Department for
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Measurement of the in-situ performance of solid biomass boilers

Annex A: Literature review

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Lead author:	Mark Lewitt
Approved by:	Iain Summerfield

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Preface

This document is the Literature Review annex to "Measurement of the in-situ performance of solid biomass boilers", a report prepared for BEIS which details work carried out from 2015 to 2018 where the real-life efficiencies and pollutant emissions of a range of biomass boilers were measured.

The work was carried out by a consortium of Kiwa Gastec, Ricardo Energy and Environment, Energy Saving Trust, HETAS, and Optimum Consultancy.

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1 Introduction

‘In-use’ performance of biomass appliances at sub-industrial/utility scale has not been studied extensively. There is limited information about the efficiency and emissions performance of biomass boilers from domestic to large commercial/small industrial scales.

The study which this review supports is designed to address this knowledge gap, in particular in relation to biomass boiler installations registered for the non-domestic or domestic RHI schemes.

The field trial data that is being collected will enable instantaneous and seasonal average boiler in use performance to be assessed for >60 boilers.

The aim of this literature review is to set the information context which will assist in the identification of the laboratory test work proposed for Phase 2 of the study. This test work is intended to fill knowledge gaps that cannot be addressed through the field trial. This might include such things as assessing for one system the effect of varying the size of the thermal store on the boiler systems ability to meet defined demand profiles effectively and efficiently.

Information from published literature and knowledge from project delivery partners familiar with the use of biomass boilers has been examined with a view to establishing the current understanding of key factors affecting biomass boiler performance in use.

The background of guidance on design and specification of systems has also been examined including publicly available information (product manuals, etc.) for boilers included in the field trial.

There are thought to be significant differences between expected performance of biomass boilers and that achieved in use. So, information collected from biomass boilers during operation under simulated or actual in-use conditions is of particular interest. Sources of such information include:

- Detailed laboratory studies examining the effect of operating boilers under simulated in-use conditions (not simple standard tests)
- Field trials – these studies can provide information about the performance of boiler systems when responding to the actual demands placed on them by heating systems or processes.
- Case studies of individual installations – could provide information about average efficiency provided that they include robust records of fuel use and heat generated.

The final part of the picture will be provided by the initial findings from the monitoring in this trial. This will identify specific issues associated with particular types of boiler and system design and control arrangements.

2 Context

To enable the issues to be clearly understood it is necessary to place them in the context of the ways in which biomass boiler performance is measured and described. The key areas are efficiency and emissions.

2.1 Efficiency

Knowledge of the efficiency of a boiler system is essential to enable likely consumption of fuel to be estimated. This is a key consideration for potential purchasers of such systems and crucial in the process of determining the levels of RHI payment.

Boiler efficiency is generally measured only at well-defined stable operating conditions as they are specified in technical standards such as BS EN 303-5[i], EN 12809[ii] and EN 14785[iii]. The results of such tests are not designed to provide an accurate measure of efficiency during operation by a user. However, they do provide a means of comparing different products under the same operating conditions and are the basis for regulating which products may be installed in buildings and which are eligible for support under incentive schemes including RHI and Enhanced Capital Allowances.

The Domestic Building Services Compliance Guide (DBSCG)[iv] identifies the recommended minimum gross efficiency for all types of biomass boiler at nominal output as 75%. The DBSCG references the HETAS guide[v] as the source of published minimum biomass boiler efficiencies. The HETAS guide provides efficiencies measured at nominal output for a wide range of solid fuel boilers.

For some purposes an annual seasonal heating efficiency is estimated based on the results of efficiency measurements at these fixed conditions.

Under the Energy Performance of Buildings Directive[vi] estimates of the thermal performance of building/heating system combinations are required. In the UK, the National Calculation Methodology for this is defined in SAP 2012[vii]. The methodology defined for estimating seasonal performance for biomass boilers is reproduced in the box below:

The efficiency at full load is obtained from:

$$\eta_{full} = 100 \times \frac{(heat\ to\ water\ at\ full\ load) + (heat\ to\ room\ at\ full\ load)}{fuel\ input\ at\ full\ load}$$

The efficiency at part load is obtained from:

$$\eta_{part} = 100 \times \frac{(heat\ to\ water\ at\ part\ load) + (heat\ to\ room\ at\ part\ load)}{fuel\ input\ at\ part\ load}$$

The seasonal efficiency is:

$$\eta_{seasonal} = 0.5 \times (\eta_{full} + \eta_{part})$$

The approach is analogous to that taken for gas and oil fired boilers. However, such boilers generally respond very rapidly to follow demand. So for them, simply determining an average of performance at full and part load to represent annual performance, although crude is not an unreasonable approach.

Boilers fired with biomass generally respond more slowly to adjustments to output controls than boilers firing gas or oil because the burn-out times for solid fuels are much longer (minutes to hours depending on sizes of fuel pieces) than for gas and oil (up to seconds). This effect can be mitigated in the boiler system design, typically by including thermal storage which can provide a more flexible response to heat demands.

This approach to determining seasonal efficiency takes no account of the ability of biomass boilers to follow demand, nor of the characteristics of the overall biomass boiler system including the size of any buffer tank or thermal store and the control philosophy. So, again it cannot be regarded as providing an accurate measure of in-use performance.

The actual annual seasonal efficiency is:

$$\eta_{seasonal} = 100 \times \frac{(annual\ energy\ supplied\ to\ the\ biomass\ heating\ system\ as\ fuel)}{(annual\ energy\ supplied\ by\ the\ biomass\ heating\ system)}$$

If this approach could be applied the effects mentioned above do not need to be considered explicitly however, measurement of these parameters, and particularly the ‘annual energy supplied to the biomass heating system as fuel’, is generally difficult, time consuming and of limited accuracy. This is apparent from studies and investigations that are or have been carried out using this approach as mentioned in Section 5.

This general approach does not provide any information about instantaneous performance and the related effects on the production of emissions, particularly where changes in firing rate and shut-down/start-up cycles.

Note: in this context instantaneous means measured over a short time frame, typically a few minutes.

To gain insight into these operational features continuous measurements of boilers during all phases of operation (including start-up, load change, shut-down and boiler-off) is required. Such data can be used to estimate the annual seasonal efficiency biomass boiler system.

The annual seasonal efficiency could be estimated by (or some mathematical variant of this):

$$\eta_{seasonal} = \frac{\sum instantaneous\ efficiencies}{n_{instantaneous\ efficiencies}}$$

2.2 Emissions

Similarly to efficiency, emissions of pollutants such as CO, OGC, Particulates and NOx are generally measured at defined steady output conditions.

Pollutant formation in combustion processes is dependent on the conditions that pertain in the combustion chamber and particularly within the flame. In turn these depend on the fuel characteristics, combustion system and operating mode:

- Fuel with respect to the individual pieces:
    - Dimensions
    - Mass
    - Shape
    - Composition including moisture
    - Structural characteristics
- Appliance:
    - Combustion chamber characteristics (size, surfaces, fuel/ash bed)
    - Air supplies (primary, secondary, tertiary, wash air)
    - Air flow controls (manual dampers vs automatic valves, naturally vs mechanically ventilated)
    - Flue arrangement (diameter, position of exit from appliance)
    - Ratio of fuel size to firebed size.
- Installation:
    - Characteristics of the chimney to which the appliance flue is connected.
    - Air availability in the space where the appliance is installed
- Operation:
    - Steady or variable output
    - Fuelling and de-ashing practices
    - Ambient conditions such as air temperature, pressure and humidity.

The processes involved are complex however, some features are generally accepted and sufficient to show that measurement of emissions at steady operating conditions is not sufficient to determine the levels of emission that are likely to occur during a boilers full operational cycle:

- Variations in fuel air ratio can lead to fluctuations in the degree of combustion achieved with high ratios leading to incomplete combustion and increased formation of CO and particulates.
- NOx formation mechanisms are complex. Nitrogen in fuel is converted to NOx during combustion (fuel NOx). High temperatures cause thermal NOx formation which can be significant (thermal NOx). The availability hydrocarbon fragments in the combustion process enables the formation of nitrogen containing species which result in NOx formation (prompt NOx).
- High air velocities can lead to increased emission of particles.

Changes in combustion conditions as a result of e.g. shut-down/start-up cycles or changes to firing rate are likely to affect the instantaneous rates of formation and emission of pollutants.

3 Biomass-boiler based heating systems

Three main 'controllable' factors affect how biomass boilers function in use, in response to the demands that they are required to meet.

1. System design
2. System operation

(although distinct these first two are intimately related with both needing to be considered at the design stage)

3. Fuel supply (both the general type on which boiler design is based and the specific characteristics as fired)

All three of these factors can affect both instantaneous efficiency (and hence average overall efficiency) and pollutant emissions.

The Biomass Energy Centre's guide to feasibility studies[viii] summarises the situation with regards to biomass boiler system design:

> *"The sizing of a biomass boiler is a complex task even for an experienced building services engineer, and it will be different for every boiler, based on the heat load demand pattern and the winter peak load. The sizing of boilers, buffer vessels and fuel stores is best left to experienced designers and boiler system installers, and a suitably qualified design engineer or contractor should be engaged for this purpose."*

A simplistic calculator[ix] is provided on their website. This is designed only for initial feasibility assessment and it is made clear that more detailed analysis is required to produce an accurate specification.

3.1 Heating system demand

System design should be based around the system meeting all (or some defined part of) the heat demands throughout the year. The fraction of a biomass boiler system's potential annual output that is actually used to fulfil the annual heat demand for a building or process is described as its 'utilisation'.

Utilisation is affected by the sizing of the boilers used, the configuration of the system and the control philosophy.

The ability of system to meet overall annual demand is constrained by 'availability'. Availability is generally less than 100% due to down-time for maintenance and time lost due to breakdowns. For seasonal space-heating systems the impact of maintenance down-time should be minimal as planned maintenance can take place outside the heating season.

However, unplanned interruptions to operation will have an impact on the availability of biomass boiler systems. Clearly these must occur but the information available is limited generally to anecdotal e.g. from blogs[x] etc. However, at a Wood Heat Association seminar the following points were presented[xi] from a review of the first Wood Energy Business Scheme in Wales[xii] (a copy of the actual report was not located during this review):

> *"79 systems surveyed (90 supported) - 5 were non-operational; 17 reported no problems; 41 reported some problems - only 21% were problem free."*

> *"Almost all serious problems were rooted in poor planning and design and inadequate external support... …lack of independent impartial help and professional advice - only suppliers offered this, leading to poorly designed and expensive schemes."*

Collated data on the frequency and impact of breakdowns was not found during this review and hence, it has not been possible to estimate the typical impact on boiler availability.

What is the size and profile of the annual heat demand?

There are four main features in the demand profile:

- Total annual demand – overall any system must have the ability to generate the total amount of heat required over a year.
- Peak demand – the maximum instantaneous demand that the overall heat supply system must be able to supply.
- Baseload demand – the size of the continuous demand regardless of instantaneous variations.
- Rate of change of demand – depending on the use of the space or process being supplied with heat the changes in the heating system output may need to occur within minutes at one extreme to over an hour or more.

Once these are determined it is possible to ask the next question.

How should the biomass system contribute to meeting demand?

Once the heat demand is understood (total, peaks, base) the way in which a biomass system will contribute to meeting this demand needs to be considered.

As mentioned above biomass boilers generally cannot respond as quickly as gas or oil fired boilers and this must be considered during system design.

The Carbon Trust guide[xiii], discusses approaches for determining the demand on the heat distribution system (which it describes as 'system sizing') and it highlights that:

> *"From both technical and economic points of view, a biomass plant is best operated relatively continuously at between c.30% and 100% of its rated output. Biomass plants do not generally respond well to rapidly varying loads, or long periods at low load conditions below a minimum modulating range."*

The selection of the most appropriate approach to sizing a biomass heating system will depend on the profile of the demand to which it will be required to respond.

It discusses three "approaches for sizing":

- *Base load: where the biomass system provides only the annual, continuous heat loads of the site.*
- *Peak-load: where the site's entire heat loads are met by the biomass system.*
- *Optimum sizing: where a balance between the above two approaches is used.*

Some examples of annual profiles are provided and in subsequent sections the determination of the plant size is mentioned. However, the actual methodology of sizing is not addressed and it is implied that this should be carried out by the system supplier.

As suggested above, biomass boilers operate best at constant loads. If they are operated to follow a varying demand, this places greater stress on them and may lead to sub-optimal performance.

As a part of determining how the biomass system will contribute to meeting heat demand it is necessary to consider other factors:

- Cycling / run-times
- Load / utilisation factor
- Control strategies, control capabilities

These considerations need to lead to a general picture of the what the biomass element of a heating system needs to be capable of and how it will operate.

3.2 Equipment sizing and boiler system design

Ensuring that a boiler system supplies the heating demand effectively and efficiently requires careful design. This needs to be realised based on the information discussed in 3.1. This will include:

- Sizing of boiler(s) – the boiler needs to be able to meet the level of demand that will be placed on it in the context of the overall system design.
- Sizing of buffer/thermal store tanks – the distinction is explained in detail in 0 but simply the buffer is a protection for a biomass boiler and a thermal store enables heat supply from a biomass boiler to be to occur over a period after it is generated.
- Configuration of buffer/thermal store tanks – these need to be incorporated into overall systems in such a way that they can be used to maximise boiler utilisation whilst ensuring boiler protection.
- System operating philosophy – setting an appropriate operating philosophy is crucial to determining the above characteristics.

One of the concerns that has been identified with regards to the RHI biomass boiler population is that the system design is in a significant number of cases inadequate. A finding in the ‘methodology report’[xiv] was that boiler utilisation was in some cases very low which suggests that boilers / thermal stores may be incorrectly sized or configured.

The performance of two large heating systems with and without the inclusion of thermal stores was investigated by Mouchira et. al.[xv]. These systems were biomass with gas fired peaking capacity. They were able to demonstrate significant increases in the proportion of the heat demand supplied by the biomass:

Parameter	Case 1	Case 2
Annual heat demand (MWh)	16	60
Volume of the tank (m^3)	200	1500
Wood coverage rate without thermal energy storage (%)	85	92.7
Wood coverage rate with thermal energy storage (%)	98.7	94.6

This illustrates the impact of thermal storage in effective use of the biomass component in a heating system.

Guidance on system design and specification is available from various sources:

Manufacturer guidance / instructions

Manuals for some of the boilers included the sample of boilers included in this field trial were obtained from websites. The information provided in them is presented in Table 1.

Table 1: System installation requirements for specification of buffer tanks and thermal stores from manufacturers instruction manuals for boiler models included in the trial

Manufacturer	Boiler Model	Document	
Eko-Vimar Orlanski	Orlan 60 Super	Operation manual	No buffer tank or thermal store shown in the boiler / heating system schematics.
ETA	Hack 130	Operation manual	The existence of buffer tanks in the systems is recognised and the control system is able to cover them but there is no guidance on specifications.
	Hack 50	Operation manual	
	PE-K 70	Operation manual	
Extraflame	LP14	User Manual	No information found
Froling	T4 - 100	Installation manual Operation manual	It is not generally necessary to use a storage tank for the system to run smoothly. However we recommend that you use it with a storage tank, as this allows you to achieve continuous reduction within the ideal performance range of the boiler. For the correct dimensions of the storage tank and the line insulation (in accordance with ÖNORM M 7510 or guideline UZ37) please consult your installer or Froling.
	T4 - 75	Installation manual Operation manual	
Herz Energietechnik GmbH	firematic 199	Operation manual	Furthermore, claims under warranty will not be applicable if there is no return flow temperature boost or it is not working properly, if commisioning1 is not carried out by specialist personnel authorised by HERZ, in the case of operation without a buffer storage tank with a heating load of less than 70% of the rated output (manually stoked boilers must always be operated with a sufficiently dimensioned buffer storage tank), if hydraulic diagrams2, not recommended by HERZ are used No guidance on sizing of buffers or stores but controls are designed to provide operational information about buffers and stores.
Kob Holzheizsysteme GmbH	Pyrot 540	O&M manual Technical manual	The Technical manual includes specifications for buffer cylinders for different sizes of boiler.
TR Engineering Ltd	Trianco Greenflame 18 Ext Slim	Installation O&M manual	No information found
Windhager	BioWIN Exklusiv BWE260	Operation manual Assembly manual	In principle a pellet boiler system does not need an accumulator tank. A guaranteed minimum heat consumption is required, e.g. fit a consumer circuit that cannot be blocked off or do not fit thermostat valves on all radiators. The BioWIN 100–260 needs a buffer if: – the total heating requirements of the building according to the ÖNORM M 7500 or EN 12831 calculation are less than 50 % of the boiler‘s nominal output. Information! If using a buffer, the BioWIN return flow temperature must be increased – see hydraulic diagram in the planning documents.

NOTE: Review author comments are in red and quotes from manuals in black

From this small sample it is apparent that the information provided is variable, but in general limited and could in some cases lead installers to believe that no accumulator is required.

MCS installer standard for biomass

The relevant MCS installer standard for biomass[xvi] provides little information about system design. It requires that systems be installed in accordance with Building Regulations and Health and Safety Executive guidance. It includes some information relating to estimation of heating demand but there is no guidance on suitable methodologies for design of a boiler system to meet that demand. There is a requirement that *"Design staff carrying out full conceptual design, must be able to demonstrate a thorough knowledge of the technologies involved and the interaction of associated technologies."* but the minimum scope of this required base of knowledge is not defined.

Carbon Trust

The Carbon Trust provides a spreadsheet based "Biomass System Sizing Tool" supported by a user manua[xvii]. This provides a method which integrates the size of accumulator vessel into the boiler sizing calculation.

A set of equations was developed for calculating buffer vessel sizes for a wide range of boiler types as part of the development of the Biomass Decision Support Tool (Carbon Trust, 2013). These enable buffer vessel sizes to be calculated for any biomass boiler ΔT[xxvii].

HETAS

HETAS training for installers of biomass systems includes comprehensive coverage of estimation of heat demand and some explanation of the considerations with regards to sizing of boilers and heat stores. It highlights the limitations of stores where the heat distribution system relies on emitters working close to the output temperature of the emitters. The functions of thermal stores are identified as:

- Reduce cycling on a chip or pellet boiler system
- Meet demand when boiler output is low
- Store heat for use after a batch fuelled appliance has finished burning
- To combine more than one heat source

Building Regulations

Several parts of the Building Regulations[1] apply to the installation of heat generating equipment in buildings. These are Parts G[xviii] for water heating, J[xix] for combustion systems and L[xx], [xxi], [xxii], [xxiii] for efficiency of heating and hot water systems.

Part G sets out restrictions on hot water stores in terms of maximum water temperature which must be prevented from "*at any time exceeding 100°C*" although this is principally in relation to domestic hot water and "*does not apply to a system which heats or stores water for the purposes only of an industrial process.*"

For solid fuel appliances Part J deals only with ensuring safe function.

Part L for domestic buildings requires that each fixed building service meets minimum performance thresholds in the Domestic Building Services Compliance Guide[xxiv]. These thresholds are set at the

[1] Each of the devolved governments in the UK are now publishing separate national building regulations. As yet there has been little divergence in them from those for England. For the purposes of this study the focus has been on those for England.

appliance level and all independent boilers firing a wood fuel (logs, pellets and chips are within the scope of the guide) should have a minimum efficiency of 75% gross at their nominal load.

Some features of heating and hot water systems are mentioned including the fact that primary hot water stores *"can have a major role to play in the installation of solid fuel. The main reason for their use is to store the heat generated during slumber periods but where unvented storage cylinders are used they also provide mains pressure hot water and possible frost protection (via electric immersion heaters) for the solid fuel system."* And *"Because of the higher than normal storage temperatures it is very important that stores are well insulated."* This guide references the Hot Water Association (HWA) thermal storage specification[xxv]. This gives guidance on relative sizing of thermal stores but not on sizing of overall boiler system.

Part L for non-domestic buildings does not address the question of minimum performance thresholds for biomass boilers apart from CO2 emission factors for dual fuel systems.

The Non-Domestic Building Services Compliance Guide[xxvi] defines minimum efficiencies for:

- independent gravity-fed boilers < 20.5 kW: 65% gross
- independent automatic pellet/woodchip boilers: 75% gross

Guidance on the performance of overall biomass heating systems is not provided and the possibility that biomass is the heat source for generating hot water is not covered.

Standards

Although standards/codes of practice are available for design of heating systems these do not deal with design of heat supply systems.

However, the current issue of BS EN 303-5[i] defines a method for determination of the minimum volume for an accumulator tank to be attached to manually stoked boilers with minimum continuous heat outputs greater than 30% of their nominal heat output.

$$V_{Sp} = 15T_B \times Q_N \left(1 - 0.3\frac{Q_H}{Q_{min}}\right)$$

Where:

V_{Sp}	is the accumulator tank volume, in litres;
Q_N	is the nominal heat output, in kilowatts;
T_B	is the burning period, in hours;
Q_H	is the heating load of the premises, in kilowatts;
Q_{min}	is the minimum heat output, in kilowatts.

It also states that *"For heating boilers using several allowable fuels, the tank size shall be based on the fuel which requires the largest accumulator tank. The minimum volume of the accumulator tank shall be 300 l."* It also requires that *"necessary accumulator storage, in litres if $Q_{min} > 0,3\ Q_N$".*

The revised solid fuel appliance standards currently in preparation (to replace current standards including EN 12809[ii] and EN 14785[iii]) are expected to include a requirement for inclusion in the installation instructions of the *"accumulator heat input, in kW or W, if applicable"*.

CIBSE

In 2014 CIBSE published a guide for biomass heating[xxvii]. This includes guidance on the biomass boiler selection and sizing and design of buffer vessels and thermal stores and it focusses on systems with wood chip and pellet biomass boiler outputs in the range of 50kW to 5MW.

It notes the difference between designing for biomass and for other heating system types emphasises that the design of biomass boiler systems is considerably more complex than that of oil and gas boiler, heat pump and CHP systems, and requires an informed design approach.

It provides comprehensive coverage of the key aspects of designing biomass heating systems. Of particular relevance to this review are:

- Designing with buffer vessels and thermal stores (chapter 5)
- Sizing a biomass boiler and suitability of biomass (chapter 6)

These two aspects play a crucial role in optimising biomass boiler system utilisation factors and efficiencies.

The distinction between buffers vessels and thermal stores is clearly made, which is not the case in some publications. Confusion over these differences could lead to inappropriate selection of vessels and in particular, absence of any or sufficient capacity for thermal storage.

Buffer vessels	Thermal stores
• Are usually 2-port devices across the flow and return from the biomass boiler. • Dissipate heat from a biomass boiler on shutdown. • Prevent water boiling in a biomass boiler on shutdown. • Prevent the connected heating system from going over-temperature/over-pressure. • Improve biomass boiler efficiency by capturing heat which would otherwise be lost by radiation from the boiler and convection up the flue. • Provide some heat to supply the load as the biomass boiler heats up. • Increase the return temperature to the biomass boiler when a very low load return temperature is present.	• May be 2-port or 4-port devices connected in specific hydronic configurations. • Allow biomass boilers to operate continuously for long periods. • Improve the operating efficiency and utilisation factor of biomass boilers. • Can incorporate a buffer vessel at the bottom of a thermal store if the biomass boiler 'stop' temperature sensor is appropriately positioned. • Enable a biomass boiler to be reduced in size while meeting up to 100% of the load from biomass at external temperatures down to the design winter temperature.

The discussion of the issues around the use of thermal stores is provided in the guides[xxviii,xxix] published by the Biomass Energy Centre for potential users of biomass heating is similar to (having been prepared by the same primary author), though less extensive than, that provided in this CIBSE guide.

3.3 Fuel characteristics

In use, the fuel fed to biomass boilers determines to a significant degree, the performance achieved.

The three main constituents of biomass fuels are:

- **Carbohydrate structure**
  This is the source of the energy released during combustion. The water vapour produced by combustion of the hydrogen in the structure holds a significant amount of energy (latent heat of evaporation).

- **Moisture**
  This may either be inherent (held within the cells of the wood) or free (on the surface of the wood or between the wood fibres). Inherent moisture content is determined by the conditions under which the tree grows and free moisture is the result of the conditions under which wood is stored or processed. All moisture introduced into a boiler with fuel is evaporated during combustion. Unless condensed to recover this energy the water vapour so created (together with that resulting from combustion as mentioned in the previous point) carries energy out of the boiler reducing the overall efficiency of the unit. Excessive moisture can also affect the behaviour of fuel in a feed system.

- **Mineral matter** – also referred to as inorganic matter or ash, although strictly ash is mineral matter after oxidation/dehydration during combustion.
  This comprises (inherent (inorganics within cell structure), adventitious (minerals trapped in structure during growth mainly in bark), and free (soil picked up during harvesting)). The mineral matter contents in biomass fuels are generally low (no more than a few % w/w) except for 'forest residue' based fuels. The composition of mineral matter determines its behaviour during combustion. If the temperature is exceeded at which it, or the resultant ash, starts to fuse the ash particles can start to stick together. A crude measure of the likely melting properties of ash is the ash fusion test. In extreme cases large agglomerates can form which interfere with ash removal or affect the distribution of combustion air leading to operational problems.

Biomass boilers are designed to burn woody biomass fuels in different forms. The three main types are:

- Pellets
- Chips
- Logs

To produce these fuels various types of processing are applied:

- Comminution – size reduction
- Drying
- Compression

The resulting fuels will depend on the processes used by fuel producers, and the way in which fuels are treated in the supply chain from production and to use.

An issue that particularly affects pellet fuels are their resistance to breakdown. If pellets are weak or are handled inappropriately they can be degraded leading to significant proportions of fine wood particles or 'fines'.

The presence of excessive amounts in fuels can affect the operation of the feed system. In the fuel store they increase the risk of auto-ignition including detonations. In the combustion system they can affect the distribution of combustion air and lead to hot spots in fuel beds and in extreme cases to ash sintering.

The 'Biomass Suppliers List' provides a mechanism for assuring that the fuel is used in biomass heating systems registered for the RHI meeting Ofgem's requirements for biomass fuels. However, this scheme addresses only sustainability requirements (as stated in the UK Government's Timber Standard for Heat & Electricity[xxx]) and not fuel quality/properties.

Standards for appliances fired with solid fuels define the permitted ranges of properties for wood fuels for use in measurement of product ratings, efficiency and emissions, and typical commercial specifications.

Nomenclature for Table 2 to Table 5:

a.f.	As fired
a.r.	As received
% w/w	Percent by weight
d.b.	Dry basis

Table 2: Key fuel properties in EN 12809[ii]

Property	Units	Test fuel specification	Typical commercial fuel specification	
		Wood logs	Wood logs	Compressed untreated wood
Calorific value	kJ/kg a.f. net basis	Not defined	17,000 to 20,000	17,500 to 19,500
Moisture	% w/w a.f. basis	16±4	12 to 25	<12
Ash	% w/w a.f. basis	<1	<1.5	<1.5
Ash Deformation temperature	°C	Not defined	Not defined	
Fines	% w/w <3.15mm	Not defined	Not defined	

Table 3: Key fuel properties in EN 14785[iii]

Property	Units	Test fuel specification	
		Wood pellets (exc. bark)	Wood pellets (inc. bark)
Calorific value	kJ/kg net basis	16,900 to 19,500	
Moisture	% w/w a.r. basis	≤ 12	
Ash	% w/w a.f. basis	≤ 0.7	≤ 2.0
Ash Deformation temperature	°C	Not defined	
Fines	% w/w <3.15mm	Not defined	

Table 4: Key fuel properties in EN 303-5[i]

Property	Units	Test fuel specification			
Type		**Wood logs**	**Chipped wood**		**Compressed wood**
Grade		**A**	**B1**	**B2**	**C**
Calorific value	kJ/kg net basis	17,000			
Moisture	% w/w a.r. basis	12 to 20	20 to 30	40 to 50	≤ 12
Ash	% w/w a.r. basis	≤ 1	≤ 1.5		≤ 0.5
Ash Deformation temperature	°C	Not defined			
Fines	% w/w <3.15mm	Not defined			

In 2014 a new standard for biomass fuels was published; BS EN ISO 17225-1:2014 Solid biofuels — Fuel specifications and classes. The parts relevant to fuels used in boilers in the DECC biomass boiler field trial are:

- Part 1: General requirements
- Part 2: Graded wood pellets
- Part 4: Graded wood chips
- Part 5: Graded firewood

The 'Woodsure[xxxi] certified by HETAS fuel scheme' is the UK's only woodfuel quality assurance scheme. The scheme standard is based on these European standards and covers the various forms of woody biomass, including firewood logs, wood chip, wood pellets and wood briquettes. The

For these aspects the European pellet certification scheme, EN-plus[xxxii], defines the properties of compliant wood pellet fuels.

Table 5: Key ENplus pellet fuel requirements

Property	Units	ENplus A1	ENplus A2	ENplus B
Calorific value	kWh/kg net basis	≤ 4.6		
Moisture	% w/w a.r. basis	≤ 10		
Ash	% w/w d.b.	≤ 0.7	≤ 1.2	≤ 2.0
Ash Deformation temperature	°C	≥ 1200		≥ 1100
Fines	% w/w <3.15mm	≤ 1.0 OR ≤ 0.5 – depending on the point at which sampling occurs		

Manufacturers usually provide some guidance on the limitations to the fuel that may be burned in their boilers. This is usually linked to product warranty conditions. In Table 6 are extracts or descriptions of the relevant content from such manuals that were found to be available for download from manufacturer or manual repository websites.

Table 6: Fuel specifications from manufacturers instruction manuals for boiler models included in the trial

<table>
<tr><th>Manufacturer</th><th>Boiler Model</th><th colspan="2">Document</th></tr>
<tr><td>Eko-Vimar Orlanski</td><td>Orlan 60 Super</td><td>Operation manual</td><td>Wood at 15-25 % humidity and length about 5 cm smaller than the loading chamber should be used as the main fuel, billet’s diameter - 15-25 cm.

Disclaimer regarding the effect of using out of specification fuel.</td></tr>
<tr><td rowspan="3">ETA</td><td>Hack 130</td><td>Operation manual</td><td rowspan="2">• Wood chips according EN ISO 17225-4:2014, quality classes A1/A2/B1/B2, size P16S-P31S, maximum water content 35% (M35)
• Wood pellets according EN ISO 17225-2:2014, quality class A1, ENplus-A1
• Shavings and swarf briquets according EN ISO 17225-3:2014, quality classes A1/A2/B
• Miscanthus-wood chips according ÖNORM C 4000 and C 4001

Operation with unsuitable fuels, in particular highslag pellets from grain waste, for example, or corrosive fuels such as miscanthus fertilised with potassium chloride, is prohibited.</td></tr>
<tr><td>Hack 50</td><td>Operation manual</td></tr>
<tr><td>PE-K 70</td><td>Operation manual</td><td>The boiler is suitable for use with wood pellets according to EN ISO 17225-2:2014, quality class A1, ENplus-A1.

Operation with unsuitable fuels, in particular those containing halogens (chlorine) or highslag pellets such as from grain waste, is not permitted.</td></tr>
<tr><td>Extraflame</td><td>LP14</td><td>User Manual</td><td>Tests performed using wooden pellets as fuel, certified according to ONORM M7135 DIN PLUS.
The pellet used must comply with the features described by the Standard:
□ Ö-Norm M 7135
□ DIN plus 51731
□ UNI CEN/TS 14961
Extraflame recommends the use of pellets with a diameter of 6mm with its products.

The use of expired pellets or any other unsuitable material can damage certain boiler components and jeopardise its correct functioning: this can determine the invalidity of the warranty and the relative responsibility of the manufacturer. Extraflame invites the user to use pellet in compliance with the described features and the Standards in force.</td></tr>
<tr><td rowspan="2">Froling</td><td>T4 - 100</td><td>Installation manual
Operation manual</td><td rowspan="2">Fuel acc. to EN 14961 - Part 4: Wood chips class A2 / P16A-P45A;
Fuel acc. to EN 14961 - Part 2: Wood pellets class A1 / D06 and/or Certification program ENplus or DINplus

The use of fuels not defined in the "Permitted fuels" section, and particularly the burning of refuse, is not permitted.

In case of use of non-permitted fuels:
Burning non-permitted fuels increases the cleaning requirements and leads to a build-up of aggressive sedimentation and condensation, which can damage the boiler and also invalidates the guarantee. Using non-standard fuels can also lead to serious problems with combustion. For this reason, when operating the boiler:
❒ Only use permitted fuels</td></tr>
<tr><td>T4 - 75</td><td>Installation manual
Operation manual</td></tr>
</table>

Herz Energietechnik GmbH	firematic 199	Operation manual	Wood chips for non-industrial use with low fines content after EN 14961-1/4 according to the following specification: Property class A1, A2, B1 G30 resp. G504 according to ÖNORM M7133 Particle size P16B, P31,5 and P45A Water content min. 15% up to max. 40% Ash content: <1.0 (A1), <1.5 (A2), <3,0 (B1)m-% Calorific value in as-delivered condition > 3,1kWh/kg Bulk density BD in as-delivered condition >150 kg/m³ The property classes A1 and A2 represent fresh wood and chemically untreated wood residues. A1 contains fuels with low ash content, which indicates little or no bark, and fuels with lower water content, while class A2 has a slightly higher ash content and/or water content. B1 extends origin and source of class A and includes additional materials, such as short rotation plantation wood, wood from gardens and plantations etc., as well as chemically untreated industrial wood waste. Class B2 also includes chemically treated industrial wood waste and used wood. Wood pellets for non-industrial use after ENplus, Swisspellet, DINplus or ÖNORM M 7135 resp. pellets after EN14961-2 according to following specifications: Property class A1 The maximum permissible fines content in the fuel store must not exceed 8% of the fuel volume stored (determined using a perforated screen with holes 5 mm in diameter)! Fines content at the time of loading: <1,0 m-% Calorific value in as-delivered condition > 4,6 kWh/kg Bulk density BD in as-delivered condition >600 kg/m³ Mechanical Strength DU, EN 15210-1 in as delivered condition, m-%: DU97,5 ≥ 97,5 Diameter 6mm The nominal power and the emission values can be guaranteed up to a maximum water content of 25 % and a minimum calorific value of 3,5 kWh/kg of the permissible fuel. From a water content of about 25% and a calorific value <3,5kWh/kg a reduced output is expected. Furthermore, claims under warranty will not be applicable if … if a nonprescribedfuel3, Pellets (ÖNORM M 7135, DINplus or Swiss Pellets) wood chips (ÖNORM M 7133) resp.. log wood is used.
Kob Holzheizsysteme GmbH	Pyrot 540	O&M manual Technical manual	If different fuels are used, KÖB will not assume any liability for the functioning or service life of the boiler plant. Refer to the "Warranty" section in the General Terms and Conditions of Delivery. The data sheet included runs to 2 pages and covers all aspects of the fuel specification. The Technical manual specifies: The Pyrot is suitable for the following dry to moist wood fuels: ■ Woodchips from forests up to a water content of 35 % (W35, G50) ■ Industry pellets, with an ash content of max. 1.0 % ■ Pellets with the quality seal DINplus or acc. to ÖNORM M 7135 Note

			The following are unsuitable types of fuel: fossil fuels and those containing sulphur, such as anthracite and coke, as well as plastics, grain, straw, material soaked in flammable liquids and wood remnants treated with plastics or wood preservatives.
TR Engineering Ltd	Trianco Greenflame 18 Ext Slim	Installation O&M manual	Use only fuel recommended by T R Engineering Ltd (Enplus-A1) may be used with this appliance. Warranty does not cover issues arising from pellets that do not conform to Enplus-A1.
Windhager	BioWIN Exklusiv BWE260	Operation manual Assembly manual	

NOTE: Review author comments are in red and quotes from manuals in black

The guidance provided is generally in relation to use of specific qualities of fuel. In some cases, the user would need some technical capability to determine whether the fuel that they have received meets the manufacturers specification.

Kiwa recently worked with Ecofys, examining issues around blending biomass fuels[xxxiii]. In general, the findings relevant to this current study were that there was significant scope for inappropriate fuels to be fed to a boiler and that there was limited empirical information about the specific impacts of variations in fuel characteristics.

4 Findings from other in-use simulations and field trials

The review identified few formal field trials of biomass boilers. Even where undertaken they have not necessarily resulted in collection of the data required to understand boiler performance. Where reports are available these have been reviewed.

Biomass Boiler Performance Evaluation Study [xxxiv]

Dates: Commenced 2013 - ongoing

Funded by: Alaska Energy Authority

Carried out by: Alaska Centre for Energy and Power, University of Alaska Fairbanks

Objectives: This project seeks to examine performance of wood-fired hydronic boiler systems in three different Alaskan communities. The boilers each receive a different fuel type; harvested cordwood, drift cordwood' from the Yukon River, and wood chips from saw mill scrap.

Methodology: Performance of the boilers will be monitored using an energy metering system comprised of an in-line flow meter, and two temperature-sensors, one on the hot water supply side and the other on the return side. By tracking the water flow rate and the temperature at both sides, the amount of heat input to the water can be measured. By correlating this against wood consumption and wood moisture content, a rough assessment of boiler efficiency may be obtained.

In addition, an emissions probe will be brought to each site during an extremely cold time, and a moderately cold time, and stack emissions will be measured for both climate points.

Findings: At the time of writing no results had been published. The researcher was contacted directly by email and phone and the methodology and status of the project discussed. The use of the direct method for measuring performance is being adopted but this relies on reliable measurement of fuel fed to the boiler and collection of this information has proved difficult.

Kiwa commentary: Published information available about this project is limited to a project profile.

Determination of the Efficiencies of Automatic Biomass Combustion Plants[xxxv]

Dates: 2006

Funded by: International Energy Agency, IEA Bioenergy Task 32

Carried out by: Verenum (Switzerland) and CRA Gembloux (Belgium).

Objectives: The main objective of the investigation was evaluation and comparison of different methods for the determination of the efficiencies of automatic biomass combustion plants.

The second objective of the study is a comparison of efficiencies and emissions at different operation modes, i.e. at full load and at part load operation.

The third objective was the introduction and validation of a modified formula for indirect determination of the annual plant efficiency.

Methodology: For the first objective, detailed formulae for the combustion efficiency, the boiler efficiency and the annual plant efficiency were described and methods for direct and indirect determination were identified. Calculation of the uncertainties was carried out for each method.

For the second objective the influence of the plant operation on efficiency was investigated by measurements on a 550kW grate boiler on a test bench in Belgium. Combustion efficiency, boiler efficiency and emissions were determined at steady operation at 100%, 60%, 30% and 10% of the nominal load.

To evaluate the determination of the annual plant efficiency, measurements were performed on a 350 kW understoker boiler operating in Switzerland. The annual plant efficiency was investigated by the direct and the indirect determination method.

Findings: For the first objective the Indirect method was found to have lowest level of uncertainty. Direct measurements had higher uncertainties, and those relying on volumetric fuel flow were higher than those using fuel weight.

For the second objective the combustion efficiency calculated by indirect determination method resulted for 100% down to 30% load in a range of 90.9 ±0.7% to 87.8 ±0.7%, the boiler efficiency calculated by indirect determination resulted in a range of 86.2 ±1.7% to 84.2 ±4.8%. For the combustion efficiency, high accuracy was achieved, while the uncertainty of the boiler efficiency was quite small for 100% load, but increased significantly with decreasing load, which was mainly due to the uncertainty of the thermal losses by radiation, convection and ash losses. The boiler efficiency calculated by direct determination method resulted for 100% down to 30% load in a range of 78.6 ±9.5% to 80.7 ±10.5%. The high uncertainty was mainly a result of the uncertainty of the fuel mass flow at the test bench.

The annual plant efficiency for the in-use boiler by direct determination method resulted in 78.4 ±10.1%. The high uncertainty of the weight-based measurement is due to the uncertainty of the net calorific value and the variations of the water content of the fuel used in the plant in practical operation. The annual plant efficiency calculated by the indirect determination method, was 80.6 ±5.6% and hence more accurate.

For the third objective it was found that determination of the annual plant efficiency together with a measurement of the annual heat production is well suited as cost-effective method for the fuel accounting for plants with one single fuel supplier.

Kiwa commentary: The main focus of the work was on annual efficiencies. Point efficiencies determined in the laboratory varied remarkably little across the range 100%, 60% and 30% although all the determination methods showed some decrease at the 10% position. The in use trial data logging of some parameters including flue gas temperature and emissions was not continuous throughout the test period. Although the laboratory testing examined more conditions than for standard boiler testing it did not investigate the effects of transition between loads or of stop and restart of the boiler. There is very little information about the configuration of the system to which the boilers are connected so no inferences can be drawn about how this affected their operation and in particular the in-use boiler.

The report provides a valuable and detailed examination of the methodologies for efficiency measurement for biomass boilers and strong support for the view that the indirect method offers confidence in the results.

Carbon Trust Biomass Monitoring[xxxvi]

Dates: February 2008 to September 2009

Funded by: Carbon Trust

Carried out by: Gastec at CRE Ltd.

Objectives: To help make the UK biomass heat market self-sustaining by reducing costs and addressing supply chain risks. The project aimed to work with existing and new sites to develop benchmarks from robust case studies, identify and demonstrate cost reductions, and raise awareness amongst end users and other stakeholders.

Methodology: 19 sites were included in this trial. These were all non-domestic with 9 schools and a mixture of commercial and residential premises. Full energy monitoring was undertaken at 13 sites but was limited to a single heat meter at the remaining sites. Information on the amount of fuel used was collected for each site and samples were collected from the sites undergoing full monitoring. A variety of system configurations were represented including biomass boiler with oil boiler support, biomass boiler with thermal store, two biomass boilers as well as single biomass boilers.

Findings:

- The efficiencies of wood chip and pellet boilers are generally good and lie within the range of 73% to 85% even when being fed with wood which is wetter than desirable.
- Many biomass boilers have been observed to give levels of smoke emission from the chimney, which are a cause for concern. The operational emissions values should not exceed those measured during acceptance or regulatory approval tests.
- The majority of biomass boilers within the trial appear to be considerably oversized. Previous experience has shown that oversizing can lead to smoke and reliability issues. A smaller boiler installed in tandem with an oil or gas unit would lead to much greater reliability of the heating system and if correctly designed only a marginal increase in annual site carbon emissions, capital cost is also likely to be substantially reduced. However, this apparent oversizing could also be a result of the boilers not being able to reach their maximum continuous rating, which could be caused by fuel supply or boiler design problems.
- The vast majority of the biomass sites suffered “faults”. Anecdotal evidence shows that where these faults can be quickly addressed by an enthusiastic operative with no disruption to the building heating, senior management are pleased with the installation, however where the operative does not correct these minor faults but reports them to senior management for further action, site dissatisfaction grows. This is further exacerbated by site management having to pay for callout attendance from a professional boiler maintenance company. Better operative training may well address some of these issues.
- Fuel quality is undoubtedly the third most important function affecting plant performance after sizing and the ability of the operative to deal with minor faults. Many of the sites have difficulty keeping track of fuel use and even on the best sites estimates of this can be 10 to 20% different to the calculations from the heat meter data. On this basis it was recommended that any energy service company (ESCO) tariffs, subsidies and any other funding relating to biomass use should be based upon heat meter data not fuel usage.

- Thermal stores did not appear to be operating effectively to increase boiler utilisation although some seemed to smooth demand somewhat. Some were undersized for the duty. There was comment on whether the control systems were configured to optimise the benefit offered by a store.

Kiwa commentary: This trial involved remote data collection from 19 boilers for a period of at least a year, up to 18 months in some cases. It was the most extensive published biomass boiler field trial found during this review. The results highlighted several areas for concern including:

- Difficulties in obtaining accurate fuel federate information which means that the indirect method of measuring boiler efficiency is more reliable than the direct method
- Smoke emissions
- Boiler oversizing
- Accumulator sizing / operation
- Fuel quality and variations in quality
- The need for an enthusiastic boiler operator.

A Methodology for Evaluating the In-Situ Performance of Solid Fuel Biomass Boilersxiv

Dates: 2015

Funded by: Department of Energy and Climate Change

Carried out by: Kiwa Gastec, Amec Foster Wheeler and BRE

Objectives: The study had four objectives.

1. Develop categories of biomass boilers by heat type and load
2. Develop evaluation methodology(s) for each category of boiler
3. Develop air quality emissions methodology(s)
4. Testing and pilot of methodology

Methodology: The methodology was developed so that each of the four objectives were met.

- For objective 1 a data set of boiler information for biomass boilers in the RHI scheme supplied by DECC was analysed. Other data sets from HETAS (via DECC) and MCS were also examined. Based on the findings an approach to categorising biomass boilers was developed.
- For objectives 2 and 3 the available methods were examined and considered. Based on the findings, use of the indirect method for determining boiler efficiency was identified as likely to provide the highest confidence. A methodology for applying this approach was defined. This was based on an assessment of the parameters that need to be measured (including emissions) for each of which a recommendation was produced.
- For objective 4 a laboratory trial and a field trial (on one site for a short period) of the method was undertaken.

Findings: Overall the findings were that if the methodology proposed is used in an extensive field trial to analyse the in-situ performance of biomass boilers, the following reasons for good and poor performance can be understood:

- Utilisation factor – by measurement of heat output and fuel input
- Boiler efficiency, including the pathways that heat is lost from the boiler – through ambient temperature, flue gas and fuel analyses
- Boiler modulation – by analysis of flue gas O_2 and temperature
- Boiler cycling – through analysis of flue gas temperature, O_2 and electrical power consumption of the boiler
- Indicative particulate emissions values can be understood through obscuration measurements which can be analysed in conjunction with flue gas temperature, O_2, and power consumption to understand when and why emissions are highest.

Kiwa commentary: The measurements undertaken for this study support the view that in-use biomass boiler efficiency can most reliably be determined using the indirect method. Although, in principle, the direct method is simpler (fewer parameters are used in calculating efficiency) it is associated with high levels of uncertainty. This is largely due to the uncertainties associated with obtaining accurate information about fuel composition and the feed rate.

5 Case studies

Many case studies of biomass installations have been published. However, these are generally focussed on showing cost saving and/or CO_2 emissions reduction achieved relative to an alternative, fossil-fuelled system.

A number of case studies were created during the desk-based study with which DECC commenced their examination of the performance of biomass boilers in the UK[xxxvii]. These were based on collecting metered heat output and user records of fuel procurement over a whole year. These studies produced annual efficiencies based on a crude form of the direct method. The results provide further evidence that this method produces relatively unreliable results. This was evidenced by some unfeasibly high efficiencies.

6 Summary of evidence gaps

From this review of literature available on the performance of biomass boilers, a number of areas have been identified where further work would extend our understanding of the issues. In several areas, the factors affecting instantaneous and overall efficiency and pollutant emissions are not well understood. These gaps in knowledge include:

- Matching boiler size to load, the impacts of seasonal variations in demand on performance, optimum plant sizing strategies.
- Boiler control strategies and capabilities – degree of output modulation, boiler off/on triggers, interaction with thermal store.
- The effects of boiler cycling, and particularly the effects of frequent boiler start-up and shutdown.
- Mis-sizing of thermal stores. Correctly sized thermal stores (accumulators) should enable biomass boilers to be operated in ideal continuous mode. The impacts of under- or oversizing.
- The impacts of different fuel types. Are boilers designed to fire logs, woodchip, or pellets more efficient or less polluting?
- Different arrangements of the system and in particular how any thermal store is connected and consequently how it is operated.
- Fuel quality (in particular, moisture content) and the effects of variations in quality.

The field trial methodology has been designed to fill these gaps.

7 References

[i] CEN/TC 57 Heating boilers. (2012). BS EN 303-5:2012 Heating boilers Part 5 : Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW - Terminology, requirements, testing and. BSI Standards Ltd.

[ii] CEN/TC 295 “Residential solid fuel burning appliances.” (2007). BS EN 12809:2001+A1:2004 Incorporating corrigenda September 2003, June 2006 and August 2007 Residential independent boilers fired by solid fuel — Nominal heat output up to 50 kW — Requirements and test methods. Management. British Standards Ltd.

[iii] CEN/TC 295 “Residential solid fuel burning appliances.” (2006). BS EN 14785:2006 Residential space heating appliances fired by wood pellets - Requirements and test methods. British Standards Ltd.

[iv] HM Government. (2013). Domestic Building Services Compliance Guide (2013 edition), 96. Retrieved from http://www.amazon.co.uk/Domestic-Building-Services-Compliance-Guide/dp/1859465366/ref=sr_1_1?s=books&ie=UTF8&qid=1434569371&sr=1-1&keywords=Domestic+Building+Services+Compliance+Guide+2013

[v] HETAS. (2016). Official guide to HETAS approved solid fuel products and services. HETAS. Retrieved from http://www.hetas.co.uk/professionals/hetas-guide/ 29/04/2016

[vi] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

[vii] BRE. (2014). The Government’s Standard Assessment Procedure for Energy Rating of Dwellings, SAP 2012. Retrieved from http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf

[viii] Palmer, D., Tubby, I., Hogan, G., & Rolls, W. (2011). Biomass heating: a guide to feasibility studies. Biomass Energy Centre.

[ix] Accessed 22 April 2016 http://www.biomassenergycentre.org.uk/pls/portal/url/ITEM/8044872F0CB125A4E04014AC08045198

[x] http://blog.greenwisebusiness.co.uk/2013/04/10-things-your-installer-wont-tell-you-before-you-purchase-a-biomass-boiler/ Accessed 22/04/2016

[xi] Harrison, N. (2015). The Standards Vacuum : How to Ensure a Quality Installation. In Usewoodfuel/WHA Seminar Dunblane, November 2015 (pp. 6).

[xii] WEBS 1 : 2004-2008 A REVIEW OF WOOD ENERGY SCHEMES IN WALES, MAY 2010 – Full Report not found.

[xiii] Carbon Trust. (2009). Biomass heating A Practical Guide for a Potential Users. CTG012 v2. Carbon Trust.

[xiv] Summerfield, I., Quinn, L., Thomas, J., Green, C., Zglobisz, N., Jennings, T., … Young, B. (2015). A Methodology for Evaluating the In-Situ Performance of Solid Fuel Biomass Boilers. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/458581/Evaluation_of_the_In-Situ_Performance_of_Biomass_Boilers_Final_Report_after_final_boiler_anonymisation.pdf 11/03/2016

[xv] Mouchira, L., Eynard, J., Faugeroux, O., & Grieu, S. (2014). Sequential management of optimally-designed thermal storage tanks for multi-energy district boilers. Applied Ther- Mal Engineering, 73(1), 253–266. Retrieved from https://hal.archives-ouvertes.fr/hal-01118300

[xvi] Microgeneration Certification Scheme - Biomass WG. (2015). MIS 3004 - Requirements for MCS contractors undertaking the supply, design, installation, set to work, commissioning and handover of solid fuel heating systems.

[xvii] Carbon Trust. (2013). Biomass Boiler System Sizing Tool User Manual. Retrieved 10/03/2016 from http://www.carbontrust.com/resources/tools/biomass-decision-support-tool

[xviii] Department for Communities and Local Government. (2010). Approved Document Part G Sanitation, hot water safety and water efficiency.

[xix] Department for Communities and Local Government. (2010). Approved Document Part J Combustion appliances and fuel storage systems.

[xx] Department for Communities and Local Government. (2010). Approved Document Part L1A - Conservation of Fuel and Power in New Dwellings.

[xxi] Department for Communities and Local Government. (2010). Approved Document Part L1B - Conservation of Fuel and Power in Existing Dwellings.

[xxii] Department for Communities and Local Government. (2010). Approved Document Part L2A: Conservation of Fuel and Power in New Buildings Other than Dwellings.

[xxiii] Department for Communities and Local Government. (2010). Approved Document Part L2B Conservation of fuel and power in existing buildings other than dwellings.

[xxiv] HM Government. (2013). Domestic Building Services Compliance Guide. NBS, part of RIBA Enterprises Ltd. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453968/domestic_building_services_compliance_guide.pdf

[xxv] Hot Water Association. (2010). Performance Specification for Thermal Stores. Hot Water Association Limited. Retrieved from http://www.hotwater.org.uk/uploads/559535EF2358B.pdf 25/04/2016

[xxvi] HM Government. (2013). Non-domestic building services compliance guide. NBS, part of RIBA Enterprises Ltd. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/453973/non_domestic_building_services_compliance_guide.pdf

[xxvii] Palmer, D., Kinnibrugh, J., Ashford, C., & Smith, G. (2014). Biomass Heating Solutions. Cibse-Am15: 2014. Retrieved from http://www.solzaima.pt/.

[xxviii] Palmer, D., Tubby, I., Hogan, G. and Rolls, W. (2011). Biomass heating : a guide to small log and wood pellet systems. Biomass Energy Centre.

[xxix] Palmer, D., Tubby, I., Hogan, G., & Rolls, W. (2011). Biomass heating: a guide to medium scale wood chip and wood pellet systems. Biomass Energy Centre brochure.

[xxx] Department of Energy & Climate Change. (2014). Timber Standard for Heat and Electricity: Wood Fuel Used under the Renewable Heat Incentive and Renewables Obligation URN 14D/025. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278372/Timber_Standard_for_Heat_and_Electricity_under_RO_and_RHI_-_10-Feb-2014_for_pdf_-_FINAL_in_new_format.pdf 16/04/2016

[xxxi] http://woodsure.co.uk/

[xxxii] European Pellet Council. (2015). EN plus For Wood Pellets EN plus Handbook Part 3 : Pellet Quality Requirements (pp. 1 – 10). European Pellet Council. Retrieved from http://www.enplus-pellets.eu/downloads/national-handbooks/ 26/04/16

[xxxiii] Thomas, J., Critchley, S., & Hardy, N. (2015) Ofgem Blended Biomass Fuel Study. Prepared for Ofgem by Ecofys and Kiwa Gastec. Unpublished confidential report.

[xxxiv] Huang, D. (2013). Biomass Boiler Performance Evaluation Study. Retrieved 03/04/2016, from http://acep.uaf.edu/projects/biomass-boiler-performance-evaluation-study.aspx

[xxxv] Good, J., Delcarte, J., & Schenkel, Y. (2006). Determination of the Efficiencies of Automatic Biomass Combustion Plants. IEA Bioenergy Network

[xxxvi] Dennish, T., Charlick, H., Storey, L., & Stephens, D. (2009). Carbon Trust Biomass Monitoring, Final Report

[xxxvii] Steve Luker Associates Ltd. (2014). Desk-Based Review of Performance and Installation Practice of Biomass Boilers. URN 14D/441.

Kiwa Gastec
Kiwa Ltd, Kiwa House,
Malvern View Business Park,
Bishops Cleeve, Cheltenham,
GL52 7DQ, UK

Tel +44 (0)1242 677877
Email enquiries@kiwa.co.uk

www.kiwa.co.uk