **maintenance** can impact biomass operation

The parallel guidance document for owners and users contains a diagnostic table that provides a useful summary of the detailed themes discussed in this document.

² For example: CIBSE AM15 Biomass Heating Design Guide

4 Operating principles of biomass systems

Every model of biomass boiler will have its own control regime, however this will broadly match the following cycle of four phases:

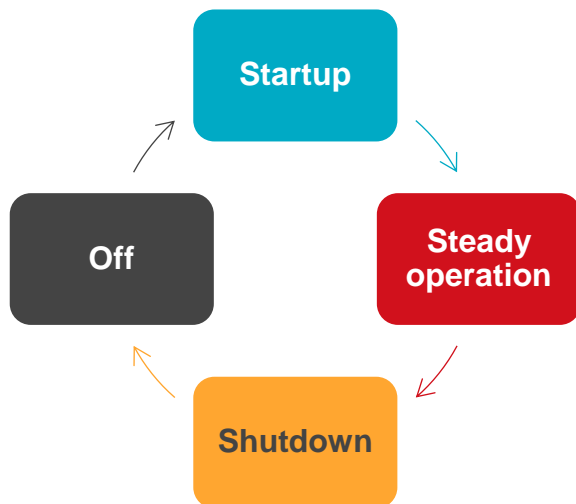


Figure 1: Four phases of boiler operation

The **startup sequence** is the period from when the boiler begins to ignite the fuel, to when combustion is established. This includes:

1. Delivery of a fixed amount of fuel to the combustion chamber.
2. Ignition of the fuel (typically using an electric hot air gun).
3. Addition of more fuel at a fixed rate until operation is stable.

The **steady operation** period includes the boiler warm-up time and then its continued operation with flue gas oxygen around 10%.

The **shutdown sequence** is from when the combustion in the boiler begins to stop, and flue gas oxygen levels rise. There is no significant combustion at the end of the period, however there may still be a fire bed which will slowly cool.

The **off period** is from the start of this cooldown period until the boiler fires again.

The field trial and laboratory testwork showed that boiler efficiency was highest, and pollutant emissions were lowest during long periods of steady state operation. Frequent switching on and

switching off of the boiler (on / off cycling) produced the worst emissions and lowest efficiencies. The work clearly showed that operating biomass boilers at close to maximum output for relatively long periods of time (several hours burn time) was the most cost-effective regime as well as the cleanest in terms of local emissions (NO_x and particulates) and greenhouse gas emissions (CO₂).

5 Load factor

Load factor is a useful way to understand the way in which a biomass boiler is working. It is somewhat similar to the annual mileage done by a car, which can suggest what mechanical problems and fuel efficiency you may expect. Biomass boilers are designed to run for extended periods, therefore they operate better at higher load factors. For this guidance, load factor is defined as the ratio of the amount of heat provided by the biomass boiler compared to the maximum amount of heat that could have been provided over a time period.

$$\text{Load factor (\%)} = \frac{\text{Total heat provided}}{\text{Maximum heat that could be provided}}$$

To calculate the amount of heat that could be produced, the **rated output or nominal heat output** of the boiler is used. This can be found on the data plate displayed on the outside of the boiler. Load factors are a useful indicator of boiler utilisation; however care must be taken in interpreting the load factor. For example, a 100% load factor indicates the boiler was running at its rated output for the entire period. A load factor of 50% means the boiler was either:

- running at its rated output for half the period and was off for the other half, or
- was running at 50% of its rated output for the entire period, or
- some combination of outputs and operating times

The load factor can be calculated on a daily, weekly, monthly, or annual basis. Use the following equation and table to work out the load factor. The equation assumes the rated output of the boiler is given in kW and the heat meter readings are in kWh (if they are in MWh then multiply them by 1,000 first).

$$\text{Load factor} = H * (B - A) / R$$

R = rated output of boiler in kW

A = initial heat meter reading in kWh

B = final heat meter reading in kWh

Daily (or any 24-hour period)	H = 4.17
Weekly	H = 0.595
Monthly	H = 0.139
Annual	H = 0.0114

5.1 Why is load factor important?

Load factor is a useful indicator of boiler performance. A low load factor is usually an indication that the boiler is too large for the load during that period. In the case of automatically fed boilers this could mean the boiler does not operate optimally as the load is too small to allow the boiler to reach its most efficient state of operation and remain at this state for a reasonable time.

In the UK, it has been found that biomass boilers tend to have very low load factors. The biomass boiler field trial on which this guidance is based has shown the average annual load factor of biomass boilers in the UK was around 14%. Average winter load factors were 24% with summer load factors at 7%.

Biomass installations in the UK are sized based on a target load factor. The target load factor used will differ greatly depending on the intended use of the boiler. Table 1 shows some common sizing scenarios.

The table shows that a single biomass boiler for space and water heating will have an annual load factor of less than 33%.

Table 1: Common sizing factors for biomass boilers

Use of boiler	System design	Design load factor
Space and water heating	One biomass boiler	Designed for coldest day in 20 years Annual load factor of 20 – 24% (>25% in winter, 10% in summer)
	Two or more biomass boilers feeding same system	Each boiler sized at 66% percent of the maximum load
	Biomass boiler as 'base load' for another boiler, such as oil or gas	Could not meet load requirement on coldest days, annual load factors significantly >25%
	Biomass boiler with solar thermal	Designed for coldest day in 20 years (>25% in winter, solar thermal in summer)
Process heating – poultry farming	One biomass boiler	Load factor varies depending on phase of poultry growing cycle
Process heating – drying	One biomass boiler	Biomass boiler is only enabled when process is operating. 100% load factor during this time

5.2 What are good load factors?

There is no load factor which will indicate good performance for all biomass boilers. As discussed in the introduction to this section, boiler load factors only form part of the larger picture of a biomass heating system. They do not provide information on run times or output. Some boilers can continue to operate with high performance down to low load factors as they modulate their output and limit cycling. Therefore, care should be taken when investigating load factor and further information should be considered, as well as boiler sizing.

The Tier 1 boundary in the Renewable Heat Incentive was set at a load factor of 15% (for non-domestic boilers less than 1 MW [1]). This is based on the expectation that every biomass system should be able to achieve an annual load factor of at least 15%. A load factor of less than

15% is an indication that the boiler has been oversized for the application.

Very low annual load factors (less than 10%) would suggest the boiler could suffer from issues due to its oversizing especially during warmer months when its load factor is at its lowest. These problems will be explored in the next section.

5.3 Problems caused by low load factors

When the load on a biomass boiler is low, it only needs to fire for a limited time to satisfy the heat demand placed upon it. This can lead to many short periods of firing, resulting in excessive cycling.

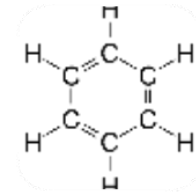
The results of the laboratory trials and testing of boilers in the field showed that boiler efficiency was highest during prolonged periods of operation at high output. During startup and shutdown, the boiler efficiency was significantly lower. This was due to high flue gas oxygen (i.e. high excess air) and high CO in the flue gas. There was also increased electrical consumption from boiler fans running at high speed.

Similarly, emissions of particulates were significantly worse during startup and shutdown periods compared with periods of steady operation. This is probably due to colder temperatures in the combustion chamber and poor mixing of air with the fuel. The field trial showed that the emissions produced from a boiler startup was roughly equivalent to one hour of steady state operation in a small boiler. Larger boilers have longer equivalent run times therefore it is even more important to ensure that larger boilers do not cycle on/off unnecessarily.

During normal operation, biomass boilers emit pollutants. The main pollutants are shown in Figure 2.



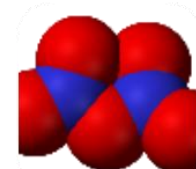
Particulate matter (also known as dust)



Hydrocarbons



Carbon Monoxide (CO)



Nitrogen oxides (also known as NOx)

Figure 2: The main pollutant emissions from biomass

For schemes such as the RHI, there are performance requirements in the form of limits on these emissions. These limits refer to the emissions during normal operation, however, during boiler startup and shutdown, the emissions of particulates, hydrocarbons and carbon monoxide can be much higher. A modern boiler set up correctly with the right specification of fuel should emit no visible smoke during normal operation.

How to identify if emissions could be higher than necessary

If smoke is visible during normal operation it is likely that the boiler has very high emissions, and the boiler operation and its fuel should be investigated and changed so that no smoke is visible.

If the boiler is starting up more frequently than it should, it is likely to be that air pollutant emissions are significantly worse than during normal operation. The boiler control panel may show historic information on the number of startups each day.

When there is no visible smoke emission, it is possible that emissions of carbon monoxide or NOx are still high.

Visible tar deposits in the combustion chamber and flue ways might indicate a problem with hydrocarbon emissions.

Low efficiencies

Each time a boiler undergoes a startup procedure, any flue gases present in the combustion chamber are purged by blowing air through the boiler, often cooling the boiler down and blowing hot air up and out of the flue. The control system will then put fuel into the boiler and ignite it in the air flow. If the demand on the boiler is met by the startup procedure alone the boiler will never operate in steady state, and components will not have enough time to come to operating temperature for optimal combustion and heat transfer. This can have the effect of simultaneously decreasing efficiency and increasing emissions.

How to identify low efficiencies

Monitor the behaviour of your boiler. If the boiler never enters a state of steady operation and goes straight from ignition to burnout it will probably be operating with low efficiencies. If operation is characterised by frequent cycles of short duration this is an indication of low efficiencies.

Low efficiencies mean that the boiler is using too much fuel. Monitor fuel use - create a fuel use log. Dividing heat generation by the units of fuel used will help to identify periods of increased fuel consumption.

Unburned fuel in the ash

Each boiler cycle will produce a small amount of unburned fuel in the ash. This is normal and the amount will depend on the boiler technology, the fuel, the burner and the grate. However, if the boiler is cycling frequently, more unburned fuel will accumulate in the ash container which indicates that there is a problem with cycling.

How to identify unburned fuel

Inspect the ash that is removed from the boiler. Unburned fuel will appear as black charred or unburned pieces of wood pellet or wood chip that are possibly broken.

Wood log boilers do not cycle as they are loaded manually before they operate. Unburnt fuel is therefore an indication of other issues occurring within the boiler.

Other issues

Frequent cycling caused by low load factors will place increased stress on internal boiler components such as refractory linings as well as other components such as fuel feed and ignition systems as they are subjected to more frequent temperature cycles.

Some boilers have self-cleaning features that are used to keep boiler tubes clean. These features normally operate once every cycle, so if the boiler is cycling excessively this will cause these features to operate more often than is necessary and could lead to premature failure.

Identifying other issues

If you notice that the boiler is using more electricity than normal, it may be an indication of damage to boiler components such as fans, augers, pumps, and automatic ignitors. If these components are also failing prematurely or more often, you may have problems caused by low load factors that require additional or more frequent maintenance.

5.4 How to solve problems relating to low load factor

Although a boiler may be oversized for the load it has to supply, it is not normally economically feasible in the short term to replace it with one with a smaller output. However, it may be possible to increase the load so that it is better matched to the boiler. This could be achieved by supplying heat to additional buildings, or by reducing the use of supplementary heating. If adding new loads to the heating circuit is not possible, increasing the size of the accumulator is another way of achieving the same result.

The other way to increase the load factor is to reduce the total time over which the boiler can operate, by turning the boiler off during periods where there is no demand. The most effective action that an operator can take is to examine the boiler operating regime and check whether it is suitable for the period that heat is required. For example, if a boiler is set up to operate continuously but the load it is supplying is to an office space, it is likely that there will only be a demand between office hours. Outside of this time the boiler will only be used to maintain the temperature in an accumulator. In this case the

operator should consider switching to a unimodal regime (only switching on, and meeting demand to cover the office day).

Similarly, if the boiler is used to heat a domestic dwelling where occupants are not present during the day, the operator should consider moving to a bimodal operating regime (switching on for an early morning and evening period, and meeting demand during those periods).

The above principle also applies in summer when the boiler may only be needed to meet hot water demand which is normally substantially less than the space heating demand. The operator should consider switching the boiler off during summer and using point of use electric or solar heating to meet the hot water demand.

If a unimodal or bimodal heating pattern is required, the time clock on the boiler should be used to ensure that the boiler does not run for the period when the heating is not needed (usually overnight). The user should not rely on the room thermostat alone to control the whole system because although the space heating will not be calling for heat, the boiler is still on and able to fire. Any heat produced during this period will be wasted as it will be used to maintain the accumulator temperature.

If there are multiple boilers installed feeding the same circuit, one or more boilers could be turned off in summer.

6 Controls

The control of biomass boilers is complex and considerably more involved than the control of a gas or oil-fired heating system. This is partly due to the interaction between the biomass boiler which reacts slowly and the rest of the heating system which responds far more quickly.

Different manufacturers use different levels of sophistication when designing the control systems for their biomass boilers. This often depends on the type, size, and complexity of the installation. However, all biomass systems, at the most basic level must maintain combustion in a safe and efficient manner.

This chapter considers control parameters which directly affect the performance of the boiler. This section is aimed at providing advice to enable the

operator to get the best performance from the existing system by using the control parameters that are available to them.

6.1 How good controls are used to optimise performance

The control of biomass boilers has been split into two areas:

Controls which can be adjusted by the operator

These controls are expected to be altered by the user during normal operation of the system. This allows the boiler control to be changed to match heating requirements. These include using time clocks to set the times when the boiler is available to operate, selecting the maximum flow temperatures, setting the minimum temperature in the system.

Controls which cannot be adjusted by the operator

Manufacturers, installers, and service engineers usually set these controls. They vary in complexity depending on the boiler and are parameters vital to the safe operation of the system. These parameters include air fan rates, fuel feed rates and internal cleaning mechanisms as well as variables used to control ignition, run mode and burnout periods. This chapter includes discussion of the problems which can occur if these controls are set incorrectly, but they should only be adjusted by competent people.

Having good control of a biomass boiler will optimise its performance. Even simple changes to control parameters can have a significant impact on boiler performance so it is important to understand how to use controls effectively.

Good controls will ensure that the boiler is able to startup and shutdown in a safe and timely manner. They ensure the air supply rate and the fuel feed rate are matched and sufficient to complete combustion of all fuel within the boiler and achieve the desired oxygen concentration in the flue gas.

Good control will also ensure that the boiler only runs when there is a requirement for heat, the length of burn periods is maximised and unnecessary starts are avoided, which leads to

higher efficiency. Finally, good controls will ensure that the boiler does not operate in a way that is damaging to it, maximising its operational lifetime.

6.2 Problems arising from poor control and their impact

High excess air

The system must supply enough air to the fuel to ensure complete combustion, but not so much that energy is wasted by blowing large amounts of hot air up the chimney. In an ideal scenario, the quantity of air supplied would be the exact amount required to completely burn the fuel. In practice, **excess air** must be supplied to prevent large amounts of CO and smoke from being produced.

However, the amount of excess air should be minimised, otherwise the boiler is just heating up air which it then sends out of the chimney – which represents one of the main heat losses from the boiler. Typically, biomass boilers are operated with around 10% oxygen in the flue gas. If the oxygen concentration is higher than 10%, the boiler is operating with **high excess air**. This will result in lower efficiency and possibly greater carry-over of fine ash material up the chimney.

High excess air is caused by the wrong fuel-to-air ratio in the boiler. Many boilers can adjust the air rate and fuel rate independently depending on the phase of operation. Some boilers will adjust the air rate and fuel feed rate during operation to reach a target oxygen set point in the flue gas.

How to identify high excess air

Check your boiler flue gas oxygen when it is operating at full output. If the oxygen concentration in the flue gas is greater than about 10% then the excess air level is likely to be too high.

You may be able to use the boiler control panel to read the boiler's own oxygen sensor (if it has one), however bear in mind that without maintenance these can report incorrect values.

If there is no oxygen sensor readout on the boiler, the best alternative is to purchase an inexpensive handheld gas analyser to measure the oxygen concentration from a sample port just after the flue exits the boiler.

Incomplete combustion

Conversely if the boiler is supplied with too little air it can lead to **incomplete combustion** where some of the fuel passes through the boiler without being burned. This will have a negative impact on performance and pollutant emissions.

Incomplete combustion is also caused by the incorrect control of fuel-to-air ratio in the boiler.

How to identify incomplete combustion

Check the flue gas for visible smoke. **During normal operation, there should be no visible smoke from biomass boilers.** If you have a handheld gas analyser then you can also use this to measure the CO in the flue gas. Check this against the manufacturer's specification.

Check the ash removed from the boiler for any unburned fuel. There should be minimal charred fuel and no unburned pieces of fuel.

If you identify signs of incomplete combustion but the excess air level is correctly set then this may indicate other issues such as problems with the fuel (see Chapter 7) or a maintenance issue with the boiler grate (see Chapter 8).

Cycling

The nature of biomass boiler operation ensures that biomass boilers go through cycles. All biomass boilers have a startup, run period, shutdown and off period. When a biomass boiler completes all four phases it has completed one cycle.

Boilers should maximise the duration of their burn periods to maximise performance. This is because **startups and shutdowns are by far the least efficient and most polluting periods of biomass operation**

There are two types of cycling identified by this guide, excessive cycling, and unnecessary cycling:

- **Excessive cycling** problems occur when the boiler completes cycles quickly i.e. the boiler completes many cycles in a short period of time. Excessive cycling adversely impacts the efficiency of the boiler as it leads to more time spent in startup and shutdown mode where the boiler is not burning efficiently.

- **Unnecessary cycling** occurs when the heat produced is not utilised. Boilers by the way they operate will cycle however cycles should be limited as much as reasonably practicable.

Excessive cycling is not only bad for boiler performance but also results in the premature failure of boiler components as internal components such as refractory lining and flue gas passageways are subjected to more frequent temperature cycling. Additionally, fans, valves and pumps are required to operate more often, and as the lifetime of these components is often measured in terms of starts and stops, cycling can reduce the lifetime of these parts too.

The graph in Figure 3 shows an example of excessive cycling, as seen at a site from the field trial. The boiler turns on and off regularly with very little time spent at the “on” state.

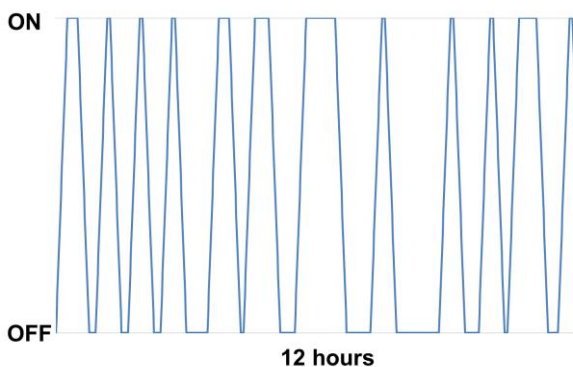


Figure 3: Excessive cycling: the boiler spends very little time in run mode, but there are many startups and shutdowns

How to identify boiler cycling

For smaller biomass boilers it may be possible to monitor the boiler for a period during which there is heat demand. It is important to remember that biomass systems are not like conventional heating technologies and take much longer to react. Please refer to section 4 for a description of each phase of biomass boiler operation. This should enable you to identify the startup, burn period and shutdown phases.

For larger boilers, it may be impossible to identify each phase through observation alone. If a simple electrical load measuring device with a historic logging and graphing function is fitted to the fan circuit of the boiler it should allow the user to identify each phase of the boiler operation. A period of high electrical consumption followed by a lower period, followed by a higher period represents the boiler going through a startup, steady operation and shutdown phase.

If you notice that the boiler goes through several starts without a period of continuous burn of reasonable duration (1 hour plus for small to medium boilers) then you may have a problem with excessive boiler cycling. Larger boilers (300 kW and up) are a special case as they take longer to startup and shutdown and therefore the length of a reasonable burn period is increased.

Unnecessary cycling can be identified easily, especially if you know when heat is required from the boiler. Boilers should not remain activated if there is no requirement for the heat i.e. the boiler should not be left activated overnight when the heating is off. Even cycles hours apart are wasteful if the heat provided is unnecessary.

As cycle time includes the off period between burns it is important to take the off period into account when identifying burn periods. Some of the worst examples of cycling behaviour occur when the boiler immediately turns back on after a short period of time.

High flow and return temperatures

Biomass boilers are often installed to replace a conventional oil or gas fired appliance. The heating system may therefore have been designed to operate with temperatures and

controls to which the biomass boiler is not perfectly aligned. In some cases, the heating system water flow and return temperatures used by biomass are similar to temperatures used by the old boiler.

Setting boiler water temperatures higher than is required can lead to high internal and flue gas temperatures. The temperature limit for biomass boilers is similar to gas and oil boilers in that it is not advisable to exceed 100°C in the heating water. Limit stats are usually set between 90°C - 95°C. Using flow temperatures near the limit may help the boiler to fire for longer however it will lead to premature degradation of the boiler. It may also cause the boiler to overheat and go into emergency shutdown. Boiler overheating is more likely to occur with biomass due to the amount of energy that remains in the fuel bed when the boiler shuts down. Gas and oil boilers can turn off quickly as there is only a small amount of fuel present in the boiler at any time.

High flow and return temperatures will also increase the likelihood of boiler cycling as there is not much temperature difference between the limit stat, flow temperature and return temperature.

How to identify high flow temperature

The best way to do this is to identify the temperature that you require in your heating system. Once you have done this you should set the maximum flow temperature from the boiler accordingly so that when the flow reaches your heating system it is at the temperature you require. If your boiler is performing frequent unscheduled shutdowns, it may be that your flow set point is too high.

Avoidable heat losses

A common problem with biomass boilers is heat losses associated with boiler operation when the heat is not required.

The best way to prevent unnecessary heat losses is the effective use of time clocks. The use of time clocks to limit operation of heating systems when buildings are unoccupied is not a new concept. Biomass is no different from fossil fuelled heating systems in that its operation should be time limited so that the boiler does not supply heat

when it is not required. Limiting the operational hours of the boiler is often vital to getting the best out of biomass.

In the UK biomass boilers are frequently installed and set up to keep an accumulator vessel at temperature. Keeping large volumes of water hot can increase losses if the heat is not being used and cycling can occur especially during periods of very low loads. Time clocks can be used to ensure that accumulators are not kept at temperature when heat is not required. Biomass systems take time to react to changes in demand, so the boiler should begin heating the accumulator tank a few hours before the heat is required and turn off a few hours before the heating is turned off. This will increase the performance efficiency of the boiler by maximising the burn periods and reducing heat losses.

Ancillary equipment can increase losses through poor control. If pumps circulate water around heating systems when not required or valves stay open allowing heat to dissipate, there will be increased losses.

We have considered high temperatures in terms of maintenance and cycling. Heat losses are another factor to consider when choosing system temperatures. The higher the temperature of a system the greater the heat losses will be and therefore should be taken into account when setting flow temperatures.

How to identify avoidable heat losses

To identify avoidable heat losses, you should identify periods where the heat from the biomass boiler is required. As a general rule, if the boiler is activated outside this period, for example when the building is unoccupied you will have avoidable heat losses. Investigating ancillary equipment is also a simple way to identify heat losses. Investigate pumps from the accumulator vessel to the system as they may continue to run when heating is not required. Investigate automated valves to check that they close correctly. Think about the temperature of your system and if it is required. Supplying 80°C water if you only need 50°C will increase unnecessary losses.

6.3 How to solve control issues

If you have identified control issues affecting performance there should be changes you can

make to boiler operation which will improve performance. Control can be time-consuming to get right due to the complexity and number of settings available for adjustment. If you have problems understanding the settings to change you can receive support from your service engineer or installer. It is important that you become confident adjusting control settings to get the best performance out of your biomass boiler. It is also important to remember that some controls should only be adjusted by people competent to do so. These controls usually require passwords to enter the required settings menu. An example of this is settings which directly affect combustion within the boiler.

Solving incomplete/inefficient combustion

If you have issues with incomplete or inefficient combustion the solution will require a competent person to adjust combustion settings on the boiler for you. They will be able to advise you on what is required to improve performance, however they may need to recommission the boiler to ensure that it operates correctly. It is important to be aware that the energy losses that lead to a reduction in system efficiency are much greater in the flue gas than in the unburned fuel within the ash (20% and higher from flue gas and 1-2% from unburnt fuel). One way to reduce the unburned material in the boiler would be to increase the air supply to the combustion chamber. This should be done with caution as once the air flow rate exceeds the level required for complete combustion the addition of further air will only increase the losses in the flue gas.

Solving problems of avoidable heat losses

Once you have identified avoidable heat losses solving the problem may often just need a change in controls. Ensuring the boiler is off when not required is one of the simplest and most effective changes you can make. Most boilers have an inbuilt time clock which can easily be adjusted. An external time clock can also be used with most boiler models and is easily installed.

Loss from ancillary equipment is a more complicated problem to solve and may need a small amount of investment. Using time clocks to activate pumps is also an effective method of

limiting losses around a system. If you have identified high system losses due to high temperatures in the heat distribution network, lower the boiler water flow temperature setting - this will determine the maximum temperature of your system.

Solving high flow temperatures

Most commercial boiler systems will operate with a flow temperature of about 70 to 80°C. If the flow temperature is higher than this then you should consider reducing this. This temperature should be a few degrees higher than the upper set point you require in your system or your accumulator tank.

Solving boiler cycling

Many biomass boilers have accumulator vessels which enable the installation to store heat and provide separation between the time of the heat demands of the building and the time the boiler generates heat. The biomass boiler normally maintains the accumulator vessel temperature between a maximum and a minimum set point. This can be done as simply as by just setting the heating water flow and return temperature set points on the boiler. Some boilers monitor the accumulator temperature and even manage the hydraulics to and from the accumulator. There are many variations in the controls used with accumulator vessels which can make adjusting controls time-consuming to do effectively. Nevertheless, they all follow the same concept and understanding the function of the accumulator will allow you to improve the control of your biomass boiler.

As stated previously, accumulators are a store of heat energy. When heating is required energy is drawn from the accumulator and the average accumulator temperature falls. Eventually the temperature in the accumulator reaches the lower set point which activates the boiler to replenish the energy store. One of the key success factors when using an accumulator is the ability to store enough energy to make an impact on boiler operation. Ideally, the accumulator will be large enough to store several hours' of heat production from the boiler. This is not always practical as there are often space restrictions on site. To maximise the heat which can be stored,

temperature set points should be chosen to ensure the largest amount of energy is drawn off before the boiler activates. Having the greatest difference between the maximum and minimum temperatures in the accumulator will achieve this. The maximum and minimum set points should fit the design temperature limits of the heating circuit.

Some installations are configured to maintain the accumulator at a high, very tightly controlled temperature. The water delivered from the accumulator to the heating system may then be blended with return water to lower the temperature to the radiators. In these situations, the user should consider lowering the accumulator lower set point by 1 or 2°C. This will cause a small drop in the average water temperature within the accumulator but the lower return temperature will allow the boiler to fire for longer and potentially cycle less.

7 How fuel affects performance

Biomass combustion is a complex process and is strongly dependent on the type and quality of fuel burned. Your biomass boiler will have been specifically designed to burn a particular type and grade of fuel cleanly and efficiently and this will have been specified by the manufacturer.

If you use it with a fuel that deviates from this specification, it may result in reduced efficiency and increased emissions. The moisture content of the fuel can also have a detrimental effect on boiler performance if it deviates from the range specified for the boiler.

The use of poor quality fuel causes more problems with biomass systems than any other single factor.

This chapter concerns wood pellet, wood chip and wood log fuels only, other types of biomass fuels are not included as they are more specialised and usually found in larger commercial and industrial applications.

7.1 What is good fuel?

There is no single fuel specification that will ensure the best performance from every biomass

appliance. Good fuel for a biomass boiler can be defined as the fuel recommended by the manufacturer for that boiler. As a minimum, the manufacturer should specify the type of fuel and acceptable range of calorific value and moisture content.

Virgin wood

It is very likely that your boiler has been designed to burn only virgin wood. This means wood that has not been treated in any way other than by heat or pressure.

Even a small amount of contamination in virgin wood fuel can reduce efficiency and increase emissions. These emissions can potentially be hazardous to health and people in the local area. Things to avoid include:

- Any 'second hand' or reclaimed wood, even if marketed as 'clean' or 'Grade A'. If you do not know the source of the wood then it may invalidate your fuel requirements if you are claiming the RHI
- Wood coated with paint or treated with preservative (fence posts, etc.)
- Wood containing glues or resins
- Wood containing metal (including fixings, such as staples or nails) or stones. These may damage your boiler
- Wood containing increased fines (fine material - such as from added sawdust). This can lead to poor air distribution in the combustion chamber and increased emissions

The Industrial Emissions Directive (IED, formerly the Waste Incineration Directive), enforced in the UK through the Environmental Permitting Regulations requires that you obtain an environmental permit from either your local authority or the Environment Agency (or equivalent devolved body) if you burn contaminated or treated wood, unless you can demonstrate you are eligible for an exemption. An RHI emissions certificate by itself is not sufficient to demonstrate compliance with the IED.

Good wood pellet fuel

Wood pellet fuel is typically produced from sawmill residues such as sawdust or other wastes from wood products manufacturing. The moisture in wood pellets is generally lower than other wood fuels. The supply of wood pellets in the UK is well controlled as the production of wood pellets requires specialised equipment.

In the UK, wood pellet fuel at domestic scale is usually purchased in 10-20kg bags. Fuel quality information, including calorific value, moisture content and percentage of fines, is usually easily obtainable through the supplier or is printed on the bags.

There is a quality certification scheme in the UK run by the UK pellet council who manage the ENplus mark for pellet fuels. Buying pellet fuels with ENplus A1 quality certification should ensure that the fuel is the right quality of pellet.

Good wood chip fuel

Wood chip fuel is produced from virgin forest material or from sawmill residues or other wastes from manufacturing wood products. Wood chip has a much more variable moisture content than pellet fuels due to the variable sources from which it is produced. There are different types of feedstocks available for the production of wood chip, including:

- Forestry material
 - Log chips: from delimbed stem wood
 - Whole tree chips: from all the above-ground biomass of a tree
 - Logging residue chips: from branches, brash, etc.
 - Stump chips: from stumps
 - Short rotation coppice/forestry chips: from energy crops
- Untreated waste wood
 - Wood residue chips: from untreated wood residues, recycled wood, and off-cuts
 - Sawing residue chips: from sawmill residues

In the UK, the supply of wood chip is less well controlled than for wood pellet fuel. Currently in the UK there is no quality certification scheme for

wood chip suppliers, however this does not mean high quality wood chip fuel is not available.

Whether fuel is self-produced or purchased from a supplier, wood chip should be solely produced from virgin material with as little forest residue (leaves and small branches) as possible. Inclusions from the forestry floor such as dirt and stones should also be kept to a minimum.

Good wood log fuel

Wood log fuel is produced from forest material and is typically split logs or tree limbs. Moisture content can vary depending on whether the logs have been seasoned or kiln dried. Seasoned logs should have been stored for between two and three years, depending on storage conditions.

Logs used as biomass should not be green wood (recently felled) unless the boiler has been specifically designed and set up to handle its high moisture content.

Only virgin material is appropriate as fuel for log boilers. Other fuels (including wooden pallets, even if clean) may cause problems with maintenance, as they can cause high flue gas temperatures and high levels of pollutants which will reduce the operating life of the boiler.

7.2 Problems arising from using poor fuel in biomass boilers

The following section describes the main problems that can occur when using poor fuel in a biomass boiler. These problems tend to affect three principal areas: efficiency, emissions and maintenance but can often affect all three simultaneously. The severity of their impact ranges from serious (which can cause a boiler to malfunction) to less serious (which can still subtly degrade performance).

Formation of clinker

Clinker can occur in all biomass systems, but the problem is **exacerbated when using poor fuels**. The presence of clinker affects the efficiency, emissions and maintenance of biomass boilers. Clinker is formed by the fusion of ash into an **extremely hard, glassy material** and in biomass systems these can build up to form large deposits.

Clinker forms when temperatures exceed the ash fusion temperature which, for good biomass fuels, is typically above 1,200°C. The use of poor fuel increases the formation of clinker in two ways:

- Firstly, a poor quality fuel may contain minerals that fuse at a lower temperature. This effectively lowers fusion temperatures
- Secondly, as the ash content of the fuel increases so does the rate of clinker formation. The temperatures required for ash fusion ensure that clinker formation occurs in areas of the fuel bed which are at the highest temperatures

Clinker affects efficiency and emissions by interrupting the flow of air through the fuel bed. This causes poor air distribution and areas of the fuel bed where incomplete combustion begins to occur. Incomplete combustion increases CO and VOC production which not only lowers the efficiency of the boiler but also increases pollutant emissions. The poor air distribution in the bed can also cause hot spots where further clinker formation occurs.

The performance can be reduced to the point where a fire can no longer be sustained in the combustion chamber and the boiler is forced to shutdown until the clinker is removed.

Clinker also affects the maintenance of biomass boilers and can **cause significant damage** to boiler components. The clinker material formed through ash fusion is very hard and can damage to surfaces which it adheres to. Maintenance issues occur when trying to remove this material from the boiler. Automatic de-ashing mechanisms such as auger screws and refractory materials inside boilers can be damaged when ash build-ups containing clinker are removed.

Identifying clinker formation

Periodically inspect the ash that is removed from your boiler during normal operation. The ash should be fine and of a uniform consistency. If you find hard, glassy objects within the ash, then it is possible you have a problem with clinker formation. Ash with small amounts of clinker will have a gritty consistency.



Fully fused bulk

Partly fused bulk

Figure 4 Fused ash deposit, "clinker"

Boilers should be inspected for clinker during maintenance and cleaning of the boiler internals, flue gas passages and fuel feed mechanisms.

Incorrect moisture content

Using a fuel with **too high or too low** a moisture content can cause problems with the combustion of the fuel, impacting both the efficiency and emissions from the boiler.

Very low moisture content can cause high flue gas temperatures in the boiler, increasing the losses in the flue gas and reducing the efficiency. In some cases, it can cause the boiler to overheat and shutdown.

High moisture content fuels can cause the boiler to struggle to keep at operating temperature, which leads to incomplete combustion in the fuel bed and unburnt fuel in the ash, reducing efficiency.

Identifying problems with moisture content

If the efficiency of your boiler is lower than expected, it may be that the fuel you are using has qualities which lie outside the range for which the boiler has been designed and commissioned.

Periodic inspection of the ash removed from the boiler during normal operation may reveal the presence of unburned fuel which could indicate that the fuel is of too high a moisture content.

Periodically inspecting the fuel entering the boiler will also allow you to detect issues with moisture content. Pellet fuels have very consistent moisture contents and are easily identified as they expand when wet. High moisture in wood chip and logs is more difficult to identify, however by regularly checking the consistency of the fuel entering your boiler, you allow for any potential issues to be addressed before they cause problems.

There is also evidence to suggest that the moisture content of fuels affects particulate emissions. Using fuels at moisture levels higher or lower than the boiler was designed for will produce an increase in particulate emissions from the boiler.

Non-virgin fuel

Using non-virgin fuels such as recycled waste wood will reduce boiler performance. The **efficiency may not be noticeably different** when using recycled fuels compared to virgin wood fuels as the combustion efficiency is similar. However, it is likely that fuels from recycled materials (even from clean sources) will have a **detrimental impact on the pollutant emissions**.

Even small changes to the fuel supplied to a biomass boiler can lead to immediate changes in pollutant emissions. This is particularly apparent for particulate emissions but also the case for NO_x emissions. Using recycled pellet fuel in laboratory trials increased the emissions of particulates by around 4 times and NO_x by around 20%, when compared with the equivalent virgin pellets.

The emission limits set by the RHI scheme would likely be **breached by most boilers** if there was a

fourfold increase in particulates. This change is subtle and would be unlikely to be noticed by an operator of a biomass system as there would be **no visual indication of poor performance**.

Identifying if you have a problem with non-virgin material

You should perform a visual inspection of your fuel to ensure that it does not contain waste material including:

- Wood coated with paint
- Wood treated with preservative (including fence posts, etc.)
- Wood containing glues or resins
- Wood containing metal (including fixings, such as staples or nails) or stones

Examination of the ash deposits removed from the combustion chamber may identify if non-combustible material has found its way into your fuel supply (see Figure 5).

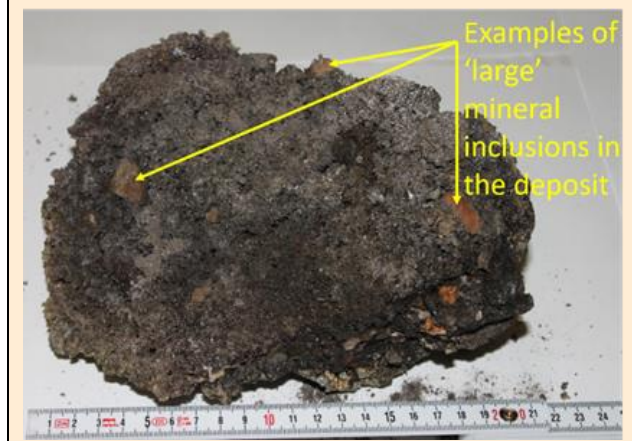


Figure 5: Evidence of contaminated fuel

Larger changes in fuel such as burning waste wood materials will have much larger impacts on performance. There can be very high pollutant emissions, including emissions of heavy metals and other contaminants which are hazardous to health. Waste wood materials have very low moisture contents and burn at very high temperatures which can cause damage to the internals of boilers, leading to maintenance issues.

7.3 How to solve poor fuel issues

The best way to avoid the problems caused by poor fuel quality is to use the fuel that meets the boiler design specification.

Avoid non-virgin material

Check fuel deliveries to ensure there is no non-virgin material. If you find any, speak to your supplier, if you are a self-supplier, check your production methods.

Use only fuel that is designed for your boiler. Information on this can usually be found in manufacturer's documentation on the boiler. They may for example list the range of calorific value, moisture content, fines content, pellet size, etc. which are required for the boiler to perform as designed.

For boilers using wood pellet

If you are receiving poor wood pellet fuel it is relatively easy to change supplier to ensure that you are getting the fuel quality that you need. This is true for both bagged and pneumatic pellet deliveries. It is not recommended that you use recycled pellet fuels as they have been found to produce higher levels of particulates and NO_x in biomass systems.

Consider using a supplier that is registered with the ENplus scheme, an internationally recognised quality certification scheme covering the entire wood pellet supply chain. More information on the scheme is available at www.enplus-pellets.eu.

For boilers using wood chip

Given the natural variability of wood chip, it may not always be possible to use the exact specification of fuel that the boiler was designed and commissioned with, however you should use fuel that meets the specification as closely as possible.

If it looks like you will only be able to source out-of-specification fuel for some time, it may be worth having your boiler re-commissioned to enable it to run as efficiently and cleanly as possible using the out-of-specification fuel.

If you self-supply wood chip, ensure that you only use virgin material chipped from wood logs not

small branches and other forestry material. Increasing the amount of material that is not from virgin logs can increase the ash content of the fuel and reduce ash fusion temperatures causing problems with clinker formation.

Ensure that your fuel is stored correctly

It is important to ensure that once you take delivery of your fuel it is stored in a correct and safe manner. Incorrect storage can not only lead to the degradation of the fuel and the associated problems listed above, but can also have health and safety implications.

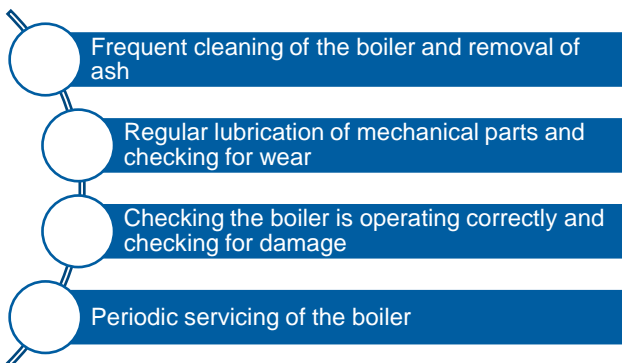
Fuel should always be stored in an appropriately sized, dry, well ventilated environment. For wood logs that are undergoing seasoning, ensure that they are covered and stacked in such a way so that cross ventilation can occur through the stack.

For further information please refer to the [Health and safety in biomass systems – Design and operation guide](#), published by the Combustion Engineering Association.

8 Maintenance

8.1 Introduction

The maintenance required by a biomass boiler is greater and more involved than that of an equivalent gas or oil boiler. By 'maintenance' we mean:



Whereas for a gas or oil boiler, an annual service and the occasional inspection of the boiler may be sufficient, a biomass boiler generally requires greater intervention.

The above maintenance activities should be performed at different time intervals and each require a different skill level, so training of personnel may be required.

Failure to maintain biomass boilers may lead to unexpected downtimes, expensive repairs, use of backup systems, and loss of RHI revenue.

8.2 What is good maintenance

To ensure maintenance is carried out regularly and any issues are raised early-on, it is strongly recommended that you have a maintenance plan for your boiler. If you do not already have one, you should discuss the maintenance schedule with your installer or service company. They may have a template you can use. Even if they provide you with a template, be aware this should be *your* document. You should make changes to it on an ongoing basis (for example, by adding extra tasks if it becomes apparent that this helps the boiler operate smoothly).

A high-level maintenance plan is shown below in Table 2. This gives an idea of activities that should be performed, their frequency and the skill level required. An example of a more detailed maintenance schedule is provided in Appendix 1.

Be aware this is purely a generic schedule and your boiler may need a different set of activities.

A good maintenance plan is written down and kept near to the boiler. There should be a place to record observations during the maintenance activities and a way of raising these as issues with appropriate personnel or the service company. A history of previous maintenance should be kept near the boiler.

Table 2: Example of a high-level maintenance schedule

Frequency of activity	Description of activity	Skill-level required
Weekly	Cleaning of the boiler and removal of ash	Basic training in cleaning operation
Monthly	Regular lubrication of mechanical parts and checking for wear	Experience with mechanical parts and safe operation
Monthly	Checking the boiler is operating correctly and checking for damage	Knowledge of how to identify issue with: <ul style="list-style-type: none"> • Boiler operation • Boiler safety issues
Yearly	Periodic servicing of the boiler	Service provider

8.3 Problems which can arise due to poor maintenance

If a maintenance schedule is not followed or is not comprehensive enough, many problems may potentially occur. Small problems picked up during maintenance may be an indication of more important underlying issues. For example, a noisy boiler ash removal system may be caused by damage to the ash removal system which may be caused by clinker in the ash. Ash fusion caused by the wrong air to fuel ratio in the boiler could indicate a problem with the lambda probe.

A regular maintenance schedule should pick up the initial stages of a problem, before it can develop and have further impact on the boiler. This guide identifies 5 maintenance areas of particular importance in biomass operation.

Ineffective cleaning

If a boiler is not cleaned thoroughly or often enough, dust can build up inside the boiler and inside flue gas pathways. This can then become entrained in the flue gas and result in higher than normal emissions. This problem will be exacerbated if cyclones and filters are not cleaned regularly and then cease to remove particulate matter effectively. Dust entering the boiler through the fuel feed can also cause maintenance issues.

Unburned material and pieces of clinker that are not removed from the combustion chamber and surrounding walls can interfere with the air distribution, leading to a reduction in efficiency and increase in emissions. This problem will be compounded if air inlets become blocked through a build-up of debris.

If pieces of unburnt fuel and clinker find their way into the ash removal system this could cause mechanical problems, particularly with augers as part of automated systems. Similarly, a failure to correctly lubricate and check for wear could lead to otherwise preventable damage to augers and fuel delivery systems.

Identifying problems caused by ineffective cleaning or servicing

A visual inspection of the boiler is the best way to identify problems with cleaning or servicing. If the boiler has automatic cleaning mechanisms, running them manually through the control panel is an effective way of checking their performance. Listen for unusual noises or vibrations when the boiler performs any mechanical operation such as running augers.

Plant rooms should be clear and free from clutter, particularly in the area surrounding the boiler. If there is fuel dust around the feed system it could indicate a problem with the fuel delivery system or the fuel itself. Dust in fuel stores should be removed before it builds up to levels where it can enter the boiler.

Periodic inspection of the ash removed from the boiler during normal operation may also reveal the presence of unburned fuel or clinker, which may indicate poor cleaning or poor air distribution. If you find clinker in the ash you should do a thorough check of the inside of the boiler for build ups of material on refractory surfaces or combustion chamber walls. Also check air inlets within the boiler for blockages.

A visual inspection of the flue gases leaving the boiler can be used to help identify problems. Visible smoke, or a "characteristic wood smoke smell", particularly during steady burning, may indicate that the boiler internals require cleaning or that cyclones or filters have become blocked. Higher than normal flue gas temperatures are also an indication that boiler tubes may have a build-up of deposits which reduce heat transfer.

Unrepaired or unnoticed damage to biomass boilers

It is important to check all parts of the boiler thoroughly for signs of wear and tear or damage because if left untreated this may worsen over time and lead to a catastrophic failure which is likely to be expensive to rectify.

Damage to the grate and refractory material surrounding the combustion chamber could be an indication of other problems (for example clinker

formation). Damage caused by normal wear and tear should be routinely repaired as it may lead to overheating or sudden failure of the refractory material.

Leaking water should be treated very seriously and the location of the leak identified as soon as possible. Leaks from inside the boiler heat exchanger or from the flow and return pipework could lead to overheating which can cause major damage to biomass boilers.

Damage to flue pipes and components within a flue (draught diverters, fans, inspection hatches etc) may lead to escape of flue gases with the risk of carbon monoxide leaks into the plant room. Wet flue gas can corrode boilers which will be very expensive to repair so the back ends of boilers should be checked for any excessive build-up of moisture in the flue.

If a boiler fails to ignite, or only partially ignites due to a damaged ignitor gun or damaged air inlets there is the risk that carbon monoxide or other flammable gases could build up inside the boiler case. This then presents the risk of carbon monoxide poisoning and also the risk of explosion should the flammable gases become suddenly exposed to an ignition source.

Should pumps or valves fail due to a lack of maintenance the heat distribution system may not be able to remove the heat quickly enough from the boiler, which may lead to overheating or boiling. This will have a negative impact on performance and emissions. If valves become stuck, it may mean that a boiler system cannot meet a space heating or hot water demand, or possibly is unable to switch between the two.

How to identify problems of unrepaired damage

Ideally the operator will notice damage to the boiler components before the problem leads to a larger failure. This should be picked up in the maintenance process.

Grate and refractory materials inside the boiler should be checked for damage regularly.

For evidence of water leakage, the operator should check the floor area around the boiler for wet patches or corrosion on pipework around the boiler. Water on the floor may also be an indication of pressure relief valves activating due to boiler overheating.

For evidence of gas leaks, the operator should examine the boiler for damage caused by hot flue gases coming in to contact with areas of the boiler that should not be exposed to hot gases. This might be revealed by areas of damaged, or discoloured paint or metal.

The emission of more smoke than usual may be evidence of ignition problems. The boiler should not be used until any ignition problem is investigated and rectified as the boiler is unsafe for use if it is unable to ignite correctly.

Pump or valve failures are usually noticed quickly, as the boiler will not be able to operate due to overheating etc. Other system components that have failed may go unnoticed for long periods if the heat demand is still satisfied, however these failed components may cause drops in performance and should therefore the boiler system should be checked regularly.

Failure of safety features

Biomass boilers have a range of safety features to ensure that unsafe situations do not arise. Should these features fail due to a lack of maintenance there may potentially be very serious consequences. Maintenance of safety features should therefore be a priority.

Fuel delivery systems are usually designed to ensure that there is never an uninterrupted passage between the fuel on the fire bed in the combustion chamber and the fuel store, to prevent the spread of fire back to the store. If this cannot

be achieved then the boiler may feature a sprinkler system to douse the fire should a high temperature be detected in the fuel delivery mechanism upstream from the boiler. If these systems fail there is a risk of fire spreading from the combustion chamber to the fuel store, a phenomenon known as “burn back”.

Biomass boilers have features to minimise the risk of carbon monoxide build up during normal operation. If these are malfunctioning or not correctly configured it could lead to the build-up of unsafe concentrations of carbon monoxide in and around the boiler. Boiler rooms should feature a carbon monoxide alarm to detect unsafe concentrations in the air, however if these are not working it will not alert people to unsafe situations.

Biomass boilers are designed to stop firing when the water flow temperature exceeds a certain limit often called the “limit stat”. Should the boiler exceed this temperature it will shutdown to protect itself. The boiler may require maintenance work to reset it after the boiler exceeds this temperature. If this safety feature fails there is a risk of damage to the internal boiler components, firstly with the material surrounding the combustion chamber and potentially with the boiler casing, . heat exchangers and flue gas passage ways as well.

How to identify failures of safety features

Ensure that the burn back protection is serviced at regular intervals and that if it uses water, the water works independently of the boiler.

There should be housekeeping procedures for the boiler house to ensure it is kept tidy and free of flammable material.

The carbon monoxide alarm in your boiler house should immediately alert you to the presence of unsafe levels caused by a leaking or non-functioning flue. Additionally, the carbon monoxide alarm may have an “history” function that can reveal any historic instances of high carbon monoxide levels that occur during unattended periods.

Ensure that the limit stat is connected and is serviced at regular intervals to ensure it will operate correctly when required.

Lack of operator training

It is important that boiler operators have clear instructions on what activities they must carry out and what controls they should and shouldn't alter (see maintenance schedule). Full training should be provided so that they are confident in changing the controls they are supposed to and do not adjust ones they shouldn't.

Identifying a lack of operator training

Incomplete or incorrectly completed maintenance schedules may indicate that an operator requires more training.

Incorrect air supply/ fuel ratios

Good maintenance of biomass boilers will maximise their operational lifetime however components will begin to deteriorate over time. This is not usually a problem as they can be repaired and replaced however this is not always practicable.

Over time, the air to fuel ratio in the boiler can drift due to fans not being as effective, or oxygen and temperature sensors becoming less accurate. This causes problems with control of air and fuel rates which could either result in too much oxygen being supplied to the boiler which has the result of lowering efficiency or too little oxygen supplied to the boiler which can lead to incomplete combustion. High levels of CO and tar due to incomplete combustion can lead to damage of the boiler internals, or to an increase of particulate emissions and damage to flues.

Identification of air supply/ fuel ratios

Visible smoke and/or strange smells in the flue gases can be an indication of a problem with boiler controls as already mentioned. High flue gas temperatures may also indicate high air ratios

For a boiler working well during steady operation, oxygen should be around 10%. If the oxygen level is much above or below this boiler control adjustment may be necessary. For monitoring oxygen levels, it may be worthwhile purchasing a handheld flue gas measurement device which will give you an indication of oxygen and flue temperature.

8.4 How to solve problems caused by poor maintenance

As already mentioned, a maintenance plan and schedule are essential as is operator training. If you own a biomass boiler it is your responsibility to ensure the operator is trained on how to operate and maintain the boiler. Be proactive about repairs and fix problems as they arise and not allow them to deteriorate.

Performing maintenance on a boiler often requires the boiler to be off. Remember that service engineers do not witness the boiler running at temperature and problems that occur after a period of steady operation may not be visible when starting from cold.

In general biomass boiler operators should observe their boiler for a period of time and see if its behaviour changes over the long-term. A good maintenance log will allow subtle changes that happen gradually to become noticeable.

If it is not possible for the owner or operator to monitor the boiler on a day to day basis then (potentially untrained) staff who work near the boiler could be asked to keep a log of any obvious issues or observations.

Keeping a log of the quantity of fuel burnt per kWh heat metered in a spreadsheet will give a useful indicator of how efficiently the boiler is burning. Although this not as accurate as a standardised efficiency measurement, a sudden increase in fuel consumption for the same heat output could indicate a problem with the boiler. Fuel delivery records can be consulted to determine fuel usage.

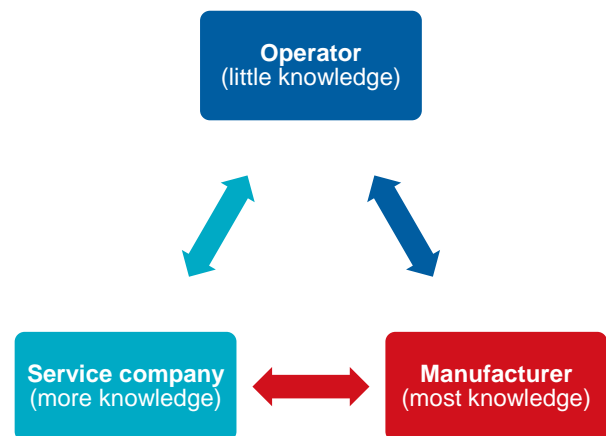
The boiler information panel may contain additional information that may help the user to solve problems these include:

- Number of auger turns – can be used with auger volume per turn to calculate fuel delivery rate
- Startup counter from boiler to find starts/day – can be used to identify cycling
- Monitor the number of faults per week and see if it changes

One of the factors which affects the performance of biomass boilers is the knowledge of the operator and owner about maintenance. If the operator has good knowledge about their boiler

and proactively look after it, they normally have fewer maintenance issues. There are more likely to be issues with installations where the operator does not have much knowledge about the system and is not proactive in looking after it.

In the UK, the situation with an operator with poor knowledge and only reactive maintenance is much more common and the expert is not the person who spends most of their time with the boiler, rather the service engineer who visits infrequently. The manufacturer knows most about the boiler, but often they are only involved during commissioning or if there is a serious problem with the boiler:



Best practice is to have operators trained to ensure that boiler maintenance is carried according to the manufacturer's recommendations and that issues (especially which may relate to safety) are recognised and corrective action is taken. The boiler manufacturer's maintenance recommendations should be supplemented by the maintenance requirements of the fuel and ash handling systems, and those of the heat distribution system.

Boiler maintenance duties should be carried out according to the schedule, if necessary by different staff. **Do not assume that an annual service will cover all required maintenance activities.**

9 Glossary

Auger – a screw in a pipe which conveys solid material

Boiler grate – metal grille or plate on which the burning fuel sits

Burnout – is when a bed of fuel burns completely and the fire goes out

Calorific value – the energy content of a fuel, normally in KJ/kg

Carbon monoxide (CO) – a toxic gas formed from incomplete combustion

Clinker – hard, glassy material formed when ash is exposed to very high temperatures

Combustion chamber – the space inside a boiler where the fire sits

Firebed – the collection (bed) of fuel which is burning in the combustion chamber

Flow (and return) – the flow of heated water leaving the boiler to go round the heat distribution circuit. The return is the cooled water returning to the boiler

Flue gas – hot gas carrying the combustion by-products to atmosphere and made up of nitrogen, oxygen, carbon dioxide, water vapour, with

smaller quantities of carbon monoxide, nitrogen oxides and particulate matter

Hydraulics – the behaviour of the flow of water in the heat distribution circuit

Lambda probe – probe measuring oxygen/carbon dioxide ratio in the flue gas, as a measure of the completeness of combustion

Load factor – the heat generated by a boiler, divided by its nominal plate rating, multiplied by a time factor

Limit stat – 'stat' is an abbreviation of 'thermostat'. A limit thermostat is a heating water temperature measurement control, which controls the boiler around a temperature setting. For example, a high limit stat will switch the boiler off when the set limit in the heating water is exceeded

Organic Gaseous Carbon (OGC) – also referred to as volatile organic carbon (VOC), this is the collection of carbon compounds given off during combustion; quantities are affected by the combustion conditions

Refractory – solid blocks of insulating mineral material lining the boiler which can withstand very high temperatures

Appendix 1: Detailed maintenance schedule

This appendix is provided as an example of a maintenance schedule. Its intention is to highlight the maintenance activities which should be undertaken so that deficiencies can be identified. This maintenance schedule **MUST NOT** be used as a substitute for **the maintenance schedule produced by the biomass boiler manufacturer** as not maintaining the boiler with the correct interval between maintenance activities **may damage the biomass boiler and connected systems**. Activities listed below may be added to maintenance schedules if applicable.

Frequency of activity	Description of activity	Description of task
Weekly	Frequent cleaning of the boiler and removal of ash	Remove ash
		Clean smoke tubes
		Clean cyclone / bag-filters
Monthly	Regular lubrication of mechanical parts and checking for wear	Check/clean fuel delivery system
		Lubricate motors
Monthly	Checking the boiler is operating correctly and checking for damage	Check ash for clinker and unburnt fuel
		Check for leaks on water pipes
		Check boiler grate and refractory lining for damage
		Check ignitor guns
		Check de-ashing system works
		Check pneumatic cleaning system works
		Check burn-back protection
		Check fans, pumps and mixing valves
		Check sight-glass
		Check flue soundness
		Check draught-diverter
		Check boiler control system and BMS for faults / alarm codes
		Check pipe and flue temperature sensors
		Check for condensation in /corrosion of heat exchanger
		Check seals on combustion chamber are air-tight
		Check lambda sensor
		Check for unusual noises / vibrations
		Check are around boiler is tidy
Check CO alarm is working and for previous activation		
Check pressure relief valves not activated		
Check light-barriers / level-switches		
Yearly	Intermittent servicing of the boiler	Check boiler flue O2/CO2 and CO levels
		Clean hopper
		Check boiler control system and BMS for software updates

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