

Biomass heating

A practical guide for potential users



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Preface

In 2005, the Carbon Trust's Biomass Sector Review¹ highlighted the significant potential of biomass heating in the UK. It showed that carbon savings of up to 20 million tonnes of CO₂ per year could be achieved using UK biomass resources alone. It also identified that using biomass for heating typically gives the most cost-effective carbon savings of all uses of biomass and that this is particularly the case for small-to-medium scale applications (100 kW_{th}-3MW_{th}).

Recognising the potential impact of biomass heating in this range for commercial and industrial applications, the Carbon Trust launched the Biomass Heat Accelerator (BHA) in 2006. By working with existing biomass heating projects across the UK, the BHA has identified that a lack of customer knowledge and understanding of biomass heating technology is a significant barrier to wider uptake.

This guide, prepared with the assistance of Black & Veatch Ltd., is the first major publication from the Biomass Heat Accelerator and is intended to provide practical guidance to businesses and public sector organisations considering using biomass as an alternative source of heating for space, hot water and/or process heat. The guide focuses on existing, conventional biomass combustion equipment, in the 100kW_{th}-3MW_{th} size range, that use solid fuels such as wood chips, pelletised biomass fuels and straw. However, much of the information in this guide will also be of relevance to those involved with other types of biomass projects (e.g. biomass CHP schemes).

The first section of the guide introduces the concept of biomass as a low carbon source of fuel and the key benefits of its use. It also covers some of the high-level policy and market aspects of biomass use in the EU and the UK.

The second section provides a detailed technical overview of the properties of biomass fuels and typical biomass heating equipment.

The third section contains a process guide covering details of the steps required to take a biomass system from initial concept to full implementation. Although this is not intended to be definitive, and individual circumstances and projects will vary, the section is intended to help potential site owners approach such projects in a logical, structured manner.

The information and processes laid out in this guide will also help organisations adopt 'best practice' approaches and avoid common errors when installing biomass heating systems. The guide should help users to design, procure, implement and operate successful, cost-effective biomass heating solutions and achieve significant carbon savings.

The Biomass Heat Accelerator

The Biomass Heat Accelerator is one of the Carbon Trust's Technology Acceleration projects which aims to accelerate the uptake of this low carbon source of energy.

To achieve this, the Biomass Heat Accelerator is working with a range of the UK's leading installers and manufacturers of biomass heating equipment to reduce the total cost of projects. The Biomass Heat Accelerator is also working to reduce risks in the fuel supply chain through quality assurance and information provision.

More broadly the aim of the project is to increase awareness and understanding of biomass heating technology amongst the customer base as a lack of this presently restricts wider market uptake.

Visit: www.carbontrust.co.uk/biomass for more information on the Biomass Heat Accelerator.

Throughout this guide, the term 'site owner' is used to mean an individual or organisation considering implementing a biomass heating system at a specific site. However, the guide will also interest project developers, energy managers, those acting on behalf of clients to help them specify and procure biomass heating systems or other interested stakeholders such as government bodies.

¹ <http://www.carbontrust.co.uk/publications/publicationdetail?productid=CTC512>

Executive summary

Biomass as a low carbon energy source

Biomass is a form of stored solar energy and is available in a number of different forms. These include wood, straw, energy crops, sewage sludge, waste organic materials and animal litter.

Although burning biomass releases carbon dioxide to the atmosphere, this is offset by the carbon dioxide absorbed in the original growth of the biomass, or captured in the growth of new biomass to replace the materials used. As a result, using biomass for heating results in very low net 'lifecycle' carbon emissions relative to conventional sources of heating, such as gas, heating oil or electricity.

The need for biomass heating

Heat in all its forms presently accounts for nearly half of the UK's carbon emissions². The UK has a legal requirement to reduce carbon emissions by at least 26% by 2020 and 80% by 2050 (against a 1990 baseline) under the Climate Change Act³. Meeting these targets will require a major shift away from fossil fuel heating systems to lower carbon forms of heating.

In June 2008, the Government's Renewable Energy Strategy consultation proposed that under one possible scenario 14% of the UK's heating may need to come from renewable sources by 2020 for the UK to meet its share of the EU 2020 target for total renewable energy. Given that less than 1% of UK heat demand is currently met by renewable sources, this implies a dramatic and rapid transformation in the way heat is provided over the next decade. To help deliver this step change in renewable heat the Government took powers in the 2008 Energy Act to establish a 'Renewable Heat Incentive' (RHI) to give financial support to those generating renewable heat. An overview of the RHI appears on page 66.

Of all possible renewable heating solutions, biomass has the potential to deliver some of the most significant and cost-effective carbon savings, particularly for commercial and industrial applications. In addition to carbon savings, biomass heating also offers significant benefits for users, including operational fuel cost savings and reduced fuel price volatility. It can also stimulate local economic activity by creating fuel supply chains and make use of resources that would otherwise be treated as waste and sent to landfill.



² <http://renewableconsultation.berr.gov.uk/consultation/chapter-4/executive-summary/>

³ <http://www.defra.gov.uk/environment/climatechange/uk/legislation/index.htm>

Biomass fuels and heating systems

Biomass heating is a mature, proven technology and has been used successfully for many years in countries such as Austria, Finland and Denmark. The two key elements of a biomass heating solution are the fuels and the heating system.

The most commonly used sources of biomass heating fuels are virgin wood, certain energy crops, industrial wood residues and certain agricultural residues. Biomass fuels are typically delivered as woodchips or wood pellets, but can also be in other forms such as logs or straw bales. Fuel is normally provided by one or more dedicated suppliers, but on-site materials can also be used in some situations, such as on farms.

The key characteristics of a biomass fuel include its moisture content which affects its energy content (the calorific value), and the particle size/grade. Factors which affect fuel costs include the type of fuel and its associated market availability, the quality of the fuel, the form the fuel is delivered in and the proximity of the fuel source to the point of use.

The heating system itself consists of biomass boiler plant, ancillary equipment (such as control systems flues and pipe work), and infrastructure to receive and store fuel and transfer it to the main boiler unit. Fuel can be stored in various ways, such as dedicated storage facilities (either above or below ground), integrated facilities within existing buildings, or in removable storage containers.

Biomass plant can vary from small, manually fed systems with few controls, to fully automatic systems with advanced controls and remote monitoring. The types of plant available range from moving grate, plane grate, stoker burner and batch-fired systems with the choice of system dependent upon fuel grade and type and the degree of automation required, with costs varying accordingly.

Biomass heating equipment is best suited to operating relatively continuously. This means that a heat store and/or back-up plant are useful means of smoothing demand. Biomass systems are also typically physically larger than equivalent fossil-fuel systems.

Implementing a successful biomass system

The Carbon Trust's experience of working with existing biomass heating installations has shown that there is currently a wide variation between common practice and best practice.

In order to successfully design and deliver a high performing, cost-effective biomass heating solution it is essential that site owners follow a structured approach to system implementation.

The key phases of this approach are as follows:

Initial assessment

In this phase the aim is to understand quickly whether biomass is likely to be an appropriate, alternative heating solution for the site before embarking on a detailed feasibility study and engaging with potential suppliers. This phase typically involves a basic assessment of site suitability, a basic economic appraisal and a review of other potential, non-financial benefits.

Detailed feasibility

In this phase the aim is to acquire all the necessary information on which to make a firm decision on whether to proceed with a project. This includes: a detailed assessment of site heat demands, required system characteristics, detailed capital and operating costs, logistics, fuel availability, fuel storage, and any required permits/consents.

Procurement and implementation

The ultimate aim of this phase is to successfully install, commission and hand over a fully operational biomass heating system. This involves specifying, tendering for and implementing a biomass heating system and associated fuel contracting.

Operation and maintenance

This is an ongoing phase which involves fuel quality monitoring, system performance monitoring and routine, planned maintenance.

About this guide

This guide has been prepared with input from some of the UK's leading experts in biomass technologies, and brings together a host of issues that potential users will want to consider. It covers a wide range of topics from choice of fuels to contracting structures. Inevitably it cannot be more than an introduction to the considerations applicable to each different subject, or exhaustive in its treatment.

The Carbon Trust recommends, and this guide assumes, that prospective users will take advice on their specific needs and circumstances from professionals in the field,

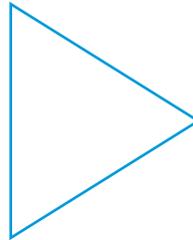
including not only technical consultants and installers, but legal, planning and other specialists as required. The guide is designed to assist readers in navigating through what can appear to be a complex technology and engaging effectively with expert advisers to ensure successful implementation.

This guide does not purport to give detailed Health & Safety information, and accordingly should be read in conjunction with specific installation advice.

Structure of the guide

Part 1 – Introduction

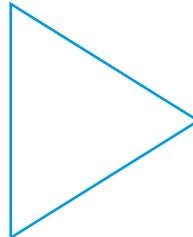
An introduction to biomass and biomass heating; the rationale underpinning biomass use; an introduction to fuel supply operations and biomass heating technology.



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Part 2 – Technical manual

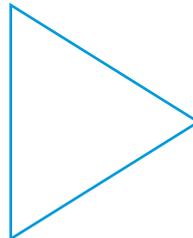
Covers detailed aspects of the fuel used in biomass heating and delivery/storage methods. Describes the basic components of a biomass heating system including outline design and sizing strategies/integration options.



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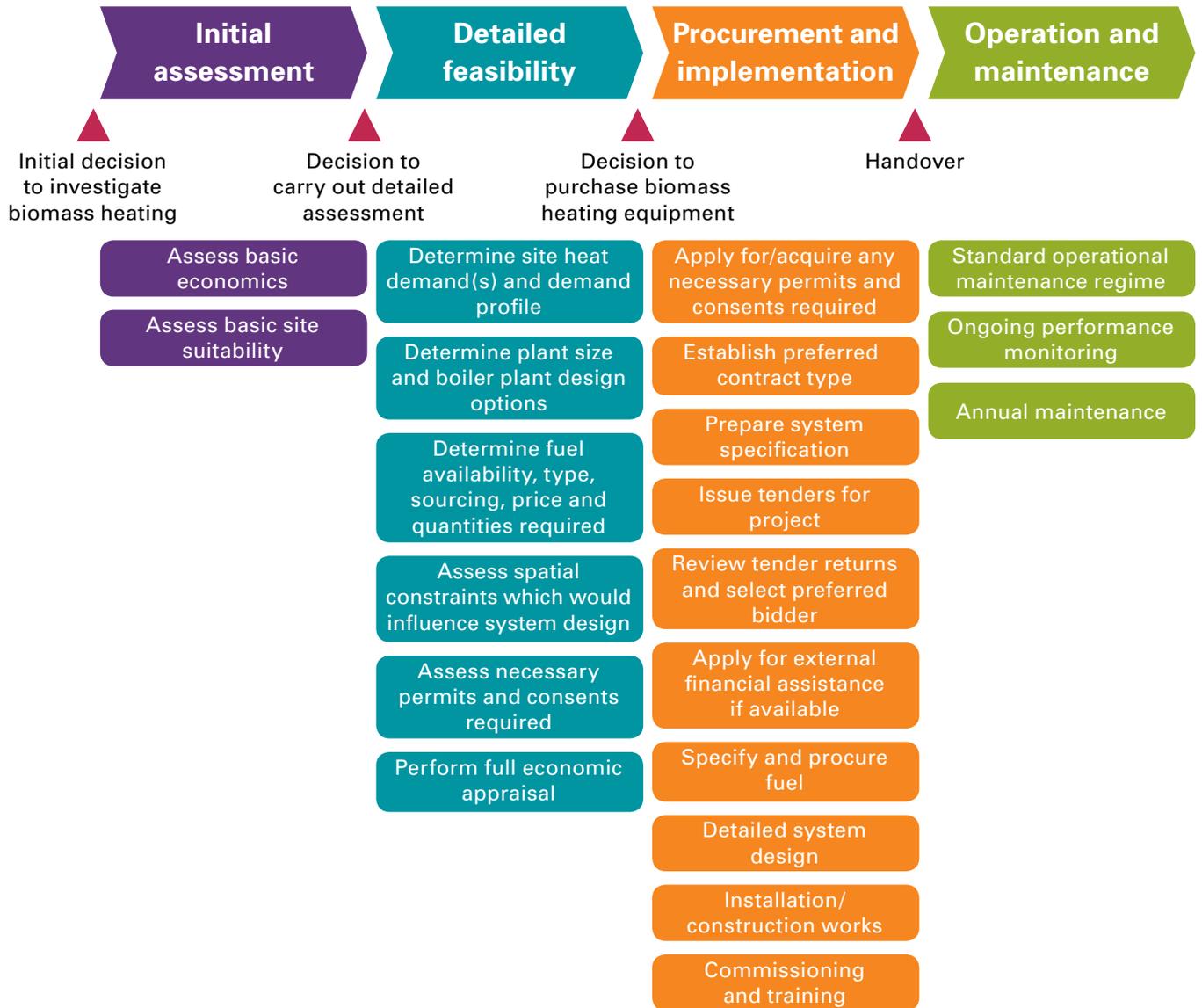
Part 3 – Implementation guide

A summary guide to conducting a detailed feasibility study for a biomass system, implementing a project and planning operation and maintenance.



Page 49

Stages in a biomass heating project implementation



Part 1 – Introduction

This section of the guide introduces the concept of biomass as an alternative fuel for heating. It describes the carbon cycle and the sustainability of biomass as a fuel. It also gives a basic introduction to the technology, the state of the current market in the UK and the EU, and general aspects of using this source of renewable, low carbon energy.

1.1 What is biomass?

Biomass is organic matter of contemporary biological origin (i.e. that was living recently) such as wood, straw, energy crops, sewage sludge, waste organic materials, and animal litter. It can be viewed as a form of stored solar energy which is captured by the organic matter as it grows. This energy is released by combustion (burning) or fermentation and distillation (to produce liquid transport fuels). Biomass materials used as fuel sources can provide heat, electrical and motive power.

Biomass already makes an important contribution to the UK's renewable energy supply, representing 82%⁴ on a primary input basis in 2006 (1.9% of total primary energy consumption). Biomass has considerable untapped resource potential and, in future, could play a significant role in helping the UK to meet a range of existing renewable energy and greenhouse gas (GHG) reduction targets.

Combusting biomass fuels (such as wood, straw or energy crops to produce heat or hot water and to raise steam for space or process heating applications) is currently recognised^{5,6} as being one of the most cost-effective ways of using biomass for energy conversion purposes, in terms of the cost per tonne of carbon emissions avoided.

In the context of small heating systems, the term 'biomass' normally refers to wood-based fuels such as woodchips or wood pellets, but it can also include other materials such as straw bales and more conventional wood logs.

1.2 Why is biomass a renewable and low carbon source of fuel?

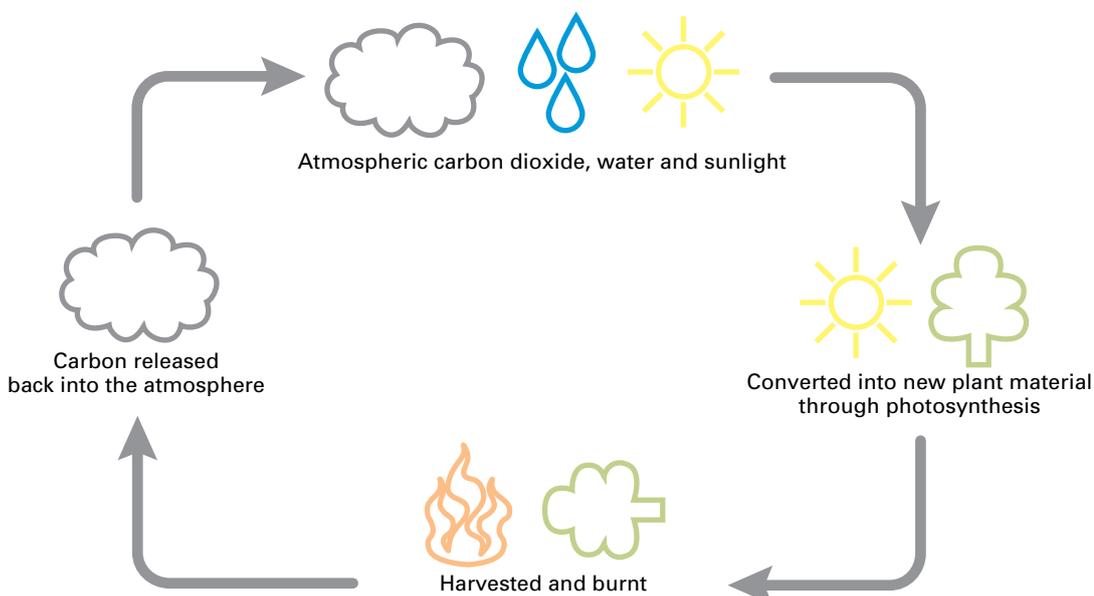
The sun is the primary source of energy contained within all biomass fuels – its energy is captured and stored via the process of photosynthesis. This energy can be released and used (e.g. by combustion). When this occurs, CO₂ and other by-products of combustion are also released. However, the CO₂ released is largely offset by that which was absorbed in the original growth of the biomass, or which will be captured in the growth of new biomass to replace the biomass being used (as illustrated in Figure 1).

Consequently biomass is considered to be a low carbon technology if the material is derived from sustainable sources.

In contrast, when fossil fuels are combusted, they release CO₂ that was captured by photosynthesis millions of years ago, and it is the release of this 'fossil' CO₂, as opposed to contemporary 'biogenic' CO₂, that is the major contributor to global climate change.

Although the CO₂ resulting from the combustion of biomass can be recaptured by the new growth of sustainable biomass, some net emissions still result from the cultivation, harvesting, processing and transportation of the fuel, and the manufacture and operation of the necessary equipment (e.g. the biomass plant). These processes consume fossil fuels and thus lead to some CO₂ emissions.

Figure 1 A typical biomass carbon cycle



⁴ BERR (July 2007) *UK Energy in Brief* (includes all biomass sources). <http://www.berr.gov.uk/whatwedo/energy/statistics/publications/in-brief/page17222.html>

⁵ The Carbon Trust (October 2005) *Biomass Sector Review* for the Carbon Trust. www.carbontrust.co.uk/biomass

⁶ Defra (May 2007) *UK Biomass Strategy*. <http://www.defra.gov.uk/environment/climatechange/uk/energy/renewablefuel/pdf/ukbiomassstrategy-0507.pdf>

Although there are some net CO₂ emissions from using biomass, the considerable body of publicly available research indicates that using solid biomass for heating typically gives reductions in carbon emissions of around 90% relative to using fossil fuel heating systems, when these net emissions have been taken in to consideration.

Table 1 shows the typical ranges of carbon emissions per unit of power which are achieved for biomass when used for heating and electricity conversion, relative to conventional fuels. These figures include raw material supply, production, transport, energy generation and eventual disposal.

Table 1 Lifecycle CO₂ emissions comparison⁷

Electricity generation	kg CO ₂ /MWh
Wind	6.9-14.5
Biomass	15-49
Natural gas	369-398
Space heating	
Biomass (woodchip)	10-23
Natural gas	263-302
Oil	338-369

However, some emissions comparisons between biomass and conventional fuels, often understate the carbon-saving benefits that biomass technologies offer relative to fossil fuels. Unlike the figures in Table 1, they often fail to account for the embodied and operational carbon emissions associated with the 'upstream' activities of exploration, extraction, transportation and processing of fossil fuels, whereas these are explicitly accounted for in any lifecycle assessment. When the full upstream emissions associated with fossil fuels are also taken into account, the net carbon emissions of most biomass heating scenarios are even lower.

1.3 Why use a biomass heating system?

Using biomass is one of the only cost effective and practical ways to provide space heating, hot water and process heating/steam from a low carbon source. Also, using biomass sources for heating provides more cost-effective carbon savings than for other uses (e.g. for electricity or transport fuels). It typically offers the highest carbon savings per unit mass of biomass, and the highest carbon savings that can be obtained by using a unit of land to grow biomass⁸.

While organisations may choose to implement a biomass heating system for a number of different reasons, the major drivers are as follows:

1) Significant carbon savings. Biomass heating systems can play a major role in reducing an organisation's carbon footprint. Many organisations now have commitments or requirements to reduce their overall emissions and improve their environmental performance – implementing a biomass heating system could help to do this.

2) Operational cost savings. The costs of biomass fuels are typically lower than the fossil fuel being displaced and biomass heating systems can therefore provide attractive operational cost savings. The scale of savings depends on the price of the fossil fuel being replaced and the cost of the biomass fuel used. On a unit cost-basis, biomass fuels can be cheaper than many fossil fuels commonly used for heating. Cheaper fuel translates into lower running costs, and hence annual savings which over time help pay back the higher capital outlay on the biomass system (compared to fossil fuel systems). When replacing electric, LPG or heating oil systems, the payback on capital can be very rapid (in some cases <3 years for applications with a high heat load). In addition, certain financial incentives from the UK Government for biomass heating projects may be available which could help to improve the economic performance of the project further (see box on page 65).

3) Reduced fuel price volatility. Security of energy supply is a recurrent concern for fossil fuels; geopolitical instabilities in oil and gas producing regions can threaten availability and lead to unexpected price changes. While biomass fuels will be subject to changes in price over time (and will be affected in some manner by international fossil fuel/commodity prices), these are likely to be less extreme than can occur with fossil fuels and may also be more manageable/predictable if the biomass is sourced locally/from known suppliers.

⁷ Drawn from: World Energy Council (2004) *Comparison of Energy Systems Using Lifecycle Assessments*.

⁸ The Carbon Trust (October 2005) *Biomass Sector Review* for the Carbon Trust. www.carbontrust.co.uk/biomass

4) Wider sustainable development benefits. Fuels used typically with biomass heating systems tend to have diverse and localised fuel supply chains. Using biomass fuels for heating can have positive side-benefits along this supply chain such as improving the biodiversity of existing woodlands⁹ and providing opportunities for rural employment and economic diversification.

5) Resources diverted from landfill. Using certain biomass resources as fuels can divert them from becoming wastes and being sent to landfill. Currently c.10 million tonnes of waste woods are produced each year¹⁰, the majority of which goes to landfill. Some organisations produce co-products such as wood off-cuts, sawdust and tree-surgery residues (arboricultural arisings) that can be used as a biomass fuel. Disposing of such wastes normally has a considerable associated cost and using wastes as fuels can therefore also bring significant financial benefits¹¹.

6) Reduced exposure to climate-change related legislation. Biomass fuels do not register as part of an organisation's overall carbon emissions (or fossil fuel consumption), thus reducing exposure to the Carbon Reduction Commitment (CRC) and the EU Emissions Trading Scheme (EU ETS), if the organisation is subject to these schemes. A biomass heating system can also help organisations to meet their Climate Change Agreements (CCAs) by reducing emissions of greenhouse gases and consumption of fossil fuels.

7) Improved energy performance ratings for buildings. Using biomass heating equipment in new or refurbished building stock could help to improve its overall environmental/energy performance. As such, it could help achieve higher ratings in such schemes as BREEAM (Building Research Establishment Environmental Assessment Method) and the Code for Sustainable Homes. Installing a biomass heating system in a new or refurbished building could also help it to achieve lower carbon emissions as represented in an EPC (Energy Performance Certificate) and DEC (Display Energy Certificate). Biomass systems can also assist compliance with 'Part L' of the building regulations and 'Merton Rule'¹² requirements.

In summary, within the context of changing energy prices and the need to reduce carbon footprints while also diversifying sources of energy, biomass heating offers a number of advantages which merit its further investigation by interested organisations.

Case study: Bell Bros Nurseries Ltd



Bell Brothers Nurseries Ltd is one of the UK's market leaders in growing bedding plants and supplies to all parts of the market including DIY stores, supermarkets, wholesalers and local councils. The enterprise has over 50,000m² of modern, automated glasshouses which require year-round heating to maintain optimum growing conditions. Historically the main heating fuel had been heating oil. Rises in the price of this fuel and the associated increase in running costs led to the need to investigate other alternatives. The nursery's management began researching the viability of biomass as an alternative heating solution to reduce heating costs in 2004/5.

After a detailed feasibility study, a decision was taken to install a 2MW_{th} biomass boiler in October 2007 which is expected to deliver approximately 60-70% of the annual heating requirement to 33,000m² of glasshouses. The boiler is of a moving (reciprocating) grate design and is expected to consume c.2000-2500 tonnes of wood-chip (or equivalent) per annum. The moving grate design was chosen to enable the system to burn a wide variety of different types of potential biomass fuels (including lower quality woodchips, miscanthus grass, agricultural residues, and fuels with high moisture contents – up to 55-60%). This gives Bell Brothers Nurseries considerable fuel flexibility and could allow them to take advantage of very low cost fuels.

The project received a capital grant which amounted to 17.5% of the total capex. Depending on fossil fuel prices, the project is expected to achieve payback in 4 years.

⁹ Forestry Commission (2007) *A Woodfuel Strategy for England*. <http://www.forestry.gov.uk/england-woodfuel>

¹⁰ Defra (2008) *Waste Wood as a Biomass Fuel*. <http://www.defra.gov.uk/environment/waste/>

¹¹ Using biomass resources that are (or could be seen to be) 'wastes' can be affected by waste legislation and potential users should read section 3.2.5 in detail before pursuing this route.

¹² The 'Merton Rule' is a planning policy, pioneered by the London Borough of Merton, which requires the use of renewable energy on-site to reduce annual carbon dioxide (CO₂) emissions in the built environment and is now in use by many local authorities around the UK.

Biomass heating technology overview

A biomass heating system is any heating system that primarily uses biomass as a fuel (some systems can also dual-fire with a fossil fuel to meet peak demands, or for back-up).

Biomass heating systems can be used for space heating of buildings, hot water production, steam production, or any combination of these. They can be used at almost any scale, from domestic (c.10kW_{th}) through to 'light' commercial (c.50kW_{th} to several MW_{th}), to industrial or district heating systems (up to hundreds of MW_{th}). While this guide focuses on the scale range of 100kW_{th} – 3MW_{th}, most biomass heating systems have strong similarities above and below this size range.

The key elements of a whole biomass heating solution are:

- Fuel delivery from a fuel supplier.
- Fuel reception, storage, and extraction from storage to the boiler unit.
- A specialised biomass boiler unit.
- Ancillary equipment: flue (chimney), ash extraction mechanism, heat storage, connecting pipework, expansion tank, fire dousing system, controls systems and possibly an integrated fossil fuel system.

From an operational perspective, one of the most notable differences between a biomass heating system and a conventional fossil fuel heating system is that the biomass boiler is best suited to being operated relatively continuously (between c.30% and 100% of its rated output). This means that a heat store, and/or a fossil fuel system to manage peak demands, is often specified in addition to the biomass boiler. Also, a biomass heating plant will be considerably larger in volume than an equivalently rated fossil-fuel plant due, in part, to the inherent combustion characteristics of solid, organic materials.

Biomass fuel is typically woodchips or wood pellets, but it can also be other biomass material such as logs and straw bales. It is normally delivered from a dedicated fuel supplier, but it can be on-site material (e.g. on farms and estates), or delivered from a fuel supplier in a less processed form (e.g. logs, slabwood, roundwood etc.).

Fuel must be physically delivered into a fuel storage system (a small shed-type building or purpose-built specialist store) and then must be transferred into the combustion grate of the main boiler via a mechanical handling system (e.g. screw auger/ram stoker).

The biomass boiler is the heart of the biomass heating system, and there are many different types and models. These are usually classified by the type of biomass they are suitable for use with (e.g. dry woodchip, wet woodchip, pellet, log, bale, etc.); by the type of combustion grate; and also by their rated thermal output. They vary from manually fed, generally small, boilers with few controls, through to fully automatically fed boilers with automatic ignition and full remote monitoring and control systems. The choice of boiler type is determined, in the first instance, by the fuel that is intended to be used, and then the level of automation required; this is a trade-off between convenience and cost.

The ancillary equipment (such as the flue/chimney) and ash handling is mostly determined by the type and size of the boiler, whilst the need for thermal stores (e.g. hot water cylinders) and fossil fuel stand-by is determined by the site heat load and reaction times required.

The biomass market

When considering the installation of a biomass boiler or CHP system, it is helpful to appreciate the current position of the biomass market. This section provides some statistics on the contributions of biomass to global energy supplies and observations about the current state of the UK biomass energy supply industry.

Contributions of biomass to energy supplies

Worldwide in 2006, of the 12.7% of primary energy that was supplied by renewables, almost 75% (9.5% of total) came from solid biomass¹³ (around 1,100 Mtoe¹⁴). This is due to the widespread use of solid biomass for domestic purposes in developing countries. However, while contributing more than any other form of renewable energy, solid biomass is also growing more slowly than other forms. For example, while wind energy grew at an average rate of 24.5%/year between 1990 and 2006, solid biomass increased at only 1.5%/year. This is perhaps due to developed nations giving solid biomass relatively little priority as a commercial energy technology, and growth in developing countries increasing only due to population growth.

Looking at Europe, the extent to which heat is derived from biomass sources varies significantly between countries. Figure 3 shows that at most (Sweden), heat from biomass sources provide approximately 38% (~60 TWh/year) of the country's overall heat demand. For comparison, the UK currently uses about 0.7 Mtoe of biomass to supply heat¹⁵, this is equivalent to less than 0.6%¹⁶ (~4 TWh/year) of the UK's overall heat demand.

There is significant potential for a greater proportion of the UK's heat to be derived from biomass. For example, it is estimated that a contribution of 6% (a more than tenfold increase) is achievable if just industrial, commercial and residential heat customers that are located off the gas grid switched to biomass¹⁷. Moreover, there is a strong requirement to move to biomass and other low carbon heating fuels to mitigate climate change. Currently around half (49%) of the UK's total primary energy demand is in the form of heat and meeting this demand with fossil fuels causes about half (47%) of the country's total carbon emissions.

With the introduction of new targets across the EU for the total primary energy to be supplied by renewables, as agreed by EU Heads of State in 2008, the question of how much heat biomass sources could provide over the next decade is highly topical. Considering the proposed UK target of 15% total primary energy, the recent BERR Renewable Energy Strategy consultation¹⁸ suggests that 14% of the UK's total heat demand may need to be derived from renewables by 2020, with a little under half of this (c.6.4%) coming from solid biomass. This is roughly equivalent to 39.8 TWh/a (3.4 Mtoe).

State of UK biomass industry

The UK biomass heat industry is currently small, reflecting the relatively small amount of heat and electricity derived from biomass. The majority of biomass boilers are manufactured and imported from other European countries, with UK companies tending to focus on biomass system installation, operation and maintenance. Approximately 35 firms are active in the installation of commercial scale systems of greater than 100 kW_{th} capacity, with services ranging from supplying and commissioning boilers to complete turnkey installations, including design and installation of district heat networks.

¹³ Source: International Energy Agency (2006 data).

¹⁴ Million tonnes of oil equivalent.

¹⁵ Source: BERR energy statistics. The figure is for 2007 and includes several forms of biomass in addition to solid biomass.

¹⁶ 0.6% is an estimate of the total heat provided from renewable sources.

¹⁷ Source: Office of Climate Change.

¹⁸ Source: *Renewable Energy Strategy Consultation*. <http://renewableconsultation.berr.gov.uk/>

The biomass market (continued)

Figure 2 Gross solid biomass heat production from thermal and CHP plant in EU countries, 2005¹⁹

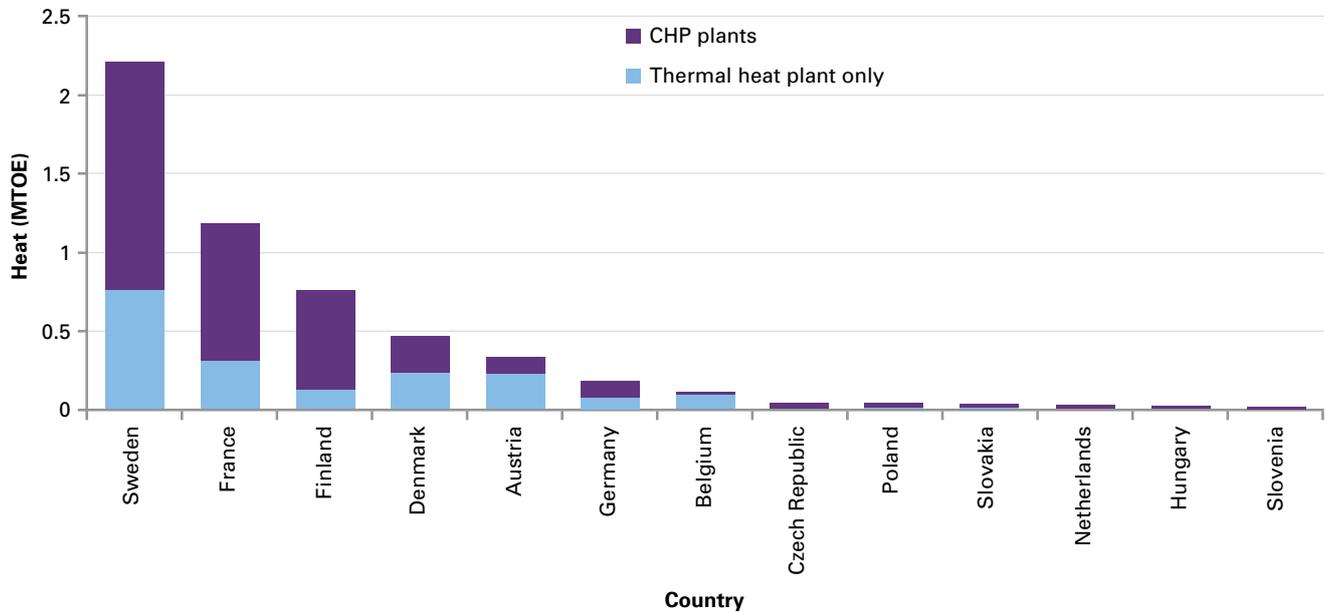
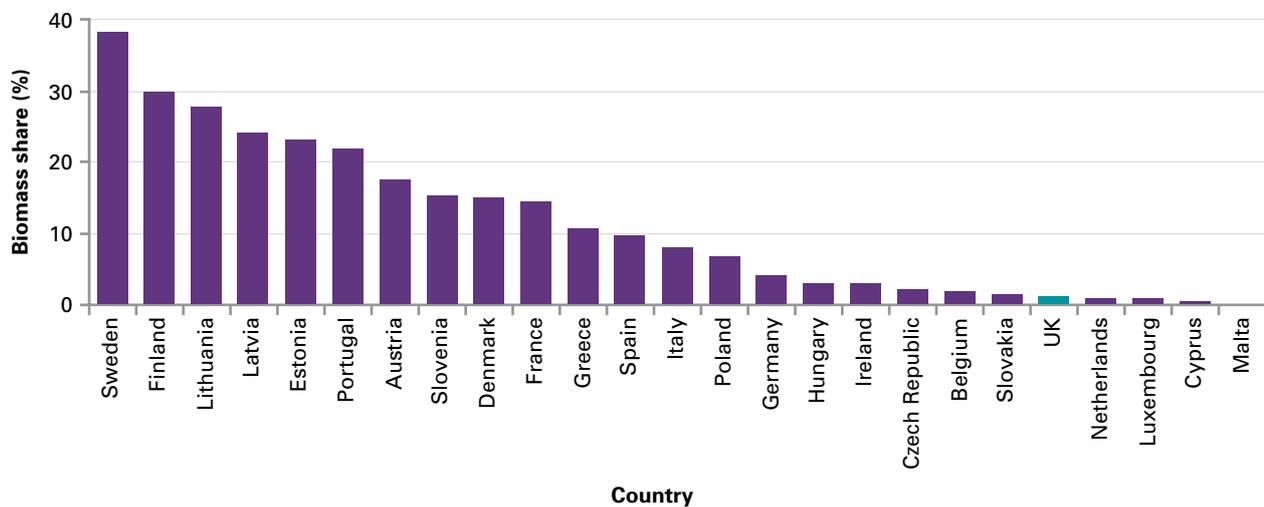


Figure 3 Shares of biomass in the national heating markets of EU countries, 2006²⁰



Considering biomass fuel supplies, at least 70%²¹ of the UK's biomass by total primary energy is estimated to originate from the UK, while the remainder is imported. There are estimated to be over 200 UK companies and organisations directly involved in the supply of biomass fuels. Current suppliers of solid biomass fuels range from small companies or individuals who may also

operate other businesses in addition to fuel supply, through to large scale, forestry contractors supplying large quantities in bulk. Recently, a number of biomass fuel supply cooperatives/brokers have emerged who provide a single contracting party but draw upon fuel sourced from a number of suppliers.

¹⁹ EurObserv'ER Barometer project (2007) www.erec.org/projects/ongoing-projects/euroobserver (note that the figures used in this chart exclude the use of biomass in domestic applications, thus the countries which feature most significantly in this figure are those having developed the use of district heating networks).

²⁰ Van Steen, H (2007) *European Commission Renewable Energy Policy* www.greenpowerconferences.com/renewablesmarkets/documents

²¹ Estimated from *UK Energy in Brief – 2008 BERR*.

Part 2 – Technical manual

This part of the guide is a reference manual containing key background information on the main elements of a biomass heating solution: fuel (characteristics, sourcing, reception, storage), and plant (design, features, operation).

2.1 Biomass fuels

This is an introduction to the range of types, physical characteristics, standards, and the delivery/storage methods of biomass fuels suitable for heating systems.

2.1.1 Sources of fuels

There is a wide range of original sources of biomass fuels which can be broadly defined in terms of 'wet' and 'dry' sources. Under these two broad headings, the sources can be grouped into five categories:

1. Virgin wood



Dry – includes roundwood, harvesting residues (brush), bark, sawdust, crowns, and residues of tree surgery.

2. Energy crops



Courtesy of Econergy

Dry – includes woody energy crops (short rotation forestry, willow, eucalyptus, poplar), grassy energy crops (miscanthus and hemp); sugar crops (sugar beet); starch crops (wheat, barley, maize/corn); oil crops (rape, linseed, sunflower); and even hydroponics (lake weed, kelp, algae).

3. Agricultural residues



Wet – includes pig and cattle slurry, sheep manure, grass silage.

Dry – includes poultry litter, wheat or barley straw, corn stover.

4. Food residues



Courtesy of B&V

Wet – includes wastes from various processes in the distillery, dairy, meat, fish, oils, fruit and vegetables sectors.

5. Industrial residues



Wet – includes sewage sludge.

Dry – includes residues from sawmills, construction, furniture manufacturing, chipboard industries, pallets.

Not all these sources, are suitable for use in the types of biomass heating plant considered in this guide.

This guide concerns itself with dry biomass fuels only. The typical sources of fuel for such biomass plant are: virgin wood, woody and grassy energy crops, certain agricultural residues, products such as wheat or barley straw and in some circumstances pressed oil cakes²² and certain industrial wood residues.

Virgin wood

Virgin wood is untreated and free of chemicals and finishes. It comes from a variety of sources; forestry is the primary source, with other sources being arboricultural arisings (tree surgery waste) and co-products from wood processing facilities (such as sawmills, furniture factories).

Typically, high quality logs and stemwood enter the wood processing industry, leaving less valuable timber available for processing into woodfuel. This generally includes branches, bark and brush²³. The provenance of the virgin wood is of critical importance as this can affect both plant performance and any environmental permits that may be required (see section 3.2.5).

²² Some existing users of heating-oil fired plants have investigated using biodiesel in place of heating oil in conventional plant. However, it should be noted that using biodiesel in this manner may not offer significant cost benefits over heating oil and will have the associated sustainability/carbon saving uncertainties that using biodiesel as a vehicle fuel has.

²³ It should be noted that high levels of dirt (from stumps) can cause performance issues with boilers and wood from seaside and roadside areas can contain high levels of salts which can also affect plant performance/service life.

Energy crops

Energy crops are crops grown specifically for the production of energy. Currently only small quantities are cultivated in the UK (c.0.2TWh/yr²⁴); however, it is possible that considerably more could be grown in the future. Woody energy crops could supply up to 38TWh/yr²⁴ by covering an area of 680,000ha. Short rotation coppice (SRC) is the most common energy crop grown in the UK; willow is the preferred species although poplar is increasingly being used²⁵. Similarly a growing number of systems are using miscanthus.

Users would typically purchase energy crops in a processed and chipped form, although miscanthus can be baled and/or chipped. It is important to ensure that the equipment specified is suitable for use with such material – particularly miscanthus as the chemical composition of the fuel may affect the combustion characteristics and users need to be sure that the system can tolerate its particular combustion profile.

Agricultural residues

Wheat or barley straw is commonly used in batch-fired plant in the UK, typically in systems located on farms and rural situations. For these types of application, batch-fired biomass systems can offer a very cost competitive alternative to fossil fuel heating, though the systems require daily user input.

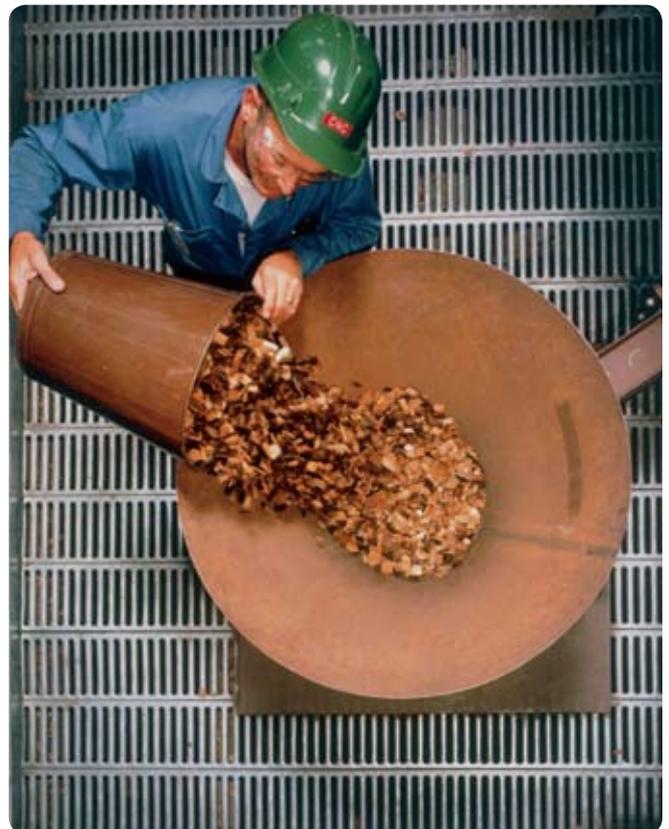
Corn stover and oil cakes are other agricultural residues that have been used as biomass fuels for heating too and a wide variety of other dry agricultural residues have been processed into pellet form for fuel²⁶. However, pellets for biomass heating systems made from agricultural residues are less common in the UK than pellets made from compressed sawdust.

Industrial residues

'Treated' and 'untreated' wood residues may be used in biomass plants, but it is important to consider if:

- The fuel complies with the appropriate environmental legislation. The installation of a biomass system for use with waste biomass material will require an appropriate consent.
- The specified system is able to tolerate the fuel characteristics of the waste material. For example, the use of extremely dry woodchip may be detrimental to plant performance unless it has been commissioned specifically to burn this type of material.

Typically untreated wood residues or co-product comes from off-cuts and sawdust from those industries that work with untreated wood, for example, sawmills and timber yards. Sources of treated wood residues might include construction and demolition sites, or furniture manufacturers.



²⁴ Carbon Trust (2005) *Biomass Sector Review*. www.carbontrust.co.uk/biomass

²⁵ It should be noted that energy crops are not always suitable for small heating systems, and their suitability should be checked with the system supplier.

²⁶ Pastre, O (2002) *Analysis of the technical obstacles related to the production and utilisation of fuel pellets made from agricultural residues*.

Fuel supply and sustainability

Like conventional heating systems, biomass systems are reliant on physically produced and traded fuel supplies. The availability and costs of these supplies vary over time, subject to the demand for fuels for energy production but also due to wider market factors, (for example, the case to grow dedicated energy crops depends on conditions in the farming industry). Yet it is possible to estimate the total quantity of biomass available for heating systems in the UK, as outlined below.

The production of organic material for energy purposes (heat, electricity and transport) can have environmental and socio-economic impacts, some of which are negative. Over the past year, media attention has been drawn to these impacts and cases made for improved sustainability standards and changes in Government policy²⁷. Fortunately, the types of biomass fuel used for UK heating systems are unlikely to raise sustainability concerns, as this box explains.

UK fuel supplies

It is currently estimated that 3.11 MToe (36.2 TWh) of biomass is being used annually to generate electricity, and 0.45 MToe (5.2 TWh) to produce heat²⁸. Studies of UK biomass resources suggest this usage is about half the total quantity of biomass currently available. The 2005 Biomass Task Force²⁹ estimated this as 4.8-5.7 Mtoe (55.8-66.3 TWh), and 5.6-6.7 Mtoe (65.1-77.9 TWh) was suggested by a more recent study³⁰.

Current resources represent only a fraction of what could be available in future. In a scenario in which quantities of biomass from forestry and waste resources stay the same as today, but increasing amounts of energy crops are produced, 8.3 Mtoe (96.5 TWh) has been forecast for 2020³¹. This is equivalent to almost one hundred and forty thousand 400 kW_{th} boilers (operating at a 20% capacity factor). This suggests that for the foreseeable future, sufficient UK biomass fuel resources could exist to supply a large number of new biomass heating systems – therefore in theory, any new installation should not have difficulty in securing supplies.

From the perspective of site owners, biomass fuels can be purchased from an increasingly wide range of suppliers. However, since biomass heating is still currently an early-stage market, extensive fuel supply chains have yet to be fully developed. As consequences of this:

- Fuels tend to vary in their specifications and quality, and obtaining biomass of a required or desired standard can sometimes be challenging. For further details, see the box on fuel standards and specifications on page 23.
- Sourcing fuels may be difficult in certain areas of the UK. However, new networks of suppliers are beginning to take shape with support from bodies such as regional development agencies. A list of such supplier networks is available on the Carbon Trust website (www.carbontrust.co.uk/biomass).

Sustainability

When considering biomass and issues of sustainability, it is important to understand that:

- The types of solid biomass likely to be used for UK heating systems (e.g. wood chips or pellets) are based on feedstocks different to those used for the current generation of liquid biofuels (e.g. palm oil) for transport.
- This distinction is highly significant to the carbon cases for such types of biomass and other aspects of their sustainability, with solid biomass offering many advantages over current transport biofuels.

For example, whereas growing palm oil in a developing country may involve land degradation or large-scale deforestation (both of which could increase carbon emissions), using compressed sawdust or residue materials such as forestry brash in the UK to make wood chips and pellets requires no such compromises. Such materials (residues, sawdust, brash) are:

- Unlikely to have been grown on prime agricultural land, so are not in competition with food crops.
- Likely to have been harvested as part of a sustainable land management process. For instance, the majority of UK forestry activities are subject to Forestry Commission sustainable management regulation.

²⁷ UK Government perspectives are given in the House of Commons Environmental Audit Committee report *Are Biofuels Sustainable* (2008), and the Department for Transport report *Review of the Indirect Effects of Biofuels*.

²⁸ Defra UK Biomass Strategy (2007).

Fuel supply and sustainability (continued)

Where biomass is imported to the UK, for example from North America, it is likely that the biomass feedstocks will also have been harvested sustainably. However, the impacts of transport should be included in assessment of the lifecycle carbon emissions.

It is worth noting that where biomass materials used for heating fuels would otherwise have gone to landfill as waste, there is a significant, additional benefit: by averting the methane that would have been emitted during their decomposition. Methane is a greenhouse gas with a global-warming potential 21 times higher than that of carbon dioxide.

At present there are no international standards³² for the overall sustainability of solid biomass fuels. However, work is underway to introduce these; the CEN (European Committee for Standardisation) has convened a Technical Committee (CEN TC 383) to produce sustainability criteria for all biomass fuels. The International Standards Organisations (ISO) is also examining such criteria.

In the absence of such standards, it is advisable for site owners to ask suppliers of biomass material, both locally produced and imported, about the sustainability of their products.

2.1.2 Types of fuel

The majority of raw biomass materials (feedstocks) require some form of processing before they become biomass fuels. Processes can range from simple cutting and drying to more involved processes like pelletising.

The method of processing which a biomass feedstock undergoes is important because it will determine its eventual application and usefulness as a fuel and will also determine the type of biomass heating plant that can be used for a project.



Table 2 Typical fuels for biomass heating projects

Fuel format	Utilisation
Logs	Most commonly used in small-scale systems (<50 kW _{th} – domestic to light commercial scale) requiring daily input to load the system with fuel.
Bales	Generally either manually fed 'batch-firing' systems below 300 kW _{th} (as above, requiring daily input to load the system with fuel) or alternatively very large (multi-MW _{th}), automatically-fed heating/CHP plant.
Chipped/shredded wood	Typical fuel for most automated biomass systems (50 kW _{th} – multi-MW _{th} applications).
Pellets	Most commonly used in smaller or urban systems (light commercial <150 kW _{th}) due to their greater energy density (at larger scales the higher cost of wood pellets compared to woodchip becomes significant). Wood pellets are also used for 'co-firing' within existing electricity power stations.
Woodworking off-cuts/sawdust	Some biomass plant is specifically designed to burn co-products from the wood industries such as furniture off-cuts and sawdust.
Cereals/grains	Some biomass plant can burn common agricultural commodities such as oats and spent grain.

²⁹ Defra (2005) *Biomass Task Force – Report to Government*.

³⁰ Defra (2007) *UK Biomass Strategy* (2007).

³¹ Defra (2007) *UK Biomass Strategy* (2007).

³² For details of other relevant standards, see the box on page 23.

Characteristics

Biomass fuels have a range of characteristics which affect their performance and also the type of biomass heating equipment they can be used in. Some of the most important factors are listed below and a table presenting the most common fuels and their associated characteristics is given at the end of this section.

Calorific Value (CV)

This is a very important characteristic; it indicates the heating potential of a fuel and is a measure of its energy content. It is defined as the amount of heat released from a specific unit of fuel by its complete combustion. Biomass fuel CVs are conventionally expressed as MJ/kg. The calorific value of a fuel is expressed either as Gross Calorific Value (GCV – also sometimes known as Higher Heating Value (HHV)), or Net Calorific Value (NCV – also sometimes known as Lower Heating Value (LHV)).

- **Net Calorific Value (NCV)** – is the quantity of heat given off by the complete combustion of a unit of fuel when the water vapour produced remains as a vapour and the heat of vaporisation is not recovered. This can be calculated by subtracting the heat of vaporisation of the water produced from the GCV. The NCV is more widely used in the UK than the GCV.
- **Gross Calorific Value (GCV)** – is the quantity of heat liberated by the complete combustion of a unit of fuel when the water vapour produced is condensed, and the heat of vaporisation is recovered. The water is condensed by bringing the products of combustion (flue gases) below 100°C (as in a condensing plant). This generally does not apply for biomass as the flue gases cannot be cooled below c.130°C, and hence the water vapour cannot be condensed.

Note that (for wood) the GCV is usually 6-7% higher than the NCV.

The key determinant of biomass material's calorific value is the inherent moisture content (MC). The MC of material can vary greatly from c.5-8% for wood pellets, c.35% for conditioned fuel and up to 65% for freshly felled timber.

The greater the MC the less energy is contained within the fuel.

Moisture content (MC)

This is expressed as a percentage, measured either on a 'wet' or 'dry' basis. Wood suppliers (for example) typically use the wet-basis method because it gives a clearer indication of the water content in timber.

The wet basis calculation expresses the moisture content as a percentage of the mass of the material including any moisture. In the formula below 'oven dry mass' is defined as the mass of biomass which has had all the moisture driven out:

Wet basis

$$MC = \left(\frac{\text{Fresh mass} - \text{Oven dry mass}}{\text{Fresh mass}} \right) \times 100 (\%)$$

The dry basis calculation expresses the moisture content as a percentage of the oven dry mass:

Dry basis

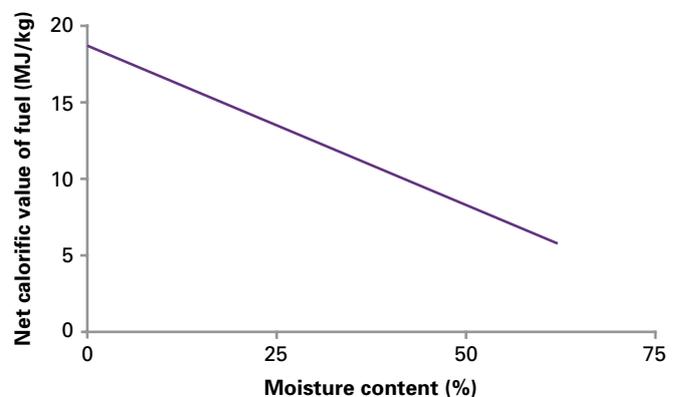
$$MC = \left(\frac{\text{Fresh mass} - \text{Oven dry mass}}{\text{Oven dry mass}} \right) \times 100 (\%)$$

A higher MC implies a lower calorific value as each unit mass of fuel contains less oven dry biomass – which is the part of the fuel that actually undergoes combustion to release heat. The effect is more noticeable for most biomass heating systems where the water vapour in the combustion products cannot be condensed. This is because the moisture in the fuel also has to be vaporised before combustion can occur and this requires energy input that cannot be recovered later.

The majority of the biomass industry uses wet basis when discussing biomass fuels.

Figure 4 shows the calorific value of wood (measured in MJ/kg) as a function of its moisture content (MC). Clearly, dry wood has greater energy content than wet wood, and this is reflected in the typical market price for woodfuels.

Figure 4 The effect of moisture content (MC) on calorific value (NCV)



The formula for calculating the effect of fuel moisture content on net calorific value is outlined in Appendix B.

Bulk density

This is a measure of the mass of many particles of the material divided by the volume they occupy; the volume includes the space between particles. The higher the bulk density, the more mass of fuel exists in a given volume. For example wood pellets (c.660kg/m³) have a higher bulk density than wood chips (c.250kg/m³). Bulk density, unlike density, is not intrinsic to a material; for example, the same piece of wood could have different bulk densities if processed into logs, pellets or woodchips. Moisture content also affects bulk density as each particle has a greater mass but does not occupy more space.

This is an important point because fuels with higher moisture contents will have greater masses and, therefore, have lower bulk densities. With higher moisture content comes lower energy density, and therefore the volume of fuel required for a given amount of heat will be larger.

Energy density

Energy density is derived from the bulk density of a fuel and is a measure of the energy contained within a unit of fuel. Energy density is conventionally expressed in MJ/m³.

It can be derived by multiplying calorific value (MJ/kg) by bulk density (kg/m³).

Energy density is an important variable that will help users understand volumetric fuel consumption rates, the size of fuel storage required, the number of deliveries required and the total annual quantity of fuel required.

$$\text{Energy density (MJ/m}^3\text{)} = \text{CV (MJ/kg)} \times \text{Bulk density (kg/m}^3\text{)}$$

Table 3 Typical bulk, calorific and energy densities of different biomass and fossil fuels

Fuel	Net CV1 MJ/kg	CV kWh/kg	Bulk density kg/m ³		Energy density by volume MJ/m ³		Energy density by volume kWh/m ³	
			Lower	Upper	Lower	Upper	Lower	Upper
Woodchips @ 30%	12.5	3.5	200	250	2,500	3,125	694	868
Log wood (stacked – air dried: 20%MC)	14.6	4.1	350	500	5,110	7,300	1,419	2,028
Wood – solid oven dried	18.6	5.2	400	600	7,440	11,160	2,067	3,100
Wood pellets	17	4.7	600	700	10,200	11,900	2,833	3,306
Miscanthus (bale – 25%MC)	12.1	3.4	140	180	1,694	2,178	471	605
House coal	29	8.1	850		24,650		6,847	
Anthracite	32.1	8.9	1,100		35,310		9,808	
Oil	41.5	11.5	865		35,898		9,972	
Natural gas	-	-	-		36		10.13	
LPG	46.9	13.0	500		23,472		6,520	

Source: Gastec at CRE Ltd. and Annex A, Digest of UK Energy Statistics 2007

Particle size/dimensions

Biomass heating systems require physical handling mechanisms for transferring fuel from where it is stored to where it is combusted (in the plant). Fuel particles that are too large can jam certain fuel feed systems (e.g. augers) and, therefore, particle size is an important characteristic of a biomass fuel. All biomass fuels can come in a wide variety of shapes and sizes. Aside from moisture content, the particle size is the other key issue to consider when matching system design with the fuel available (see box on page 23 for further details on fuel specifications and classes).

Certain fuel feed systems can handle fuels with a broader range of particle sizes (e.g. walking floors and 'ram stokers'). Others (e.g. those designed to use pellet fuels) can only tolerate a more narrow range of particle sizes.

Mechanical durability

If the system being specified can only use pellet fuels, then the mechanical durability (how well the pellets stay together during handling) is a key consideration and should be specified. One issue that can occur with pellet fuels is disintegration (during the handling process). Good quality pellets should have a mechanical durability of at least 97.5%, meaning less than 2.5% of the pellets will be broken down after delivery. Many pellet fuels need some form of additive to act as a binding agent, which should be known and specified by the manufacturer.

Very small particles in the fuel (such as sawdust) may represent a certain proportion of the total weight of a sample of biomass fuel. Excessive amounts of such material may cause problems such as compaction in augers and smothering of the fire bed.

Original source

This characteristic is important as it has a bearing on whether or not the fuel is classed as a waste, and thus whether a project will need specific permits. The original source and knowledge of the supplier may also indicate that certain physical and chemical contaminants may be present in the fuel. For example, stones, gravel and dirt (which can affect plant performance through the formation of clinker in the combustion chamber, and through jamming augers) can become caught up in fuel if it has been sourced from tree surgery materials originally. Also, material from tree surgery can sometimes incorporate leaves and other green material (which are not suitable for combustion in most biomass heating systems). If it is known and accepted that the fuel may

contain residual materials such as solvents, chemical treatments and the others listed above, then the plant must be specifically designed to deal with these.

The source should be clearly identified when procuring fuel to guide environmental consent practice and plant specification.

Ash content

Although the amount of ash produced is partly dependent on the type and performance of the biomass plant it is being used in, it is also an inherent fuel property which is specified as a fuel characteristic. For example, a woodchip or pellet fuel would be expected to have an ash content of around 1% by weight (1-3% by volume) of the fuel consumed, whilst miscanthus (a type of energy crop) and straw will be higher.

Chemical content

It is natural for biomass to contain low levels of mineral salts and other trace 'non biomass' material, taken up from the soil or air during growth. The presence of these salts and other elements in 'virgin' biomass fuels does not normally cause any significant issues, but it does partly determine the level of gaseous/particulate emissions, ash, and slagging (also known as 'clinkering'). If, for instance, an annual crop is being used (e.g. straw) then more care is required, as these can have higher levels of alkaline metal salts. Also, if amounts of sand are present in fuel, this can result in glass formation during combustion.

For more detail on the specific properties of a wide range of biomass feedstocks used for fuels, the Phyllis database (www.ecn.nl/phyllis) contains information on a wide range of different chemical and physical characteristics.

Note that fuel characteristics such as the original source, ash content, chemical content and, to an extent, moisture content will have an effect on the level and composition of certain emissions to the air from the biomass heating plant that they are ultimately used in. This should be borne in mind when choosing fuel if local air quality is to be a key consideration as part of the necessary planning/consenting/permitting process required for the project in question (see section 3.2.5 for further detail).

Fuel standards and specifications

Successful operation of a biomass heating system is strongly dependent on the use of properly specified fuel.

To aid the matching of heating systems with fuel supplies, fuel standards have been introduced in several European countries. One of the best known sets of standards are the Önorm standards from Austria, which specify size, moisture content and various other important properties of solid biomass fuels³³. These standards are being used by some UK fuel suppliers in the absence of equivalent UK standards.

The CEN (European Committee for Standardisation) is developing a common methodology for specifying the key characteristics (those mentioned above plus original source, calorific value, chemical composition, physical properties etc.) of all forms of solid biomass sold within the EU, and also methods for testing these properties. The CEN specifications will eventually be transposed into member states' standards systems (e.g. those of the British Standards Institute).

At the time of writing, the specifications are available only in draft form, yet they are sufficiently well developed to be suitable for reference in fuel supply contracts, and the final versions are likely to be very similar. They can currently be downloaded free of charge from the Biomass Energy Centre website³⁴.

Regardless of which set of standards are referred to, it is important that the site owner works closely with both the fuel supplier and system installer to ensure that the fuel purchased is suitable for the system, that the fuel supplier undertakes to deliver a consistent quality of fuel and that the fuel can be stored and handled at the site in the correct manner. Draft fuel supply contracts to facilitate such cooperation can be downloaded from the Carbon Trust website (www.carbontrust.co.uk/biomass).



³³ http://www.sewf.co.uk/links/SEWF_Chip_Spec.pdf

³⁴ http://www.biomassenergycentre.org.uk/pls/portal/BIOAPPS.BSI_REGISTRATION_FRM.show

2.1.3 Fuel delivery, storage, extraction and feed

This section deals with the delivery and storage of biomass fuel for heating systems as well as how it can be extracted from the store into the combustion unit.

A well-designed system for delivering, storing and transferring solid biomass fuel is essential to ensure a smooth-running biomass heating system.

The solution must be fit for purpose and suitable for the life of the installation (typically up to 20 years). Specific site circumstances may mean that a degree of compromise to the 'ideal' solution is necessary. However, time spent planning and consulting with parties involved in the design, installation and operation (plant installer, fuel supplier, engineering contractors, architects etc.) at an early stage will help to ensure that common problems are avoided.

A good fuel delivery, storage and extraction solution will typically:

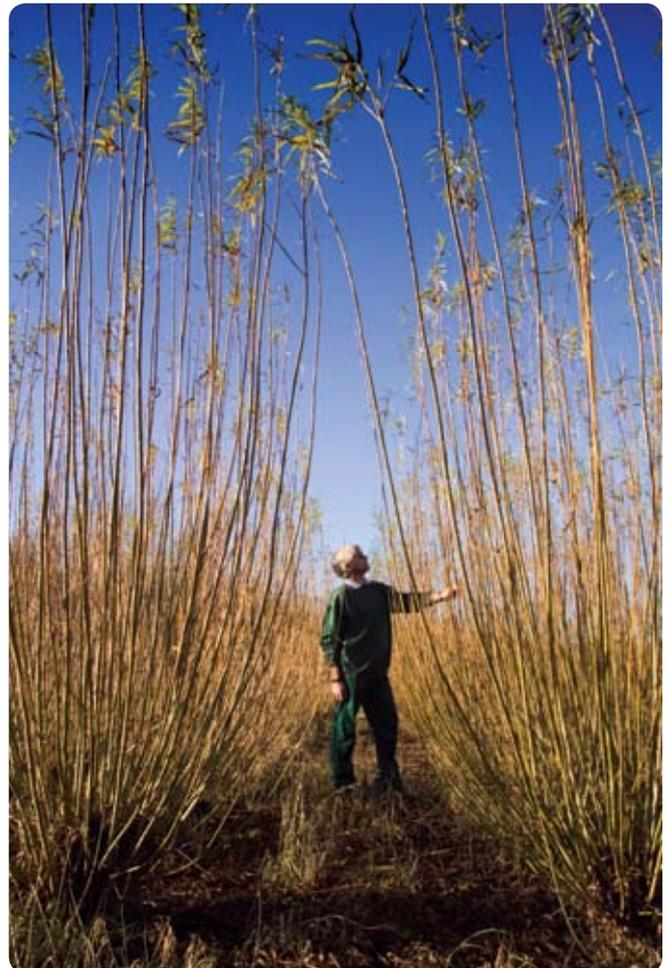
- ✓ Allow delivery by standard vehicles thus allowing fuel supply from a range of different parties.
- ✓ Enable speedy and simple discharge of fuel without the need for large amounts of attendance by staff.
- ✓ Prevent the ingress of water but also allow moisture vapour to escape from stored fuel.
- ✓ Allow safe dust venting and management where required.
- ✓ Meet necessary building regulations and health and safety requirements.
- ✓ Keep costs to a minimum³⁵.

Fuel delivery

There are a number of different fuel delivery and reception options available. Ultimately, the nature of the system adopted will be dependent upon:

- The proposed fuel for the application (wood pellet, chip, logs, bales etc.).
- The area available and any other physical access constraints at the site.
- The area required for the delivery vehicle to access the fuel store.
- The proposed delivery vehicles available from prospective fuel suppliers.

The typical methods and vehicles used in supplying biomass fuel for heating systems are outlined in Table 4 opposite. The major advantages and disadvantages of each option are shown in Table 5 (overleaf).



³⁵ In most biomass heating projects, the fuel delivery, storage, and extraction solution will be a major component of the overall cost. Careful design and also, where possible, designing to minimal requirements can help to control this cost.

Table 4 Type of fuel delivery method/vehicle and typical payloads

Delivery method	Example	Typical fuel type	Typical payload	Availability
Flexible hose from a blower tanker		Most commonly pellet but also chip	Pellet: c.15-20m ³ (10-14 tonnes) Chip: c.10-20m ³ (4.5-6 tonnes)	Pellet – common delivery vehicle. Chip – specialist delivery vehicle, not common.
Bulk bag deliveries		Pellet or chip	1-2m ³ /bag	Common in some areas (e.g. Scotland).
Tipper trailer		Pellet or chip	Chip: c.20-30m ³ (6-9 tonnes) Pellet: c.20-30m ³ (14-21 tonnes)	Tipper trucks widely available and common delivery method, particularly for chip.
Scissor lift tipping trailer		Pellet or chip	Chip: 20m ³ -30m ³ (6-9 tonnes)	Specialist delivery vehicle required.
Blower trough and tipper truck		Chip	c.20m ³ (6 tonnes)	Tipper trucks widely available but blower troughs are specifically purchased for site fuelling.
Hook lift bin/Ro-Ro bins		Chip	30m ³ -35m ³ (9-12 tonnes)	Specialist delivery vehicle required.
Front loader		Chip and bales	c.1m ³ (0.3 tonnes)	Common machinery for farm/estate application.
Walking floor trailer		Chip	60m ³ (18 tonnes)	Specialist delivery vehicle required – suited to large scale deliveries.

Images courtesy of: Wood Energy, Econergy, BSRIA, Highland Wood Energy, B&V

Table 5 Pros and cons of different fuel delivery methods

Delivery system	Benefits	Drawbacks
Flexible hose from a blower tanker	<ul style="list-style-type: none"> • High volume discharge possible (up to 15-20m³ max payload). • Pellets may be delivered through a hose over a length of c.30m, thus benefiting sites with restricted access. • Metering of delivery is possible. 	<ul style="list-style-type: none"> • Specialist vehicles are required (though these are relatively common amongst pellet suppliers). • Time taken for discharge will be approximately 30-45 minutes for a full discharge of 20m³. • Longer blower runs may result in high levels of noise during discharge. • If fuel store is not designed for this method of delivery, wood pellets can become damaged and disintegrate upon delivery – causing excess dust.
Bulk bag deliveries	<ul style="list-style-type: none"> • Low-cost solution. • Fuel type flexibility (suitable for wood chip or pellets). • Suitable for smaller fuel consumption volumes. • Lorries with built-in cranes are generally widely available. 	<ul style="list-style-type: none"> • Low delivery volumes (1-2m³ per bag) and therefore deliveries may require multiple bags, especially if using wood chip. • Fuel may be exposed to moisture if not covered during delivery. • More expensive due to the small load discharge per delivery.
Tipper trailer	<ul style="list-style-type: none"> • High speed of delivery. • Tipping trailers/lorries are generally widely available, therefore offering the potential for fuel supplier flexibility/switching. • High volumes and discharge rates possible, which can reduce cost. 	<ul style="list-style-type: none"> • Requires good vehicle access and clearance to allow tipper bed to be raised. • Requires large storage area to allow full trailer discharge (e.g. 20-30m³). • Requires underground/semi-underground store or vehicle ramp to allow fuel delivery. • Partial discharges are difficult to achieve. • Space may be required on-site for vehicle to turn. • Delivery by tipping may cause fuel in the store to be unevenly distributed (manual raking may be necessary to rectify this).
Scissor lift tipping trailer	<ul style="list-style-type: none"> • High volume discharge possible. • Can deliver fuel to above-ground fuel stores (less costly than subterranean/semi-subterranean counterparts). 	<ul style="list-style-type: none"> • Limited potential to change fuel supplier as requires a more specialist delivery vehicle. • Partial discharges are difficult to achieve. • Delivery by scissor lift tipping may cause fuel in the store to be unevenly distributed (manual raking may be necessary to rectify this).
Blower trough and tipper truck	<ul style="list-style-type: none"> • Flexible delivery solution in space-constrained sites (particularly retrofit sites where standard fuel delivery methods may not be possible). 	<ul style="list-style-type: none"> • Requires careful discharge of material into the blower trough. • Discharge rate limited to c.25m³/hour. • Noisy delivery method (may cause disturbance in built-up areas). • Maximum blower distance is c.2.5m from the trough.

Delivery system	Benefits	Drawbacks
Hook lift bin/ Ro-Ro bins	<ul style="list-style-type: none"> Minimal civil works required (concrete pad only). Offers an integrated fuel storage and delivery solution (cassette-style containers of fuel replaced as necessary by fuel supplier). High volume of fuel in one delivery (c. 35m³). 	<ul style="list-style-type: none"> Requires specialist fuel supplier or Energy services company (ESCo.) operator. Ties up capital in the containers for supplier. Above ground solution may not be suitable for all sites and aesthetics.
Front loader	<ul style="list-style-type: none"> Simple solution. Widely available. Can deliver fuel to out-of-reach locations (above ground stores). 	<ul style="list-style-type: none"> Low delivery volumes. Slow speed of delivery.
Walking floor trailer	<ul style="list-style-type: none"> High volume discharge possible. Widely available. 	<ul style="list-style-type: none"> Requires significant amounts of space for delivery and turning.

Logs and bales are normally delivered using less automated processes such as a self-loading lorry with a crane (larger sizes) or via net bags (smaller sizes). Fork-lift trucks also used to deliver bales and move them around sites.

Fuel storage

Fuel storage facilities normally account for a significant proportion of the overall capital cost of biomass heating projects and careful consideration needs to be given to their design and functionality.

The most appropriate type of fuel store is usually site-specific, and the decision should be based on a reconciliation of the following factors:

- The flexibility/availability of the delivery method from the fuel supplier(s).
- Available space at the site and any site-specific physical access constraints.
- The location of the existing or proposed plant room in relation to the fuel store.
- Appearance/aesthetic requirements.
- Fuel type to be used, which will affect fuel store volume.
- Site topography and geology (i.e. ground conditions if a subterranean store is being used).
- Costs of different configurations.

Liaison between prospective suppliers and the project design team is essential to deliver a cost-effective solution for fuel reception and storage.

Fuel stores can be categorised into four main types, (with variations on each present in the UK).

1. Below-ground/partially below-ground (subterranean) stores.
2. Above-ground stores.
3. Integrated stores within existing buildings.
4. Removable containerised storage.

Biomass boiler unit with automatic ash removal bin and fuel feed auger



Photo courtesy of Asgard Biomass

Wood log fuels may be stored outside; however, they should be covered to ensure fuel remains dry/conditioned.

Bales may be stored in a simple, covered but ventilated environment (e.g. barn).

Key considerations in the design and construction of fuel stores are:

1. Preventing the ingress of water but also having sufficient ventilation to allow the escape of any condensation given off by the fuel residing there.
2. Having sufficient strength to be able to tolerate the outward pressure exerted by a full load of fuel (and any inward forces imposed by surrounding earth if using a subterranean store).
3. Having a simple method of inspecting the level of fuel (e.g. hatch, window, webcam).
4. Keeping the interior free from electrical sockets, switches, and exposed electrical fittings.
5. Meeting the relevant building regulations where they apply (approved document J – *Combustion appliances and fuel storage systems*³⁶ provides guidance).
6. Minimising fuel auger distances from the plant.
7. Ensuring safety during deliveries (e.g. including a 'stop bar') if fuel delivery method requires a vehicle to reverse up to the store (can avoid the need for additional staff to oversee deliveries).
8. Having appropriate security measures in place (if it is in a place that will be accessible to the public) to prevent illegal access.
9. Allowing for complete discharge from the supply vehicle particularly if tipping.



The different physical properties of the two main sources of biomass fuel for heating (pellets and chips) necessitate specific considerations:

Pellets:

- If blower delivery is used, the storage unit will need the appropriate couplings to allow connection to the pellet blower hose (e.g. a camlock), and the end of this will need to be within the reach of the blower-truck driver. Also, in this situation a flexible rubber/plastic sheet hanging opposite the inlet pipe is advisable to avoid pellet damage during delivery.
- The storage unit will need an exit port to allow the release of air when deliveries take place (which can be fitted with a filter to reduce excessive dust exiting the storage silo).
- The point of entry for pellets must be high up enough to enable even filling.
- If there need to be bends in the delivery pipework, tapered bends may be preferable, as a 90° angle could cause damage to pellets during delivery.
- The floors of the storage unit will need a slope of at least 40° going towards the feed mechanism (e.g. auger) to ensure pellets can flow into it.
- Any delivery pipe on the storage unit may need to be made from metal and should be earthed to prevent static build-up on plastic piping.

³⁶ <http://www.planningportal.gov.uk/england/professionals/en/400000000503.html>

Woodchips:

- Woodchips do not flow as pellets do. Stores will need to be carefully designed to avoid 'bridging' of fuel and thus jams (i.e. by avoiding inclined floors or funnel constructions as these may cause blockages).
- If an agitator arm is used as part of the fuel feed system, the height of fuel above this may need to be restricted to 1.5 times the diameter of the agitator itself to avoid jams and motor breakdowns.
- Ideally, a woodchip store should be designed to allow the delivery of a fuel load with as little manual intervention from the site owner/operator as possible.

A summary of some of the main options possible for storing pellet and chip fuels is given in Table 6 (over).



Photo courtesy of Peter Kernohan

Case study: Cwm Taff NHS Trust



Ysbyty Cwm Rhonda is a 100-bed healthcare facility providing outpatient services and care for the elderly. It is a completely new building designed to replace the Llwynypia hospital which was built in the 1900s. A 1.2 MW_{th} biomass boiler has been installed as part of the building services and has been combined with both an independent gas back-up boiler and a 600kW absorption chiller. Hot and chilled water is provided for both underfloor heating and cooling, maintaining a cooling load in the summer months (and improving the capacity factor for the boiler). The system has been designed to accommodate either a woodchip or pellet fuel source and has been specified with 14 days of storage at continuous load. The boiler selected has a good turndown ratio (5:1), enabling all loads to be met from one single unit (from 1.2 MW_{th} down to 240 kW_{th}).

One of the key project considerations was the need to secure fuel from clean virgin materials that had been sourced locally. It is expected that fuel will be sourced from forest residues. The system is expected to consume approximately 1,200 tonnes of woodchip per year.

It is estimated that the system will provide a £35k per annum financial saving (relative to heating oil), providing a total system payback within five years.

Table 6 Storing pellets and chips

Fuel type	Storage location
Wood pellets	<p>Below ground Use for sites with an elevation difference, where land is at a premium or aesthetic considerations demand.</p>
	<p>Above ground Lower cost than below ground, with easier access for maintenance. Widest range of fuel store types.</p>
	<p>Building integrated Can be above or below ground. Stores can be simple and cost-effective, if minimal modifications to existing internal structures are required.</p>
Woodchips	<p>Below ground See considerations above for pellets. Need to consider that the fuel supply vehicle has adequate manoeuvring space.</p>
	<p>Above ground Same cost advantage as for pellets, but reduces fuel delivery vehicle flexibility.</p>
	<p>Building integrated Can be above or below ground. If minimal modifications to existing internal structures are required, these can be simple and cost-effective, but will be governed by fuel supply vehicle and the method of discharge.</p>

Type of fuel store	
<p>Purpose-built pre-fabricated bunker Typically filled pneumatically from blower tanker. Fuel extraction via straight auger or vacuum tube.</p>	
<p>Constructed bunker Possible forms are adapted grain silos, modified storage bunkers, existing cellars with wood panelling and basic concrete/brick covered spaces. Fuel extraction requires tapered floor to funnel pellets to a central auger. Typical fuel extraction via straight auger.</p>	
<p>Bag silo Flexible bag which sits in a support frame. Simple and cost-effective, avoiding need for civil/construction works. But needs to be positioned in sheltered area or building, not exposed to rain. Typically filled pneumatically from blower tanker. Fuel extraction by straight auger or vacuum tube.</p>	
<p>Integrated storage hopper Most suitable for small systems where hopper is attached directly to plant. Usually filled manually using pellet bags. Fuel extraction by auger direct to plant.</p>	
<p>Purpose-built pre-fabricated or bespoke storage hopper Prefabricated steel structure or re-enforced plastic hopper. Usually available from plant manufacturer/supplier. Typically filled pneumatically from blower tanker. Fuel extraction via gravity: tapered floor to central auger.</p>	
<p>Storage container A shipping container, for example. Filled via blower unit or bagged or removable system to allow off-site refilling. Depending on the route from fuel store to plant unit, extraction can be via straight auger, vacuum tube or gravity fed (inclined floor with auger running along base).</p>	
<p>Bespoke internal structure Can be constructed from wide variety of materials, e.g. brickwork for main structure with wood panelled interior, or concrete. Filled by tipper trailer, pneumatically from blower tanker or front loader. Fuel extraction typically via straight auger.</p>	
<p>Purpose built external structure 'Shed-type' or 'lean-to' external constructions can be built from wide variety of materials; highly flexible.</p>	
<p>Constructed bunker Can be constructed from wide variety of materials, e.g. blockwork for main structure with wood panelled interior, or concrete. Typically filled by tipper trailer. Fuel extraction typically via walking floor or circular 'sweep-arm' agitator.</p>	
<p>Bespoke construction Can be constructed from wide variety of materials: blockwork with cladding, brickwork with cladding or steel structures (either purpose built or 'off-the-shelf' designs such as ISO container above). Highly flexible options available.</p>	
<p>Bespoke internal structure Typically suitable for retrofit site, with installation within existing building. Can be constructed from wide variety of materials, e.g. brickwork for main structure with wood panelled interior, or concrete. Filled by tipper trailer, pneumatically from blower tanker or from bags (automatically or manually lifted). Fuel extraction typically via straight auger.</p>	

Fuel Extraction and Feed

Fuel Extraction and Feed is the process of removing fuel from the store and transferring it to the combustion grate of the main combustion unit. A number of methods are already in use in the UK, as shown in Table 7.

Table 7 Fuel extraction systems

Extraction type	Picture	Commentary	Fuel type	Typical scale of applicability
Batch fed		Only appropriate for batch-fired plants. Requires continued manual intervention (daily).	Logs Bales of straw	10 kW _{th} + 30 kW _{th} +
Augers (screw feed)		The primary means of moving woodchip and wood pellet material from the fuel store to the plant unit. Blockages at transfer points between augers can arise if the manufacturer's fuel specification is not adhered to. Length of auger should be minimised to reduce risk of blockages.	Chip Pellet	30 kW _{th} + 10 kW _{th} +
Gravity fed		The use of gravity-fed systems is only appropriate for pellet plants. Wood pellets are either augered along the length of a tapered floor, or funnelled to a central point via a bagged store, etc. From here gravity drops it to the plant unit or a secondary auger/pneumatic feed.	Pellet	10 kW _{th} +
Pneumatic/vacuum feed		These systems require careful design, consideration of bends, length, size of vacuum tubes, and blowing pressures. This system is usually limited to applications smaller than 50 kW _{th} and is only applicable to pellet systems.	Pellet	10 kW-50 kW _{th}

Extraction type	Picture	Commentary	Fuel type	Typical scale of applicability
Agitator arms with auger		<p>Agitator arms with an auger run are the most cost-effective means of fuel transfer at the medium scale, and consequently they are the most widely used.</p> <p>Essentially the spring arms agitate the fuel, making sure it feeds into a central auger, which in turn feeds the plant.</p> <p>They are installed at an angle and, therefore, there will be some dead space under the agitator disc and arms (unless a false floor is installed). This area will need to be accounted for when assessing available fuel storage volume.</p> <p>Agitator arm lengths may need to be designed to avoid damage to walls and arms.</p>	Chip	30 kW _{th} +
			Pellet	30 kW _{th} +
Walking floor		<p>Walking floors shuffle the fuel along the length of the fuel store towards an auger which feeds the plant. The fuel is moved forward via hydraulic rams/fins which sit upon a concrete pad.</p> <p>Walking floor-based systems can receive bulk delivery and are therefore suited to larger systems. The concrete pad and the walls of the store need to be sufficiently strong to withstand the forces and pressures exerted by a full load of fuel.</p>	Chip	1 MW _{th} +
			Pellet	Generally not used for pellets, although technically they are compatible.
Conveyor		<p>Conveyor (belt, chain or hydraulic reciprocating) or mechanical grab systems are generally concentrated at the large scale of woodfuel installations, where there is a significant throughput of material, or where the fuel is of a large particle size that prevents the use of augers.</p>	Chip	11 MW _{th} +
			Pellet	Not applicable to pellets at this scale.
			Straw	3MW _{th} -15MW _{th}
Grab			Chip	3 MW _{th} +
			Pellet	Not applicable to pellets at this scale.

Containerised solutions

Some suppliers offer containerised systems where the plant(s), fuel storage, handling and all associated balance of plant are contained within single, prefabricated units. Systems of this kind up to 450kW in size have been installed in the UK (with larger systems possible using modular capacity). They are, essentially 'plug and play' options that offer several advantages such as minimising disruption to existing buildings, speed of installations and simplicity. In the right circumstances, they can be very cost-effective solutions.



Image courtesy of Imperative Energy

Fuel cost – factors that influence fuel cost

All feedstocks require some form of intermediate processing to convert them into a biomass fuel suitable for use in a heating system – this can be as simple as drying in the case of wood logs or more involved such as pelletisation. The major factors which will have an influence on price are outlined in Table 8.

Detailed fuel costs

For the majority of heating applications, in the scale range under consideration in this guide (0.1-3 MW_{th}), fuel is supplied in the form of woodchips or wood pellets³⁷. Table 9 provides an indication of the cost of a variety of processed and unprocessed woodfuels.

The cost of different forms of biomass fuel is highly variable across the UK, and Table 9 provides guideline figures only³⁸.

Table 8 Factors affecting woodfuel price

Logistics	Quality	Market
<ul style="list-style-type: none"> Distance from raw material supply. Delivery vehicle. Frequency and volume of delivery. Discharge rates. 	<ul style="list-style-type: none"> Form of delivered fuel e.g. slabwood < woodchip < pellet (influences processing labour). Calorific value. Quality of woodchip/pellet (influenced by the level of processing or conditioning of fuel). 	<ul style="list-style-type: none"> Source type – virgin timber, reclaimed wood, arboricultural arisings, waste, etc. Contracting type – buying fuel by weight, volume or energy. Annual quantity required. Fluctuation in seasonal demand. Local demand compared to competing markets.

³⁷ Conventionally, woodfuel is used in the domestic market in the form of logs. However this publication deals with commercial, service and industrial applications, where log-fired systems are less appropriate.

³⁸ Forestry Commission (2006) *Woodfuel Meets the Challenge*. www.forestry.gov.uk

Table 9 Guideline costs for different woodfuels

	Price (£/tonne)	MC %	Chipped	Delivered	Delivered (and chipped) (£/odt*)	Delivered (and chipped) (p/kWh)
Woodchip	30-100	60-25	y	y	75-133	1.8-2.7
Wood pellet	130-200	6-10	n	y	141-217	2.8-4.3
Slabwood – unseasoned	5-30	50	n	n	10-60	0.2-1.3
Slabwood – seasoned	20-40	25-45	n	n	36-53	0.8-1.1
Roundwood	15-25	25-50	n	n	55-80	1.2-1.6
Sawmill off-cuts	5-30	20-40	n	n	8-38	0.2-0.7
Short rotation coppice	40-50	40-55	y	y	83-89	1.7-2.0
Arboricultural arisings	20-40	40-55	y	y	0-41	1.0-1.6
Waste wood	0-35	15-45	n	y	0-41	0-0.8
Waste stream	0-35	13-22	y	y	0-40	0-0.8
Board roundwood	12-20	35-50	n	y	24-31	0.5-0.6
Wet sawmill co-product	5-27	45-60	y	y	13-49	0.3-1.1
Sawdust	20-28	50	n/a	y	40-56	0.9-1.2
Dry sawmill co-product	26	30	n	y	37	0.8
Very dry co-product	35	15	n	y	41	0.8
Sawmill off-cuts	50-70	30-50	y	y	100	2.0-2.2
Miscanthus	45-50	10-20	n	y	70-77	1.4-1.5
SRC with planting grant	40-45	35-50	y	y	69-80	1.4-1.8
Woodland management	60-104	30-60	n	n	148-150	3.0-3.6

Source: Forestry Commission, B&V market data, REGEN SW Bioheat programme, 2008 data

* Oven Dry Tonnes

2.2 Biomass heating systems

This section covers the basic processes of biomass combustion and the main features of biomass heating systems. Plant sizing strategies, system layout and integration configurations are also discussed.

2.2.1 Principles of biomass combustion

This guide covers equipment that produces heat from biomass sources via the process of 'simple' combustion (burning). This process accounts for 90% of all energy recovered from biomass worldwide. Combustion, or burning, is a complex sequence of exothermic (heat generating) chemical reactions between a fuel and an oxidant.

Biomass combustion takes place in three distinct but overlapping phases (similar to other solid fuels), the extent and nature of which are different for each type of biomass fuel:

1. Preheating phase: Moisture in the unburned fuel is driven off and the fuel is heated up to its 'flash point' and then its 'fire point' (the temperature at which it will continue to burn after ignition for at least five seconds).
2. Gaseous phase: A mixture of flammable gases is given off (volatilised) by the solid fuel and is ignited. Energy is transferred from chemical energy into heat and light (flames).
3. Solid phase: The rate of release of flammable gases from the solid fuel is too low to maintain a flame and the 'charred' fuel glows and then only smoulders.



Photo courtesy of Peter Kernohan

Some specific features of the combustion processes of biomass fuels are worth noting as they have practical implications for the equipment in which they are used:

- Moisture must be driven off biomass fuel before it can be combusted. This requires the input of heat itself and it is why fuels with a higher moisture content have a lower calorific value. In practical terms, this means that to achieve the same thermal output, a plant designed to accommodate fuels with high moisture contents will need to be larger than those used for drier fuels. This is because the fuel will need to be present on the combustion grate for a longer period of time to dry out and also because a larger amount of refractory material will be needed to reflect heat back on to the drying fuel. Systems designed to accommodate fuels above 35% moisture content are generally classed as 'wet fuel' plants and use stepgrate or moving grates to allow for this additional drying time.
- Biomass fuels tend to volatilise on the combustion grate and much of the combustion takes place above the fuel bed. This means that the fuels tend to require air above, as well as at the level of the fuel bed (at the grate). As a rule of thumb, biomass needs about two thirds of its combustion air above the grate and one third below³⁹.
- Combustion of biomass (at the range 0.1-3 MW_{th}) requires approximately 5kg of air per kg of biomass (as received) assuming an excess air level of approximately 40%⁴⁰.
- Mineral matter contained in the biomass fuel will be released as ash. Depending on the type of combustion system and the nature of the biomass fuel, some unburned carbon may be locked in the structure of the ash. Ash will be extracted from the combustor as follows:
 - Bottom-ash – left at the combustion grate and may be removed automatically by auger (in some circumstances this may be used as a fertilizer).
 - Fly-ash – airborne, light ash particles which can accumulate around the heat exchangers, at the top of the combustion chamber and in the flue. This ash is captured by special equipment in the plant unit but may also need to be periodically cleaned off the heat exchangers.
- If the quantity and pressure of air added above the grate is not correct, combustion may not be complete and carbon monoxide may be given off.

³⁹ Well-designed biomass combustion systems will have provision for the separate control of the primary and secondary air supply so that the combustion process can be properly balanced to achieve optimum conditions.

⁴⁰ Excess air is the air over and above the theoretical level of air required, which is needed in practice to ensure satisfactory combustion.

2.2.2 Components of a biomass heating system

The main components of a typical, automated biomass plant are outlined in Table 10 below. Note that not all systems will contain all of these components.

Table 10 Main components of biomass heating systems

Component	Description
Fuel transfer system	Not part of the main plant itself but the means whereby fuel is transferred from where it is stored to the plant.
Fuel feed system	The system for transferring fuel into the plant at the required rate. Typical methods include screw augers or actuating 'ram stokers'.
Combustion grate	The main point at which combustion starts, several different configurations (see section 2.2.3) are available.
Refractory material	Also known as 'fire bricks' – not always present but designed to reflect heat back onto the grate so as to drive off moisture from the fuel and maintain optimum combustion temperature.
Air feed/control system	As discussed above, biomass typically needs two or three sources of air for good combustion to take place (see also, control system below).
Heat exchangers	Where a plant is providing hot water as the heating medium (as opposed to direct hot air) this is the means of transferring the heat in the hot combustion gases to the medium (water) – e.g. via 'fire tubes' with a 'water jacket'.
Ash extraction system	Most automatic systems use an auger to transfer the ash into an external receptacle which can be emptied manually.
Control system	Most systems have some means of controlling output via the fuel feed rate and air levels. It is common for larger systems to use flue gas oxygen and temperature sensors (lambda control similar to those used in car engines) to monitor combustion conditions and operate air fans/fuel feed rates to achieve the optimum.
Exhaust gas treatment system	Some form of exhaust gas treatment system is usually required to minimise emissions of such things as particulate matter and fly ash from the plant's combustion chamber. Different levels of emissions abatement equipment are available from relatively simple, single-stage cyclones to multiple stages involving bag filters and other devices. Equipment manufacturers should be able to provide details on what equipment is fitted as standard on their plant and what additional, optional abatement equipment is available should local air quality requirements necessitate it.
Flue gas fan(s)	Some plants need a flue gas fan or induced draft fan to draw the flue gases from the combustion chamber and through the plant heat exchanger. The flue gas fan discharges to the chimney.
Flue (chimney)	The chimney stack has two functions: it draws the flue gases through the plant and disperses the gases to atmosphere at a safe level.
Ignition system	Plants may be ignited automatically using a hot air gun (smaller systems) or electrically ignited gas pilot (larger systems).
Expansion tank	Not part of the main plant itself but a key component of a system to allow the natural expansion of the water in a heating system as it gets hot – in sealed systems the 'expansion vessel' (a small pressurised container) accommodates the extra volume.
Fire protection system	Not part of the main plant itself but a key requirement to prevent fire from the combustion chamber moving back into the fuel store. Can be a water 'dousing' approach or some form of automatic shut-off gate(s) on the feed mechanism systems offering varying levels of fire protection.

2.2.3 Types of biomass plant

Within the scale range under consideration in this guide, there is a range of different types of plant available. The differences are primarily related to the type/nature of fuel that the plant is designed to be used with, the method of heat exchange and the degree of automation of the operational processes. Plants are usually classified by their type of grate, the main types being: *moving grate*, *plane grate*, *batch-fired* and *stoker*.

Ultimately, the choice of plant and its detailed specification will depend upon a range of factors: type of fuel available/to be used, level of automation required and cost. The overview given here is only intended to provide a high-level guide.

Users may want to understand some of the details of individual plant/system types in more detail, or to obtain technical details from a variety of installers/manufacturers.

Moving grate systems

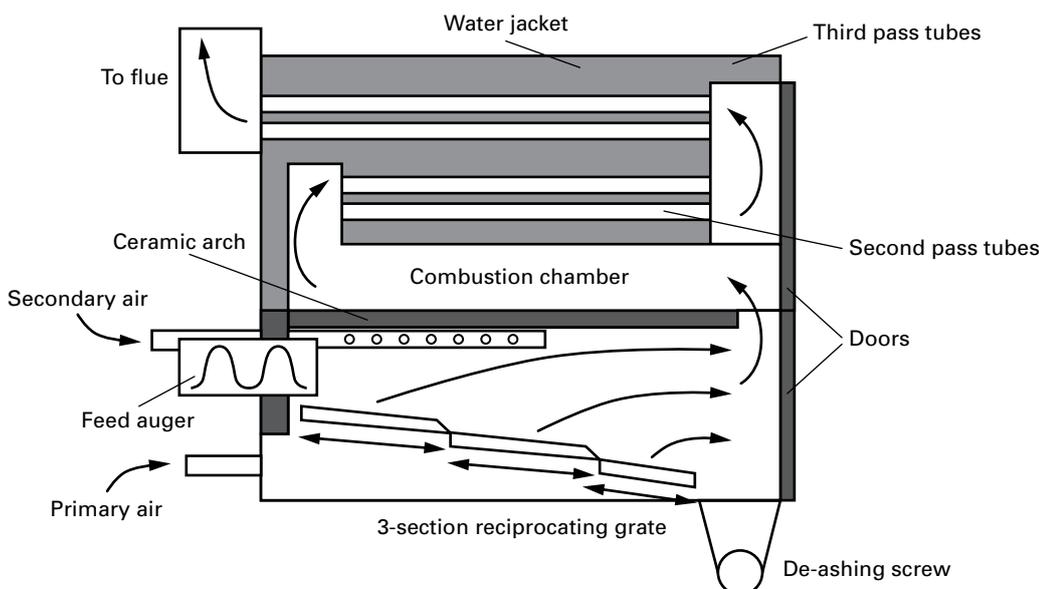
Moving grate (also known as step-grate or inclined grate) plants are the most versatile (in terms of flexibility of fuel tolerance) but the large combustion space required and the additional equipment (e.g. hydraulics) involved often make them more expensive than other types.

Fuel is delivered onto a series of inclined or flat panels of firebars which move in a sequence so that the fuel travels slowly (shuffles) down the grate towards the far end of the combustion chamber. The fuel dries and then combusts as it moves down the grate (primary air is supplied under the grate). Gases are emitted, and char burns out. This sequenced combustion is one of the great strengths of the design: by tuning the grate speed, fuel feed and air supply, it is possible to burn a wide range of fuels of varying moisture content. The addition of a ceramic arch over the grate reflects heat back, encouraging drying and subsequent ignition, and thus permits the combustion of wet fuels – tolerating up to 60% moisture content.

Once the wood has combusted, the remaining ash falls off the lower end of the grate, and is removed mechanically into the ash pan or ash bin.

Moving grate plants are popular in Northern Europe and Scandinavia where unseasoned softwood is commonly used for fuel. They are generally more common at the higher output range (300kW-1MW+).

Figure 5 Schematic of a moving grate biomass plant



Source: R.Landen

Moving grate plants can use pellets or woodchips, although woodchips are used more commonly because of the capacity of the plants to burn wet fuel. Pellets are usually used in cheaper plane grate (underfed) biomass plants, discussed below.

Table 11 Advantages and disadvantages of moving grate systems

Advantages	Disadvantages
<ul style="list-style-type: none"> • Wide tolerance of fuel type, moisture content (up to 60%), and particle size. • As a result of wide fuel tolerance, cheaper fuel may be procured, helping to offset higher capital cost. • Positive movement of fuel down grate avoids clinkering and blockages. • Well-regimented combustion leads to high efficiency. 	<ul style="list-style-type: none"> • Relatively large fuel inventory in the plant leads to a slow response to load swings, although modulating controls improve controllability. • Large amounts of refractory (heat reflective) material on wet wood plants can result in a long warm-up time from very low to full-load (up to 2 hours). • Prolonged low-load mode operation can result in higher maintenance costs and reduced efficiency as a result of tarring of heat exchangers and condensing gases. • More complex design and bulky components can lead to higher capital costs.

Plane grate systems

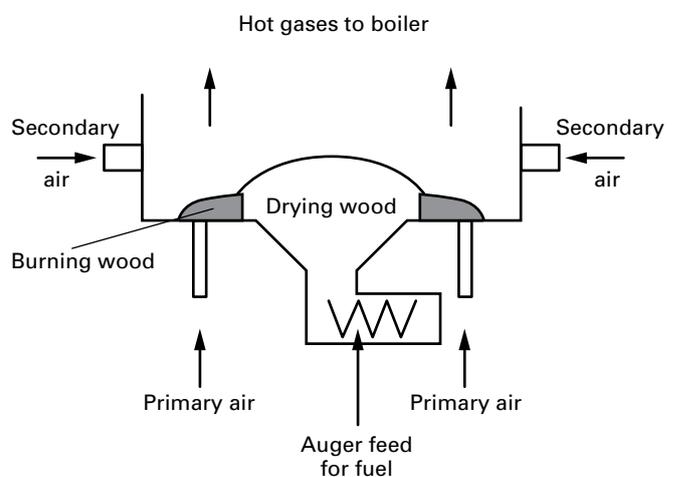
Plane grate biomass plants can feature either underfed or side-fed combustion chambers. The main difference to the moving grate system is that the combustion bed is smaller.

The plane grate was developed from designs commonly used in coal plants, and is widely used for the combustion of drier fuel, (e.g. joinery waste), good quality woodchip, and wood pellets. Plane grate systems are suitable for fuel with moisture content below 35% MC (wet basis).

This is because the fuel is fed directly into the combustion chamber by the fuel feed mechanism, rather than being dried first as in the case of the inclined grate plants. Some plane grate plants can tolerate 40% MC fuels if they have a ceramic-lined combustion chamber.

In the underfed type, fuel is fed by auger into the base of an inverted cone or trough, where it wells up into the combustion chamber, spreading out to the sides. Primary air is supplied below the fuel, and secondary air above.

Figure 6 Schematic of a plane grate biomass plant



Source: R.Landen

Underfed stokers are usually supplied as part of a complete plant package; however, they may be constructed as a separate unit to the plant itself (i.e. the heat exchange element of the system where heat in the hot combustion gases is transferred to water in the plant). In such instances, the heat exchange unit will be of an open-bottom construction that sits on top of the stoker unit. On larger units, the stoker may be situated within the combustion chamber of a shell-and-tube plant.

Ash is created on all sides of the combustion zone, and its removal from the combustion bed relies on simple displacement due to the emergence of new fuel in the centre of the combustor. The removal of ash from the bottom of the combustion chamber is sometimes by manual intervention, but it is more common to have the ash augured from the bottom of the combustion bed to an external ash bin.

For side-fed grates, the grate is vibrated regularly to shake ash through holes within it, and it tips periodically to allow the removal of larger non-combustible items. In terms of their ability to tolerate moisture content in fuels, side-fed units offer an intermediate option between underfed and moving grate systems.

Plane grate systems tend to be most common in the 25-300kW range (up to 500kW on pellets), and can use both pellets and woodchips (a change of grate may be required in some models).

Table 12 Advantages and disadvantages of plane grate systems

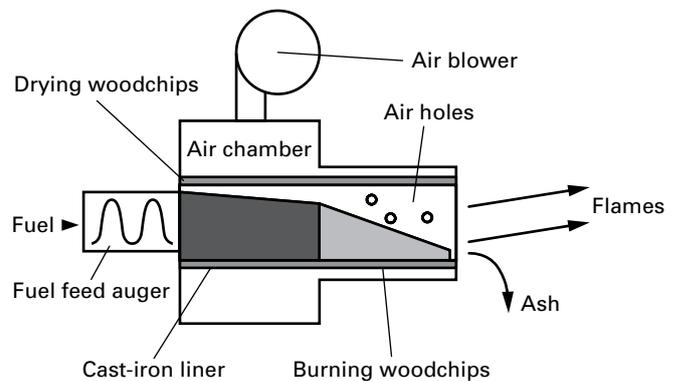
Advantages	Disadvantages
<ul style="list-style-type: none"> • A smaller combustion area and less refractory material means that these types of plant have a smaller spatial footprint. • Commonly dual fuel plants, therefore providing flexibility of operation⁴¹. • In total capital cost terms (£/kW, installed) they are cheaper than the moving grate systems due to the simpler design and exclusion of refractory material. 	<ul style="list-style-type: none"> • Due to the smaller combustion bed, the plant require lower fuel moisture content – typically 20-35% – rising to 40% if the plant has some refractory material lining the combustion chamber. • Due to the smaller combustion bed and lower moisture content tolerances, these systems require consistently good quality fuel. As a result they are best suited to applications where site owners are confident of securing good quality fuel (<35% MC).

Stoker burner systems

Stoker burner systems are often cheaper than plane grate or moving grate options because they are generally less sophisticated. They are most common in the size range 30-500 kW_{th}.

This type of combustion system is similar to a pressure jet oil burner. Biomass fuel is augured into a burner head, which has a special cast iron liner to reflect heat back onto the fuel. Air is introduced by a small fan, which passes around the outside of the cast-iron liner, thus heating up. The air then enters the fuel space via small holes, some below the fuel to provide primary air, some above to provide secondary air.

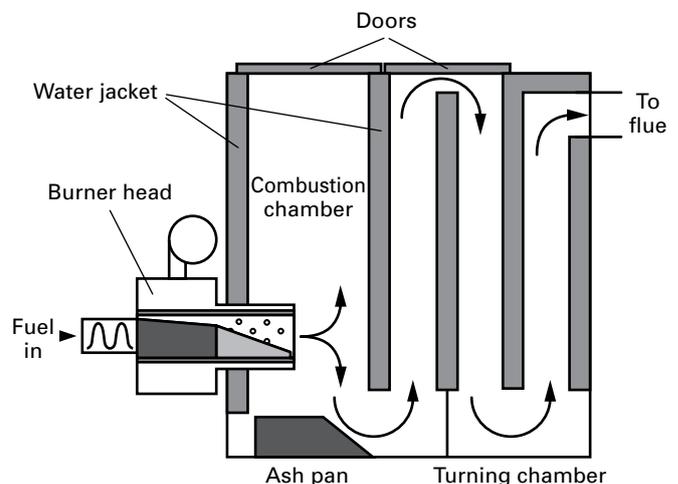
Figure 7 Schematic of a stoker burner system



Source: R.Landen

The burner head produces a vigorous flame in the combustion chamber, and the resultant hot combustion gases pass into the heat exchanger unit.

Figure 8 Schematic of a stoker burner within a purpose-designed plant unit



Source: R.Landen

⁴¹ These systems can use both woodchip and pellet material, although the system would have to be re-commissioned to allow for fuel switching.

Ash from the burner head is pushed away and into the ash pan by the incoming fuel. De-ashing is almost always manual, especially on smaller units. The stoker burner is probably the lowest-cost biomass plant available that can use both pellets and woodchip, but it does have limitations as described below.

Table 13 Advantages and disadvantages of stoker burner systems

Advantages	Disadvantages
<ul style="list-style-type: none"> • Small fuel inventory makes for relatively rapid response to load swings. • The heat generated on slumber (when there is no heat requirement and the unit is simply maintaining ignition with as little heat output as possible) is very low. • Often lower cost than plane grate or moving grate systems. 	<ul style="list-style-type: none"> • The fuel must be fairly dry: preferably <30%, never more than 35%. • The fuel particle size and moisture must be consistent: the small, intense combustion zone is easily disrupted. • In the lowest cost, smaller units, no separate provision for primary and secondary air supply exists, limiting the opportunity for fine-tuning to the needs of varying fuel.

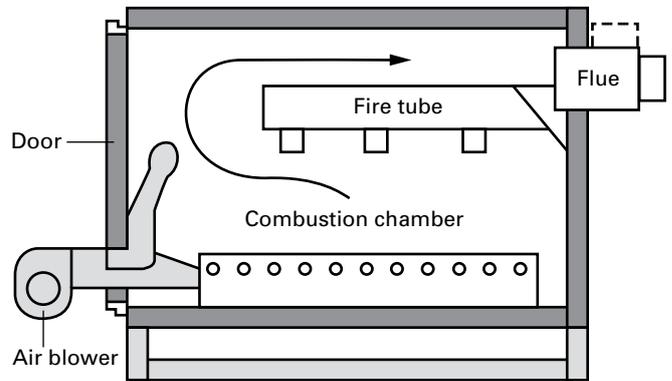
Batch-fired systems

Batch-fired systems are fed manually, either with bales of straw/miscanthus, or with large billets of wood, logs, and other off-cuts, etc. They generally require no more user input than filling the combustion chamber or hopper each day, although the exact frequency depends on the site heating profile. The loaded fuel burns in a single ‘burst’ rather than continuously in response to varying demand (as in the above examples). Fans are usually fitted to help ensure complete combustion. Heat is transferred to a buffer/storage tank⁴² from where hot water is taken to service demands.

While this is clearly not an automated solution, batch-fired systems do offer very cost-effective solutions where biomass material is available at low cost and where there is labour available to attend to the system. Their typical scale range is from 20kW to 500kW. They tend to have less sophisticated control systems and, therefore, generally require more seasoned biomass material (20-25% MC).

The flexibility of batch plants means they can be particularly suited to light industrial and farm use.

Figure 9 Schematic of a batch-fired system



Source: P. Tewen

Table 14 Advantages and disadvantages of batch-fired systems

Advantages	Disadvantages
<ul style="list-style-type: none"> • Simple and cost-effective solution where biomass material and labour are available at low cost and efficiency is not a prime consideration for the system. • Robust designs mean lower (non-fuel) maintenance issues. 	<ul style="list-style-type: none"> • The fuel must be fairly dry: preferably <25%. • A high level of user input – often on a daily basis.

⁴² Tank volumes should be at least 40 litres/kW.

Biomass Combined Heat and Power (CHP)

In the Carbon Trust Biomass Heat Accelerator (BHA) and this report, the focus is on biomass boiler systems in the range 0.1-3 MW_{th} which produce heat. This is because such systems have been found⁴³ to offer the most cost-effective carbon savings when using a unit of biomass fuel in the absence of any policy support. Yet biomass CHP systems, which produce both heat and power, can also offer low carbon and low-cost energy in the appropriate circumstances. Such circumstances would typically be where the full outputs of the CHP system (both heat and electrical) are needed and are consumed on-site and that these site electrical and heat loads are relatively continuous throughout the year. This box briefly introduces such systems⁴⁴.

Market status

Across Europe, a number of biomass CHP plants fuelled by solid biomass are in operation. Plant sizes vary but most installations have a rated boiler output of more than 5 MW_{th}; there are just a few instances of plants generating less than 500 kW_e. Biomass CHP plants are larger than the typical sizes of heat-only biomass boilers because of the additional size of the electricity generating pieces of plant. These systems tend to use a mature combustion technology such as a steam turbine.

In addition, there are a number of CHP plants across Europe that use the gas produced by anaerobic digestion of liquid biomass (e.g. methane from animal slurries) to operate an internal combustion engine. The technology for this is also commercially mature and can operate effectively at smaller scales (down to 330kW_e).

In the UK there are relatively few biomass CHP systems installed.

Main technologies

There are four main conversion routes for biomass CHP systems:

- **Combustion.** In this case combusted fuel is used to generate heat which is then used to raise steam, which operates in a standard steam generator set as the prime mover to produce electricity. At small scales, the use of steam is inefficient due to the high temperatures and pressure required. Replacing water as the working medium with an organic compound with a lower boiling point (i.e. using the Organic Rankine Cycle) allows greater efficiency at lower temperatures.
- **Anaerobic digestion.** This is a biological process where micro-organisms break down biodegradable material in the absence of oxygen. The products are a methane and carbon dioxide rich gas (biogas) and a solid 'digestate'. The biogas produced from this process can be used in reciprocating gas-engine CHP systems or microturbines as the prime mover. This is common in the water-treatment industry and with anaerobic digesters which take 'wet' biomass such as animal slurries.
- **Gasification.** This is a process of converting the input fuel to a gas mixture – a synthetic gas or 'syngas' – by reacting it at high temperatures with controlled amounts of oxygen or steam. The syngas is typically combusted in a reciprocating engine (but could also potentially be used in a gas turbine). However, this process is inherently more complex than simple combustion.
- **Pyrolysis.** This is a thermal degradation process that occurs in the absence of oxygen, which produces a variety of products such as a fuel gas, char, bio-oil and tar. These products can be used for power generation and are typically combusted in reciprocating engines (but could also potentially be used in a gas turbine).

Gasification and pyrolysis technologies are not yet fully commercially mature.

⁴³ See the report *Biomass sector review for the Carbon Trust*, CTC512, October 2005.

⁴⁴ For further guidance on CHP systems, see the following Carbon Trust guides: GPG388 – *Combined heat and power for buildings*; GPG234 – *Guide to community heat and CHP*; GPG043 – *Introduction to large-scale combined heat and power*. Also see the BSRIA guide *CHP for existing buildings, guidance on design and installation*.

Biomass Combined Heat and Power (CHP) (continued)

Installation considerations

Like heat-only biomass boilers, one of the principal considerations when planning to install a biomass CHP system is its size relative to a site’s energy (electricity and heat) demands – both from an economic and environmental point of view. Typically biomass CHP systems are designed primarily to satisfy a site’s base load heat demand, on the grounds that:

- Excess heat cannot be stored or exported easily.
- Excess electricity can be exported via a grid connection to an electricity supplier for revenues (which may be enhanced by subsidy regimes such as the Renewables Obligation in the UK).

Having sized the system for base-load, the electricity generation capacity is likely to be fixed by the heat to power ratio of the system’s prime mover.

Typically, industrial applications are well suited to biomass CHP as they tend to have larger and more continuous heating/electrical demands than commercial or smaller applications thus offering better efficiency and economics. In addition, CHP technologies for smaller applications tend to be more expensive on a unit basis and less efficient than larger systems.

The inherently greater levels of complexity and relatively small market for biomass CHP in the UK mean that costs can be in the region of 5-10 times that of an equivalently sized biomass heat-only plant⁴⁵.

2.2.4 Plant sizing

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.

Systems supplying buildings that are generally only occupied during working hours (‘general occupancy buildings’) normally have the lowest utilisation (or capacity factor). This is due to the fact that the space heating (which is normally a much greater demand over the year than hot water) is generally only used in the heating season between October and April, and for limited times throughout the 24-hour day as well as during the 7-day week.

Conversely, ‘service’ applications (e.g. swimming pools, hospitals) and process applications (e.g. horticulture, food and drink manufacturing) typically have much higher utilisation (capacity factor), as the heating system is used for much longer periods during the year. These capacity factors can be double or treble those for general occupancy buildings. Consequently applications of biomass within these sectors tend to be significantly more cost-effective.

To be able to size systems well, it is important to have an accurate view of the likely daily/seasonal heat demand profile of a proposed site before deciding on the sizing/integration strategy.

Table 15 Typical biomass capacity factors for different applications

Category	Typical capacity factor
General occupancy building	0.2 (20%)
Service applications	0.45 (45%)
Process applications	0.6 (60%)

Appropriate sizing is important to achieve good levels of utilisation, to ensure performance profiles are suitable for biomass systems, and to enable effective integration with existing/new fossil fuel heating systems.

There are different approaches for sizing a biomass system, and the most important of these are discussed in the following pages.

These are:

- **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.

⁴⁵ See the report *Biomass sector review for the Carbon Trust*, CTC512, October 2005.

Base-load sizing

Base-load sizing is an approach where the biomass plant is sized to meet only the base load of the heating demand profile.

Figure 10 shows two different example annual demand patterns. It can be seen that the minimum load conditions for both load profiles occur in July. Sizing the biomass plant at the minimum heat load means that it can operate at full load almost continuously providing the base-load heat demand (shaded blue) throughout the year. The overall area under the curve represents the energy delivered by the different fuel sources.

This type of sizing regime is likely to be close to optimal where there is a substantial base-load throughout the year, as can be seen in the example A. This type of heat load profile might be found in service applications, such as leisure centres with swimming pools.

Example B exhibits some periods of very low heat demand; base-load sizing in this case would mean the biomass plant would only contribute a very small proportion of the annual heat demand at the site, and base-load sizing in this case would be sub optimal.

Figure 10 Examples of base-load sizing:

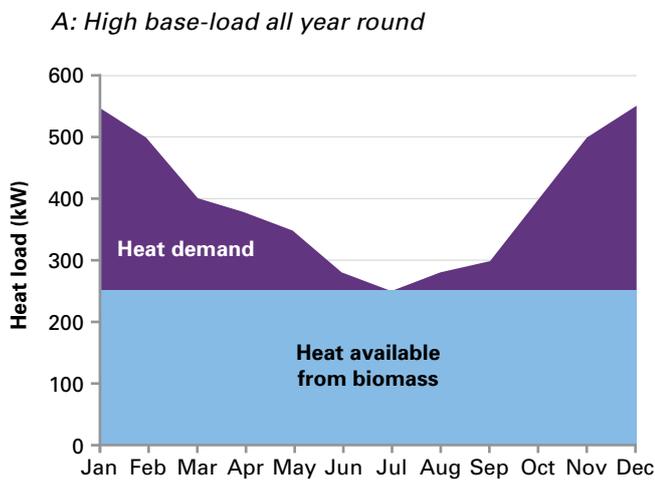
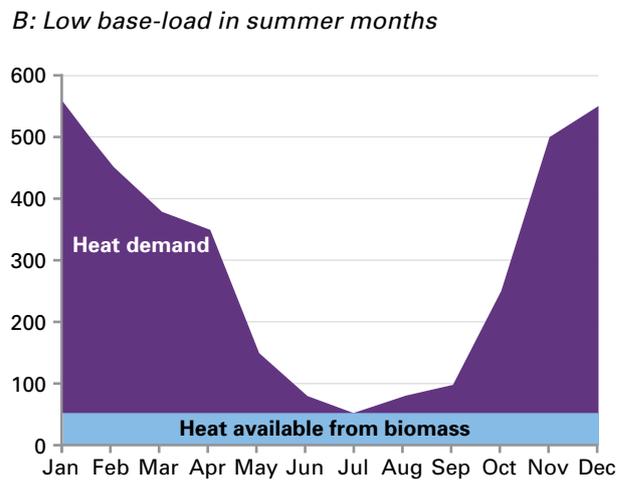


Table 16 Base-load sizing

Advantages	Disadvantages
<ul style="list-style-type: none"> • Plant operated almost continuously – well suited to biomass plant. • High utilisation means lower cost of CO₂ saved (£/tonne) than other options. • Lower total capital costs investment than other options as system sized to provide base-load only. 	<ul style="list-style-type: none"> • Some sites have either no or very low summer (or intra-day) load, and hence a small base-load, which will limit the plant size. • Lower CO₂ savings than other options. • Requires back-up conventional plant.

In this situation, the additional loads which the biomass plant does not meet (such as instantaneous demand, peak heating requirements or during start-up from cold) are met by an additional fossil fuel plant.



Peak-load sizing

Peak-load sizing is an approach where the biomass plant is sized with the capability to provide the peak heat load and all of the annual heat requirements at the site (shaded blue in Figure 11). The key consideration for peak-load sizing is the over capacity of the plant (shaded purple).

Example A shows where peak-load sizing is likely to be close to optimal. The heat load remains relatively consistent throughout the year and thus the biomass plant will have little need for modulation below the maximum rated output and will also have high utilisation (or capacity factor), and only a small amount of plant capacity will not be utilised (shaded purple).

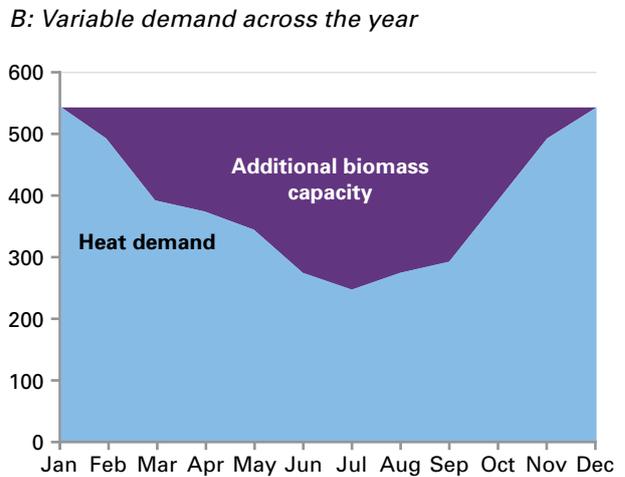
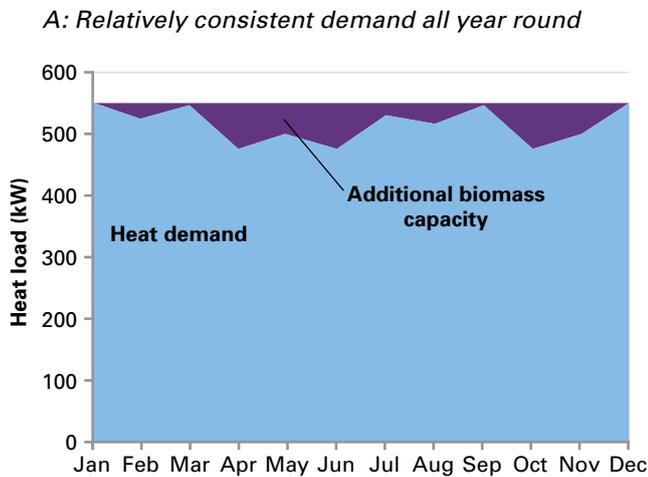
Example B has relatively long periods when the load required at site is significantly lower than the capacity of the biomass plant, thus leading to a greater under utilisation (shaded purple); in this instance peak-load sizing would be sub optimal.

Sites which favour peak-load sizing are those whose demand profile exhibits little fluctuation throughout the year such as industrial or manufacturing applications.

Table 17 Peak-load sizing

Advantages	Disadvantages
<ul style="list-style-type: none"> • Ability to provide all heat demand from biomass system. • Ability to maximise CO₂ savings and potentially eliminate all emissions from fossil fuel systems. • Lower unit (£/kW) installed costs due to economies of scale. • Does not require back-up conventional plant. 	<ul style="list-style-type: none"> • Higher total CAPEX investment. • Higher £/tCO₂ saved than other operating scenarios. • Potentially higher maintenance cost if need to run at low load conditions for extended periods.

Figure 11 Examples of peak-load sizing:



Optimum sizing

The optimum plant sizing approach tries to achieve a balance between CAPEX investment and operational costs. It aims to combine the benefits of:

- Base-load sizing – minimising total CAPEX and CAPEX per tonne of CO₂ saved.
- Peak-load sizing – maximising the fossil fuel displacement and hence increasing CO₂ savings.

Figure 12 Example of optimum sizing

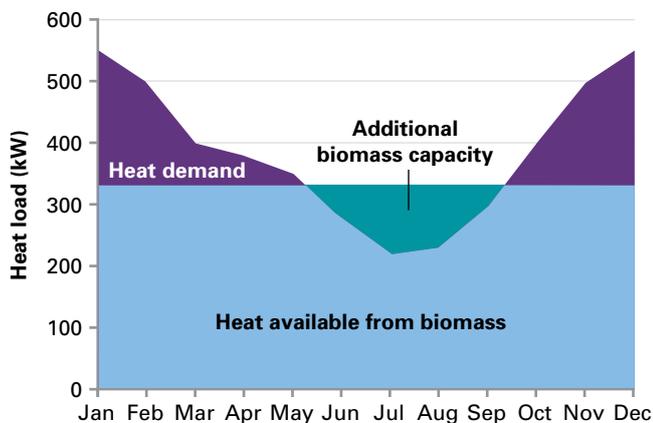


Figure 12 shows an example of a typical seasonal heating load profile. It can be seen that the amount of the heat load offset by the biomass system (shaded blue) is increased compared to the base-load sizing example, but the additional unused plant capacity (shaded green) is reduced compared with the peak-load sizing example. This allows the biomass system to run at a relatively high level of utilisation and displace a significant amount of the heat load that would otherwise be delivered by fossil fuels.

In this situation, the additional loads which the biomass plant does not meet (such as instantaneous demand, peak heating requirements or during start-up from cold) are met by an additional fossil fuel plant.

As a general rule of thumb, sizing the biomass plant in this scenario at between 55 and 65% of the peak load can in fact deliver 80-90% of the annual heat demand for the site.

Table 18 Optimum sizing

Advantages	Disadvantages
<ul style="list-style-type: none"> • Maintains relatively high capacity factor. • Avoids potential maintenance issues associated with low load conditions. • Maintains reasonable £/tCO₂ saved. • Medium CAPEX investment. • Allows larger plant installation where base-load sizing would be very small. 	<ul style="list-style-type: none"> • Does not completely displace fossil fuel consumption and associated emissions. • Higher CAPEX investment than sizing for base-load only. • Requires back-up conventional plant.

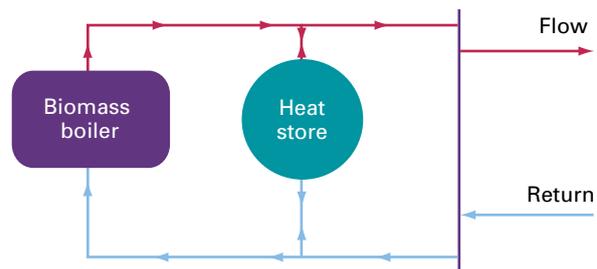
2.2.5 System integration

The main configuration options for biomass plant are outlined below:

Biomass plant with buffer tank

Where a biomass plant is the only item of heating plant, installing a buffer tank (heat store) can smooth out its running profile, allowing it to respond to variable demand in a number of situations:

Figure 13 Biomass plant with heat store*



- Seasonal load conditions – there may be periods of time when the heat load at a site is low, such as in the summer months. If the heat load is below the lower limit that the biomass plant can provide (typically 20-30% of the plant rating), this can lead to short-cycling, with the plant switching on and off very frequently. The inclusion of a heat store can avoid this as it can act as a buffer to allow the biomass plant to switch off for an extended period while the heating demand is met from the heat store. This reduces short-cycling, improving performance and reducing maintenance issues.

- Daily load conditions – over a day, the heat load at a site may vary quite significantly. The buffer allows the plant to operate at a constant rate, allowing the plant to store heat when the system load is low, and draw heat from the buffer when heat demand is in excess of the plant output. For sites that have significant variation in heat demand over a daily or weekly timeframe, this can allow the biomass plant to run at a constant rate while the heat demand at the site fluctuates above and below the plant's operating output. **A useful rule of thumb for sizing the buffer is to allow for 10 litres/ kW_{th} plant capacity where loads do not fall to zero, and at least 20 litres/ kW_{th} where they do.**

This type of system requires careful optimisation to ensure that both the plant and heat store are carefully matched to the heat load at the site.

Biomass with fossil fuel stand-by/back-up

A biomass plant with a fossil fuel peak-load back-up plant is useful in instances where the biomass plant will provide the base load and the back-up system will meet occasional peak loads above the base load (for example, where these are of comparatively short duration). This is known as 'peak-opping'.

Figure 14 Biomass with conventional fossil fuel stand-by/back-up*

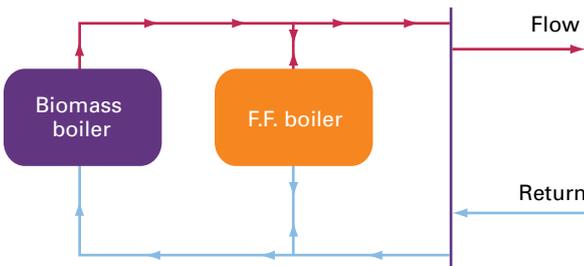
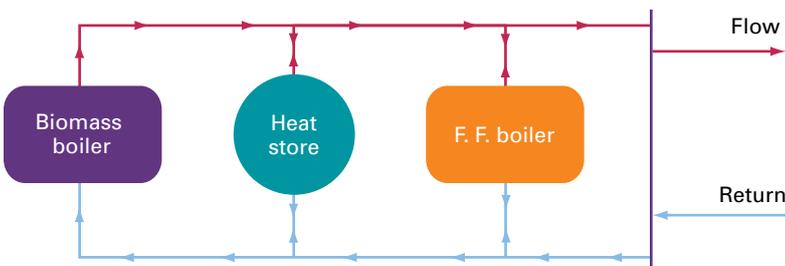


Figure 15 Biomass plant with heat store and fossil fuel stand-by/back-up*



Depending on the site's load profile and the level of redundancy desired, a fossil fuel plant with capacity to meet peak demand can be provided as back-up. This is useful where uninterruptible heat supply is necessary (e.g. hospitals), and effectively provides a stand-by system. The fossil fuel plant can also be used to provide heat at times when there is a very low heat demand (below the minimum output of the biomass plant, typically c.30% of its maximum). It can also provide redundancy for any planned or unplanned system downtime (service/maintenance/repairs/cleaning of the biomass plant). When an existing fossil fuel plant is still within its operational life, it makes practical and economic sense for it to remain in use as part of the biomass heating solution.

Biomass plant with buffer and conventional fossil fuel stand-by/back-up

A system utilising a biomass plant, heat store and a conventional fossil fuel stand-by/back-up plant, allows the biomass system with the buffer to offer the operational flexibility discussed above, thus maximising the heat delivered by the biomass plant. The fossil fuel plant can then be used to meet extreme peak loads or act as a stand-by system.

Increasing the size of the buffer shifts the energy balance in favour of biomass by reducing the contribution of fossil fuel stand-by to cover demand spikes of limited duration.

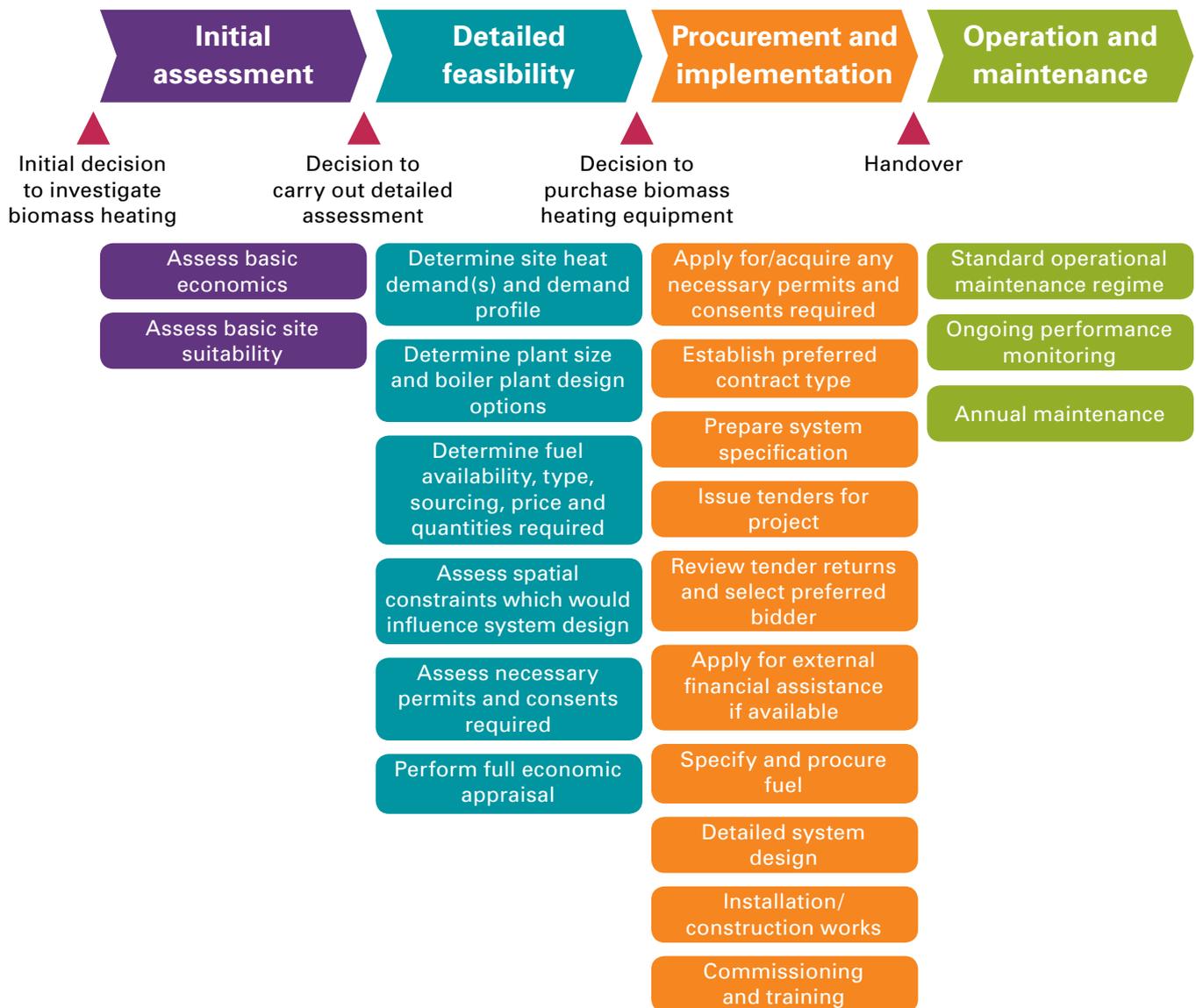
*Schematic for illustration only.

Part 3 – Implementation guide

This section of the guide describes the steps a typical biomass installation project may go through from concept to full implementation. These are illustrated in Figure 16. While in practice the exact course of a project may vary, the process described allows potential users to approach projects in a logical, structured manner.

Following a process like this should help organisations as they work to implement successful projects and seek to achieve best value for money by avoiding some common pitfalls.

Figure 16 Stages in a biomass heating project implementation



Objective of each phase in the project

- Understand the proposed site's basic suitability for implementing a biomass heating system.
- Perform a basic economic appraisal.
- Assess the non-financial benefits of installing biomass heating.
- Carry out a detailed assessment of the likely costs of a system, where and how it will be sited, the most appropriate fuel storage and general system layout.
- Identify appropriate fuel supplies and assess quantities required.
- Acquire the necessary information to be able to make an informed decision on whether or not to purchase biomass equipment.
- Perform the necessary stages in the specification, procurement and implementation of a biomass heating system.
- Ensure that all the relevant information is specified when procuring plant and fuel.
- Successful handover of a fully operational plant.
- Ensure the successful and trouble-free ongoing performance of the plant.
- Monitor plant performance.
- Monitor fuel quality.
- Conduct routine maintenance.

Key considerations

In light of the differences between the operations of biomass heating systems and conventional (oil and gas) systems, the Carbon Trust has identified three key considerations to maximise the chances of implementing a cost effective and successfully operating system.

These are:

- 1) Sizing:** due to the capital premium of biomass heating equipment it is very important to optimise the size of the biomass element of a system relative to the annual heat loads of the site. A well-sized system should enable the size (and therefore capital costs) of the biomass component to be kept to the minimum required, while still being able to deliver a very significant proportion of the site's annual heating load.
- 2) Fuel storage and handling:** a well-designed and implemented solution for receiving, storing and handling fuel at the site will pay dividends over the lifetime of the project. Solutions usually involve site-specific variations on some standard themes and concepts. However, they should seek to find the right balance between:
 - The capital cost (seek to avoid over-engineering or unnecessary "gold-plating").
 - The volume of fuel storage required vs. the available space, alternative demands on that space and construction costs.
 - The practicalities of delivering fuel vs. the capabilities of fuel suppliers.
 - The need to keep fuel transfer solutions simple (limiting the complexity and distance that fuel has to travel to be received in the combustion chamber).

Good lines of communication between the key parties: site owner, equipment installer/contractors and fuel supplier are very important here.

- 3) Fuel to equipment matching:** it is vital to secure a supply of fuel which is within the required operational parameters for the equipment in which it is intended to be used. It is also important to secure supplies of fuel that can remain consistently within those required parameters. Time spent researching the fuel supply options and in discussions with prospective suppliers can improve cost effectiveness and significantly reduce operational risks.



Image courtesy of Imperative Energy



3.1 Initial assessment

The initial assessment is an exercise to determine at a high level the likely economics and practicalities of installing biomass heating. This will help the site owner decide whether to carry out a more detailed feasibility study.

3.1.1 Assess basic economics

Biomass heating systems generally have higher initial capital cost than fossil fuel systems of equivalent rated capacity. However, this difference can be recouped through annual fuel cost savings.

Given this, biomass heating tends to be most cost-effective in:

Situations which are off the national gas grid. The capital recovery from the annual fuel cost savings is fastest when biomass heating replaces heating oil, LPG or electricity in off-grid sites.

Situations which have relatively consistent and high heat loads. The more the biomass boiler is used in meeting the heat demand (higher capacity factor), the greater the impact of the fuel cost savings on the payback of the capital expenditure.

Situations requiring limited building/reconfiguration works. Compared to fossil fuel alternatives, the larger size of biomass plant and the associated fuel storage/handling equipment means that space must be found to house these. If existing buildings can be used or modified slightly for this purpose, capital costs will be kept lower. Alternatively, if a biomass heating solution is being designed into a new build or major refurbishment project, this process is more straightforward.

Online assessment tool

To assist in the high level pre-feasibility assessment of a potential project, the Carbon Trust, with input from Black & Veatch Ltd. has developed an online tool⁴⁶ to undertake a basic economic appraisal of the financial performance of a biomass system compared to the equivalent fossil fuel alternative.

To conduct such an appraisal, the site owner will need to know the:

- Site's annual energy consumption.
- Heat demand profile (utilisation patterns).
- Costs associated with fossil fuel use.

The key outputs provided by the tool (based on the assumptions provided by the site owner, as well as industry data collected by the Carbon Trust) will be estimates for:

- Total capital investment required (£).
- Simple payback (years).
- Unit cost of heat from the project (p/kWh).
- Annual energy cost (£/year).

These basic estimates should assist site owners to consider in the first instance whether a biomass project is likely to meet their specific investment criteria.

3.1.2 Assess basic site suitability

In addition to the economics, an initial site assessment should consider practical issues that might present barriers to the installation of a biomass heating system. Sometimes such barriers can cause the cost of installation to increase significantly.

Spatial constraints – biomass plant and associated fuel storage and reception areas are significantly larger than those required for fossil fuel plant. Where space is a major constraint, it may be that the site is not suitable for a biomass system, or that more expensive civil engineering works are required.

Site access – a site must be accessible for fuel deliveries. Vehicles need adequate space to deliver fuel safely, turn around and exit the site.

Planning constraints – if a site is located within a 'designated area'⁴⁷, or is adjacent to any listed buildings, the design and construction of the plant house and fuel store will need to be sympathetic to the local surroundings which can add to the costs. Additionally, the number of fuel deliveries and vehicle movements should be estimated, particularly in sites near residential areas. The relevant regulations which apply to the air quality in the local area may also affect planning considerations for a proposed installation. Section 3.2.5 gives more detail, but in general certain areas of the UK have stricter controls on emissions to the air from combustion appliances than others (due to background levels of air quality). Depending on which regulations apply, these may require more advanced emissions abatement equipment to be fitted. In all instances, consultation with the relevant local planning officer should enable site owners to identify which planning-related issues may affect basic site suitability if undertaken at an early stage.

⁴⁶ www.carbontrust.co.uk/biomass

⁴⁷ Examples of designated areas include National Parks, Areas of Outstanding Natural Beauty and Sites of Special Scientific Interest. Local planning authorities can provide details of any relevant designations.



Further guidance is given on assessing project economics in Section 3.2.6 and also on project practicalities in Section 3.2.4.

Key milestone:
Decision to carry out detailed assessment

Based on the results of the economic and site suitability assessments, a decision is taken whether or not to carry out a detailed feasibility study.

3.2 Detailed feasibility

Site owners will need to carry out a detailed feasibility study when considering installing systems, to assess the viability of a project for themselves and structure a plan for implementation. The section covers some recommended steps in such a study. Several of these steps are interrelated and it is often necessary to perform some of them concurrently or in an iterative manner.

3.2.1 Determine site heat demand(s) and demand profile

It is very important to evaluate the heat demand profile that the biomass heating system will be required to meet, so the system can be correctly sized.

The heat demand level at any particular time is normally expressed as power (kW_{th}).

Understanding both the size and nature of heat demand for a proposed project is essential to be able to accurately determine the size of system, which in turn affects total cost and fuel requirements.

Ideally, a site's heat demand profile should show:

- The different grades of heat used at the site (e.g. process steam and hot water at different temperatures and pressures). This may also include a cooling demand (such as absorption cooling).
- (For process applications) The daily variation in heat demand, with at least an hourly resolution. Care should be taken to identify any significant spikes in heat demand, such as in certain industrial processes.
- (For space heating) Seasonal variations in heat demand, such as for space heating.

Ideally, a full year's worth of heat demand data should be gathered for space heating applications. For process applications, this can be less than a year if there is little variation in the profile of use within the process across the year.

There are a number of ways that a site's heat demand profile can be estimated:

- **Existing fuel consumption records from metered/recorded data.** This is the easiest way of estimating the heat demand profile.

If primary energy (such as with a mains gas meter) is being metered, this should be converted into delivered energy. This is done by multiplying primary energy by the efficiency of the plant; for example:

$$\begin{array}{rcccl} 100\text{MWh} & & 80\% & & 80\text{MWh} \\ \text{metered gas} & \times & \text{(plant} & = & \text{(delivered} \\ \text{(primary energy)} & & \text{efficiency)} & & \text{energy)} \end{array}$$

The data can be shown against time to give an energy profile (weekly, daily or hourly).

If metered heating data for the site is available, then hourly, daily or monthly load profiles can be constructed (depending upon the metering frequency), showing variations in load over time.

Metered data will usually show energy delivered (e.g. kWh). To construct a load profile the data must be converted into units of power (kW) by dividing by the period of time over which the metered data was measured. For example:

$$\frac{100,000\text{kWh (delivered energy)}}{160 \text{ hours}} = 625\text{kW}$$

Note that this will have an averaging effect over the period of measurement and so the site owner should also consider peak demands over the supply periods.

- **On-site measurements** can be used if no metering data is directly available. This measurement can be done manually (e.g. manually logging the main meter at site) or by hiring a fuel/heat/steam meter with data logging capability. Again, where metering primary energy, the energy should be converted into delivered energy (as above), and also then converted into power. Care should be taken when taking spot measurements as heat demands can vary considerably by time of day and time of year.



- **For steam systems** it may be useful to convert the steam flow rate (normally kg/s or tonne/hr) into power. This can be performed using steam tables⁴⁸ which show the enthalpy of the steam (normally as kJ/kg) at the specific temperature and pressure at which it has been measured. The enthalpy value is then multiplied by the mass flow-rate, and then divided by the time period for the flow-rate measurement. For accuracy, when considering the energy demand required for raising process steam, the energy in any condensate return should be allowed for by considering the enthalpy of the condensate return (determined by the temperature and pressure of the condensate return).
- **For process heat systems** it may also be possible to build a heat demand profile from the times of operation of different pieces of process equipment and their individual heat consumption. This should then be compared to measurements and/or metering records to ensure that there is good validation of the different data.

For sites where there is to be industrial use of hot water, process steam or absorption cooling, it will be necessary to evaluate the load profile based on planned activity patterns at the site and the consumption of individual pieces of equipment.

For new build sites where no historical data exists, calculations and estimations will have to be used to derive the likely peak heating load and its profile. Building heat loss calculations can be calculated based on the building fabric and degree day data⁴⁹ which is dependent on the geographical location.

Building modelling software (e.g. Hevacomp, TAS, IES, etc.) can also be used to model the thermal performance of the proposed building, and give greater insight into the predicted heat load on an intra-day basis. Domestic hot water consumption can also be calculated based on the occupancy of the building and building use (residential, office, leisure centre, etc.).

Alternatively, benchmark data, such as CIBSE Guide F⁵⁰ can be used to derive approximate heat loads for the appropriate building type. However, benchmarks are often not very accurate, partly as they are generally based on limited data sets. It is therefore recommended that their use is confined only to providing indicative plant size calculations.

General considerations

There are a number of general considerations that must be taken into account when estimating the heat loads for both new build and existing sites:

- It is normally more economic (in terms of monetary, and cost of carbon, savings) to undertake energy efficiency measures before installing biomass heating systems. Implementing energy efficiency measures for existing or new build sites should be considered before sizing the biomass heating system. This will reduce the overall level of heat demand (and potentially peak loads) in the first instance so that the capacity of the biomass heating system can be reduced and thus the capital expenditure on this is reduced.
- If the consumption is related to external temperatures, it may need to be degree day normalised⁴⁹.
- It is possible that calculated heat profiles will change over longer time periods than for which they were measured, especially into the future. For example, energy demand at the site may expand/contract (e.g. through varying occupancy or new buildings/loads being added/unoccupied at a later date).
- Other nearby requirements for heat could be linked to the system via a district heating network to provide additional heat loads.

3.2.2 Determine plant size and boiler plant design options

The specification and design of the heating system (including any controls, pumps, and the associated balance of plant) is a very important and quite complex task.

It is best performed once a preferred bidder has been selected and in consultation with an appropriately qualified mechanical and electrical contractor or biomass installer.

Section 2.2.4 of the guide introduces the approaches by which one can estimate the size of biomass plant best suited to a site and which configuration option is preferable (for the purposes of a feasibility study).

As discussed in Section 2.2.5, in many cases a biomass plant may be integrated with a conventional fossil fuel plant, and often a heat store too.

Therefore a value-engineering analysis will determine the ultimate choice of plant and configuration as it will be a compromise between the site's heat profile and:

- The capital costs of the biomass plant.
- The capital cost of the fossil fuel plant, any heat storage equipment and any storage facilities required.
- The unit cost of fossil fuel and biomass fuel.
- Organisational drivers to maximise carbon savings/renewable energy capacity or minimise upfront capital expenditure.

⁴⁸ Online steam tables - <http://www.spiraxsarco.com/resources/>

⁴⁹ Carbon Trust Good Practice Guide – *Degree Days*. www.carbontrust.co.uk/resource/degree_days

⁵⁰ CIBSE Guide F *Energy efficiency in buildings* – available from the CIBSE bookshop.



In general, there are two additional factors that should be considered before deciding on the sizing and integration approach:

- *Which loads are to be supplied (space heating, hot water, process heat)?* For instance, a small, infrequent and distributed hot water demand may be more efficiently met by point-of-use electric water heating.
- *When will the biomass plant be operated?* The method by which the current fuel is purchased (for instance on an annual flat rate contract or at the spot price) will affect the comparative cost of fossil fuel heat. Seasonally variable pricing (e.g. mains gas) may mean that it is not cost-effective to run the biomass heating system at certain times in the year, for example over the summer months when the cost of fossil fuel is lower.

3.2.3 Determine fuel availability, type, sourcing, price and quantities required

When operational problems are encountered in biomass heating systems, they are often due to a mismatch between the fuel and the biomass plant, or poorly engineered mechanical handling of fuel. Using the right fuel for the equipment is absolutely vital for successful operation.

Mismatches between fuel requirements and fuel supplies can arise for a number of reasons:

- **The system installer** not fully informing the site about the specification of the fuel required.
- **The fuel supplier** not understanding the importance of adhering to the correct fuel specifications or having insufficient technical knowledge to be able to supply the specified fuel.
- **The site owner** not understanding the importance of buying the correct fuel to specifications that are suitable for their equipment, or ignoring these in favour of a lower cost fuel which may not be of the correct specification (usually a false economy).

For a new installation, a good understanding of the proposed equipment's technical requirements and close liaison with both the plant supplier and fuel supplier minimise the risk of such problems occurring.

Site owners should consult the proposed biomass equipment suppliers about the best fuels for their equipment.

Section 2.1 provides a detailed explanation of the technical properties of different biomass fuels and Section 2.2.3 covers the various fuel handling characteristics of different types of heating plant.

Alternatively, the formulae in Appendix B provide a means of calculating fuel-energy requirements, based on expected loads and then expressing them in a weight or volumetric basis.

To do this, you will need to have an understanding of the estimated capacity factor of the biomass plant or the proportion of total annual heat demand that you expect the biomass plant to meet.

Identifying fuel suppliers

There is a wide range of biomass fuel suppliers in the UK. They differ in terms of the scale and nature of their businesses and the amounts of fuel they can deliver. Suppliers include:

- Specialist brokers that draw on biomass feedstocks from a variety of sources and then process the materials into conditioned fuels for onward sale. Such companies tend to have a fuel turnover in excess of 3,000 tonnes annually and fuel supply is their core activity.
- Small companies that have excess biomass feedstocks which they condition and sell as fuel. These suppliers often have limited volumes and fuel supply is a peripheral activity to their core business. Examples include sawmills and forestry contracting.
- Large forestry contracting companies that have diversified into fuel supply and are able to meet large contract volumes. This supplier group is typified by large national forestry contracting companies and multinational sawmill groups.

The Biomass Energy Centre (BEC) was set up by the UK government in 2006 to act as a national source of up to date, unbiased information for individuals and businesses seeking to produce or use fuels derived from all forms of biomass. This information is made available via its website (www.biomassenergycentre.org.uk) and its telephone and email enquiry service. As well as holding a considerable body of information and expertise 'in house', BEC has established links to other national information providers, including the Carbon Trust, and to regional organisations involved in developing local biomass supply chains. This strong knowledge base and network of contacts enables BEC to direct users to the most appropriate source of information to help take new biomass projects forward.

In addition to BEC, the Carbon Trust has listed a series of sources of information on fuel supply in the UK on its website (www.carbontrust.co.uk/biomass). Biomass equipment suppliers and companies which have been set up by the Regional Development Agencies to promote the development of renewable energy in their region (e.g. Future Energy Yorkshire) may also be good sources of contacts for fuel supply.



Information presented by third parties relating to fuel supplies can vary considerably. It is therefore important to make contact with several suppliers directly and ascertain their ability to meet requirements and whether or not they are supplying fuel of the required type.

When approaching fuel suppliers, potential site owners should consider asking for references or question the prospective fuel suppliers about the number of systems they currently supply (if at all) and the length of time they have been supplying fuel.

Key topics for a potential site owner to investigate with a fuel supplier are:

- Factors that will affect plant specification and operation.
- Factors that will affect fuel store design and fuel delivery.
- Factors that will affect cost.

These are covered in Table 19 (below).

Further points to consider in conversations with fuel suppliers are as follows:

- **Optimising fuel store volume for delivery** – asking the fuel supplier to confirm their standard fuel delivery volumes. Once this is known, it is possible to design the store to accommodate a full load discharge so that delivery is simpler and more convenient for the fuel supplier and no resource is wasted on partial load deliveries.
- **Flexible fuel store reception** – designing the fuel store reception to allow for more than one delivery method, thus encouraging competition between potential suppliers. For example, at retrofit sites it is sometimes difficult to provide flexible woodfuel reception, but at new build sites potential woodfuel suppliers should be consulted early in the design process to allow for maximum flexibility to reduce cost.
- **Optimising fuel discharge rates** – blower units for woodchip can result in longer delivery times, requiring the delivery vehicle to be on-site for longer and thereby increasing costs. For example, a tipper vehicle can discharge approximately 1 tonne/minute, whilst a blower unit may discharge at approximately 1 tonne in every 8 minutes.

Table 19 Issues to be covered in fuel supply investigations

Plant specification	Fuel storage and reception area	Economic appraisal
<ul style="list-style-type: none"> • Grade of fuel available. • Moisture content and likely variance. • Source of the material (<i>is it waste?</i>). • Details of quality assurance procedures. • Levels of potential contaminants (e.g. metals, stones, etc.). • Reference contacts from systems already being supplied by the proposed fuel supply operation. • Minimum delivery quantities to achieve competitive pricing. 	<ul style="list-style-type: none"> • Delivery vehicles used. • Volume of fuel deliveries possible. • Minimum volume of fuel store required to discharge a full load. • Physical access required for the delivery vehicles. • Area required for manoeuvring the vehicle⁵¹. 	<ul style="list-style-type: none"> • Price of the material to be paid at delivery point. • Minimum and maximum delivery quantities. • Variation in fuel price with different delivery quantities.

⁵¹ The Freight Transport Association (www.fta.co.uk) can provide information on different vehicles sizes and turning circles etc.

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3.2.4 Assess spatial constraints which would influence system design

Biomass systems generally need more physical space than fossil fuel systems of the same rated output. Not only are the plant units themselves larger, but they also require:

- Sufficient free space around the unit for maintenance and cleaning.
- Fuel storage facilities.
- Vehicle access for fuel delivery.
- Associated ancillary plant (heat storage vessels, chimneys etc.).

The spatial requirements of parts of biomass heating systems are described further below:

Plant size and cleaning access – Table 20 indicates a range of typical biomass plant sizes. A biomass plant will also need a degree of clearance around certain areas to enable cleaning and such tasks as ash emptying. Selected equipment providers should be consulted to give exact plant footprint and access requirements (for cleaning etc.) of their particular chosen models.

Installation access – if considering using an existing space to house the biomass plant, thought should also be given to the access that may be required to install the unit. Some biomass plant arrives fully assembled, and others arrive in a modular, dismantled state; this varies between manufacturers. Where installation access is constrained, a modular kit may be preferable as temporary building works (e.g. removing roof sections) to allow placement can be costly.

Fuel storage facilities – as biomass is a solid fuel, careful consideration needs to be given to the storage of fuel so as to enable straightforward delivery to the combustion chamber (i.e. it is important to limit the length and particularly the complexity of the fuel feed system).

If space is not available for fuel storage adjacent to the proposed plant location, it may be possible to construct a dedicated 'energy centre' (a separate building containing both plant and fuel storage). A district heat pipe can then be used to deliver heat to where it is required via an underground pipe network.

The simplest way of assessing the size of fuel store needed is to estimate the amount of fuel required for a given number of hours of continuous operation. CIBSE Guide B recommends 100 hours of continuous operation⁵² at full load for solid fuel stores. However, different organisations may have different requirements. The amount of fuel consumed in such a period will be a function of:

- The calorific value of fuel.
- The energy density of fuel.
- The plant efficiency.
- The plant size.
- The heat output of the plant.

A calculation to determine fuel quantities is given in Appendix B.

Table 20 Typical biomass heating plant sizes (indicative)

Plant size (kW)	Footprint (m ²)	Length (m)	Width (m)	Height (m)
250	22	5.5	4	2.1
320	33	8.2	4	2.5
400	33	8.2	4	2.5
500	42.5	8.5	5	2.7
700	42.5	8.5	5	2.9
900	45	9	5	3.6
1500	47.5	9.5	5	4.3
2500	55	10	5.5	4.7
3500	60.5	11	5.5	5.6
4500	69	12.5	5.5	5.9

Source: B&V market data

⁵² Larger systems (1-2MW+) will tend to have storage capacity for around 3 days of continuous operation, with smaller systems (<500kW) often having capacity sufficient for 2-4 weeks.



Where the site has other heating equipment capable of providing most or all of the full peak load (e.g. a fossil fuel boiler), it may be possible to reduce the number of hours-worth of fuel that needs to be stored. This may be necessary where the site owner needs to balance several factors:

- The space available at the site.
- The construction costs for fuel stores.
- The capacity of delivery vehicles and the frequency of deliveries desired/possible⁵³.
- The level of back-up biomass fuel desired (i.e. ability to continue operating on biomass fuel in the event of a fuel supply disruption).

Once the volume of fuel required has been estimated, the full size of the fuel store can be estimated based on the 'live volume'. This is the volume of fuel in the store which is accessible to the fuel extraction system.

Some fuel store layouts/configurations have areas where the fuel cannot be accessed, known as 'dead space'. Suppliers of fuel handling equipment should be consulted to determine the dead space allowance. For example, a square fuel store with a circular agitator will have areas that cannot be reached by the agitator – the corners and the area below the sweep of the agitator arms. The dead space may be up to 15-20% of the total fuel store volume.

Alternatively, there may be areas of a fuel store that are not actually used for storage but are taken up by sloping floors to channel fuel into an auger. This is common for pelletised fuels.

Other considerations include:

- Whether the fuel store is big enough to accommodate a full delivery load from the fuel supplier. Suppliers should be consulted to see whether they can deliver only a partial load, and if so, whether this has an impact on fuel price.
- The overall dependability of the fuel supply chain, including the proximity to the fuel supplier, general confidence in their reliability and local weather conditions. If interruptions to fuel supply deliveries are likely, a larger store should be specified to reduce the risk of fuel shortages.

Vehicle access for fuel delivery – biomass plants need regular deliveries of a solid fuel and consideration needs to be given to the space available for delivery vehicles. The space required depends on the type of vehicle used by the supplier and the chosen fuel store configuration.

Generally, space is needed for vehicles to reverse before offloading their fuel and also to turn before leaving the site. Some fuel suppliers are equipped with pneumatic blower-trucks which can deliver fuel into less accessible locations via a flexible hose. Generally pellet delivery by this method is more common in the UK, but some suppliers can provide this for chip fuel too. Such suppliers are less common in the UK but if one is available locally, this may provide delivery flexibility if access to fuel storage is severely constrained.

Associated ancillary plant – the key items of ancillary equipment that affect the space required are:

- *The buffer/thermal store* – (this may or may not form part of the final specification). The spatial requirements will depend on the buffer capacity required by the system (e.g. 2,000 litres = 2m³, 10,000 litres = 10m³).
- *The pipework* – some space will be required for the pipework connecting the plant to the existing/new heat system.
- *The flue/chimney* – as a general rule, a biomass plant will typically require a flue that is taller than that required for an equivalently sized gas or oil system and wider in diameter (flues for biomass plants are usually twin wall stainless steel or have ceramic liners).

Chimneys for biomass systems are typically required to fulfil three criteria (on which detailed guidance will need to be provided by the manufacturer/supplier). These are that the flue must be:

1. Of sufficient height and appropriate diameter to remove the products of combustion from the flue outlet of the plant (the manufacturer/supplier can supply the appropriate criteria).
2. Of sufficient height to discharge the products of combustion so as not to cause a nuisance to people either within or outside the property (as specified in building regulations).
3. Visually acceptable to the planning authorities.

⁵³ Bear in mind that a high frequency of deliveries may cause a noise disturbance.

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3.2.5 Assess necessary permits and consents required

There is a range of legislation and regulations applicable to biomass plants and the requirements depend on the size of the project, the type of biomass fuel used and the location of the site.

- **Planning permission** is usually required for biomass boiler installations. Exceptions to this normally relate to the replacement of existing fossil fuel systems with some types of smaller biomass boiler. If planning permission is required, the main issues that need to be taken into account in designing the site and obtaining planning permission are traffic, emissions to air, noise, visual impact and compliance with legislation and regulations.

It is strongly advised that the site owner or project developer should engage with the Local Planning Authority (LPA) at the earliest possible opportunity. If the site owner or developer can provide sufficient outline information about the proposed project, the LPA will be able to advise on the legislation, regulations and procedures that are applicable to the project. Other potential sources of advice are the suppliers of the boiler equipment and operators of similar plant in the area.

Irrespective of whether planning permission is needed or not, the following areas of regulation may apply to the project and therefore may be areas in which a permit or some form of approval is required for it.

- **Building regulations 2000**⁵⁴. These cover issues which affect the health and safety of building occupants, building energy efficiency, prevention of waste, fire and contamination of water etc. They apply to most new buildings and building alterations. It is the responsibility of both the person carrying out the work and the owner of the building to ensure compliance and approval is carried out by the Local Planning Authority (LPA). The sections with particular relevance to biomass installations are those covering fire safety, resistance to contaminants and water, conservation of fuel and power, materials and workmanship, air vents, flues and chimneys, and electrical safety. There are a number of practical guidance documents available ('Approved Documents'⁵⁵).

- **The Clean Air Act 1993**⁵⁶. Under this act, local authorities may declare the whole or part of the district to be a Smoke Control Zone⁵⁷. Only Authorised ('smokeless') fuels can be burned in a Smokeless Zone. There are almost no biomass fuels which are Authorised as 'smokeless'. However, some biomass fuels can be burned in a Smokeless Zone provided that an Exempt Appliance is used and there are many biomass heating appliances that have been classified as such⁵⁸. In addition to Smokeless Zones, Local Authorities can declare areas with pollution higher than the national objectives as Air Quality Management Areas (AQMA)⁵⁹. No guidance exists on the use of biomass heating in AQMAs at present and in this case the Local Authority should be approached directly for guidance as to whether or not the proposed appliance can be used. Emissions information from the supplier of the plant under consideration should be sought early on in this process as it may help to avoid delays later on (in the implementation process) if there are likely to be air quality requirements at the proposed site.
- **Environmental Permitting Regulations 2007 (EPR)**⁶⁰. Certain industrial processes (including some biomass plants) must be authorised under the EPR. These regulations have replaced and encompassed the Pollution Prevention and Control Regulations 2000 and effectively combined the latter with the Waste Management Licensing Regulations. The EPR require all those processes prescribed in Schedule 1⁶¹ (which includes combustion processes) to operate under a permit regime. Processes within Schedule 1 fall under the definition of A(1), A(2) and Part B activities, which are often determined in accordance with certain capacity thresholds and/or types of feedstocks. Table 21 provides a general guide as to how these regulations apply to biomass.

All these systems require the operators of the affected installations to obtain a permit to operate. Once an operator has submitted a permit application, the regulator then decides whether to issue a permit. If one is issued, it will include conditions aimed at reducing and preventing pollution to acceptable levels. A(1) installations (e.g. >3 MW_{th} plant burning biomass fuels qualifying as wastes) are generally perceived to have a greater potential to pollute the environment than an A(2) installation, and Part B installations would have the least potential to pollute.

⁵⁴ <http://www.opsi.gov.uk/si/si2000/20002531.htm>

⁵⁵ <http://www.planningportal.gov.uk/england/professionals/en/1115314110382.html>

⁵⁶ http://www.opsi.gov.uk/acts/acts1993/pdf/ukpga_19930011_en.pdf

⁵⁷ <http://www.uksmokecontrolareas.co.uk/locations.php>

⁵⁸ http://www.airquality.co.uk/archive/smoke_control/appliances.php

⁵⁹ <http://www.airquality.co.uk/archive/laqm/laqm.php>

⁶⁰ <http://www.defra.gov.uk/environment/epp/guidance.htm>

⁶¹ http://www.opsi.gov.uk/si/si2007/uksi_20073538_en_8#sch1



Table 21 Summary of environmental permissions for biomass heating equipment

Biomass fuel	Scale of project	Relevant environmental permissions	Regulator
Virgin wood derived biomass fuels and energy crops	<20 MW _{th}	Clean Air Act	Local Authority
	20-50 MW _{th}	IPPC (PPC Part B)	Local Authority
	>50 MW _{th}	IPPC (PPC Part A1)	Environment Agency
Residues or waste derived biomass exempted from WID: untreated wood e.g. disused pallets	<0.4 MW _{th} (<50kg/hr)	Clean Air Act	Local Authority
	0.4-3 MW _{th} (50-1000kg/hr)	IPPC (PPC Part B)	Local Authority
	>3 MW _{th} (>1000kg/hr)	IPPC (Part A1)	Environment Agency
	>50 MW _{th}	IPPC Part A1 (Large Combustion Plant Directive applies)	Environment Agency
Residues for which WID applies – treated wood e.g. painted furniture	<3 MW _{th}	WID applies (IPPC Part A2)	Local Authority
	>3 MW _{th}	WID applies (IPPC Part A1)	Environment Agency

(IPPC): Integrated Pollution Prevention and Control

(LA-IPPC): Local Authority Integrated Pollution Prevention and Control

Source: AEA Energy and Environment

The primary difference between Part A and B activities is that the permit conditions for a Part A activity regulate emissions to air, water and land, together with a number of other issues; permits for part B activities only relate to emissions to air. Guidance and fee structures for these permits can be found on the DEFRA website⁶².

- **The Waste Incineration Directive 2003 (WID)**⁶³ imposes requirements on the waste that is permitted to be combusted at a given plant. The WID applies to certain solid biomass fuels used for heating and should be consulted if the proposed project will be using waste or discarded materials as a fuel source. Note, however, that certain materials are exempted from the WID such as:

- Vegetable waste from agriculture and forestry.
- Fibrous vegetable waste from virgin pulp production and from production of paper from pulp (if it is co-incinerated at the place of production and the heat generated is recovered).
- Wood waste with the exception of wood waste which may contain halogenated organic compounds or heavy metals as a result of treatment with wood-preservatives or coating, and which includes in particular such wood waste originating from construction and demolition waste.

If a site owner/developer expects to use a biomass waste classed as a waste under the WID, then their project must comply with waste incineration regulations. Since their introduction, permissions for waste incineration are controlled through the EP Regulations (as above). For more information on WID see the Defra guidance⁶⁴.



⁶² <http://www.defra.gov.uk/environment/epp/guidance.htm>

⁶³ <http://www.opsi.gov.uk/si/si2002/20022980.htm>

⁶⁴ <http://www.defra.gov.uk/environment/ppc/envagency/pubs/index.htm>

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3.2.6 Perform full economic appraisal

As well as offering lower carbon emissions, biomass heating systems can have lower lifetime (or net present value) costs than fossil fuel plants. This is due to the costs of biomass fuels being lower than those of several fossil fuels typically used for heating (e.g. heating oil, LPG, electricity).

However, the capital costs of biomass systems tend to be higher than for fossil fuel boilers. Consequently, in order to choose biomass systems on financial grounds, one needs to take a long-term view towards the overall investment, rather than a short-term view of just upfront costs.

This section introduces the main factors affecting costs, both capital and operational, and gives a worked example for a 400 kW_{th} biomass heating system.

Before performing an economic appraisal of the proposed system, it is useful to understand the different components, structure and indicative levels of biomass heating systems' costs, both capital and operational.

The main reasons why biomass heating systems are more expensive than equivalent fossil fuel systems are:

1. Some of the basic principles of solid fuel combustion mean that the biomass plant unit needs to be larger than typical fossil fuel systems. Also, biomass plants will generally contain more mechanical components (such as fans, ash extraction equipment etc.).
2. As solid fuel systems, biomass heating plants need fuel storage facilities (and extra space to accommodate the larger plant unit itself). Unless an existing building can be used to perform this function, fuel and plant storage is usually a significant part of overall system cost.
3. Some form of fuel extraction/feed method will be required (e.g. a screw auger), which adds to overall system cost.
4. At present in the UK, biomass systems are sold in small numbers (compared to the market for fossil fuel equipment) and are offered by a relatively small number of providers. Accordingly biomass heating equipment does not benefit from the economies of scale that fossil fuel equipment does.

5. The majority of systems installed in the UK are imported from continental Europe which can involve additional importation costs. In addition, variations in the Sterling-Euro exchange rate at the time of system procurement can have an effect on final costs (although this could be positive as well as negative).

Capital costs

Figure 17 provides a cost breakdown of the major elements for a recent real-life example of a (500 kW_{th}) biomass heating system.

Individual site circumstances will mean that the actual costs of projects may vary significantly – even for systems of a similar installed capacity.

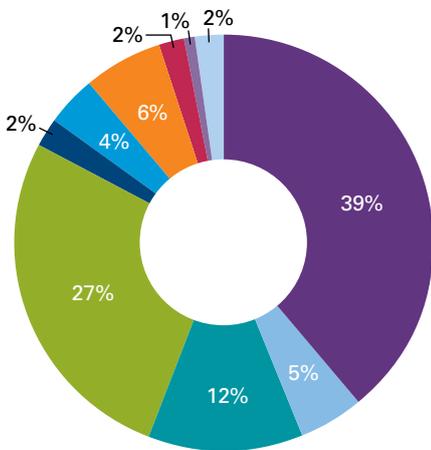
The reasons for such variations are largely connected to the specific circumstances of the site and the owner's requirements for the project:

1. Some sites may be able to make use of existing buildings or simple on-site structures to act as the fuel storage facilities and/or boiler housing facility. However, certain projects may require very complex constructions/alterations to enable a biomass heating system to be deployed.
2. Certain contract structures can have an impact on total costs – for example if the site owner is able to carry out any necessary civil, electrical and/or design works 'in house' this can reduce the overall capital cost. However, complex contracting structures within projects (multiple layers of contracting companies) may increase costs as contingency funding is factored in to take account of any uncertainties in the contract.
3. Historically, some projects have been specified above the minimum functional levels necessary for correct operation. This is usually either for aesthetic reasons or because the system is to form part of an 'exemplar' or demonstration scheme to promote renewable energy.
4. In some cases sites require significant building alterations or integration works to enable retrofitting of a full biomass heating solution.

Figure 18 (over) gives illustrative installed capital costs of complete biomass heating systems across a number of size ranges and shows a spread of costs within each size range.



Figure 17 Capital cost breakdown for an example biomass heating project



Detailed breakdown:
 Total system cost = £187,000
 Cost (£/kW) for each element:

Boiler	£146
Fuel feeding system	£20
Fuel storage	£43
Boiler house	£102
Accumulator	£6
Flue system	£16
Design, PM, commissioning	£21
Transport/delivery	£7
Pipes and fittings	£4
Wiring and control	£9
Total installed cost	£374

Note: The exact composition of the balance of plant for specific projects is variable and may contain some additional items to the above. However, this represents a 'typical' project breakdown.

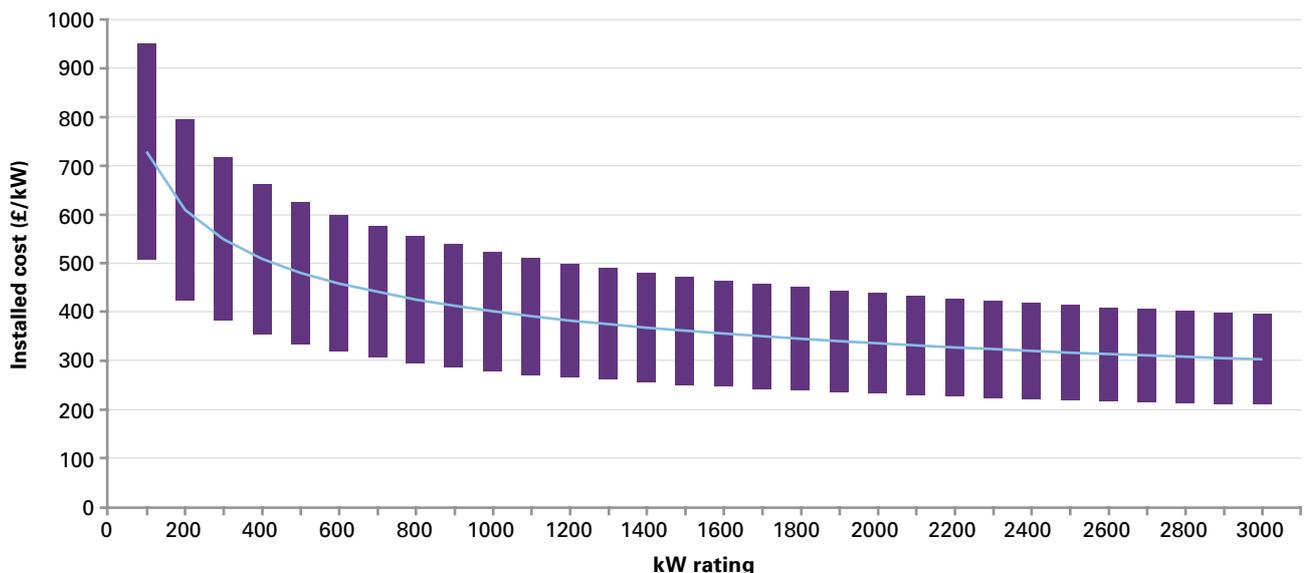
- Boiler
- Boiler house
- Design, PM, commissioning
- Pipes and fittings
- Fuel feeding system
- Accumulator
- Transport/delivery
- Wiring and control
- Fuel storage
- Flue system

Notes: Based on a recently designed and costed project of 500 kW_{th} rated capacity. The total installed cost is at the lower end of the indicative range given for 500 kW_{th} systems in Figure 18 – reflecting good site selection, good design and best practice. The relative weighting of cost centres will vary depending on the scale of projects e.g. projects >1 MW_{th} will probably require large fuel storage facilities – this being reflected in a greater proportion of the total project cost. However, the cost centres

remain the same; fuel storage, plant storage facilities and fuel feed systems can represent significant proportions of total project cost. (Note that some biomass heating systems may be installed as part of a district heating system requiring extensive underground pipework. However, the costs of such infrastructure would necessarily apply to a fossil fuel district heating system too and have not been covered in the example above).

Source: Carbon Trust/B&V market data

Figure 18 Capital cost ranges for a biomass heating system



Notes:

- The bars in this chart represent indicative ranges at today's prices (2008) for complete biomass system costs (i.e. inclusive of all required construction and other balance of plant necessary).
- The prices represented in the chart are for indicative purposes only.
- The chart is based upon data gathered from 44 system costings for biomass heating applications as part of the RegenSW 'Bioheat' programme run in 2007/8 in the South West of England.
- Price quotes received have been conditioned to allow comparability across size ranges and then analysed using a power curve regression.
- It is important to note that changes in market prices and variations in exchange rates as well as the specific requirements of individual projects (discussed above) may mean that final project costs or quotes received could be above or below these indicative ranges.



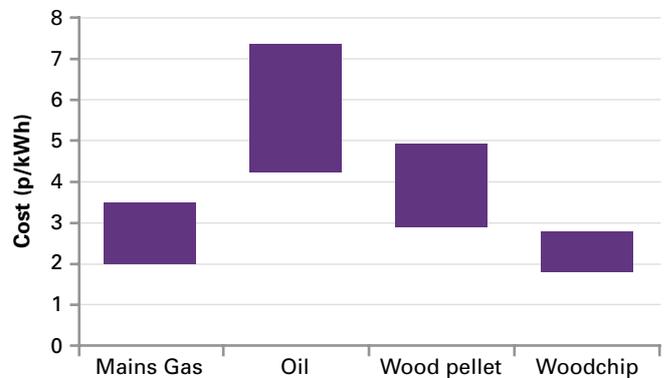
Operational costs

There are two main aspects to the operational costs of a biomass system: fuel costs, and system operation and maintenance (O&M) costs.

Figure 19 provides an estimate of current fuel costs for two of the most common biomass fuels (wood pellets and woodchips) compared to those of fossil fuels. This illustrates that the procured cost of biomass fuels can vary considerably. The main reasons for this variation are outlined briefly in Table 22. Although these factors are the main determinants of price paid for biomass fuels, there is also a degree of variation in price brought about by geographical location in the UK. For example, in certain areas, greater levels of competition in the fuel supply chain in certain areas and widespread availability of certain materials may mean that costs are lower.

If a site owner intends to supply fuel from their own sources then the costs of fuel will be affected by factors such as labour costs, the cost of either hiring or purchasing and maintaining the necessary processing equipment, and also the cost of fuel storage (to allow drying). It is outside of the scope of this document to discuss the processing and management involved in a fuel supply operation. However, the Biomass Energy Centre provides a number of technical reference documents on this topic that are available via their website for information⁶⁵.

Figure 19 Delivered heat cost (fuel only)



Source: Carbon Trust/Biomass Energy Centre market data, 2008

Table 22 Typical cause of variation in biomass fuel costs

Logistics	Quality	Market
<ul style="list-style-type: none"> • Location in relation to raw material supply/delivery distance. • Delivery volume (partial load deliveries may not be as cost-effective for suppliers as full loads, which may reflect in price). • Delivery vehicle type. • Delivery frequency. 	<ul style="list-style-type: none"> • Form of delivered fuel (processing of biomass feedstocks clearly adds costs therefore more processed fuels such as pellets will be more expensive than less processed forms such as logs). • Quality (fuels that are processed to a high specification will also tend to be more expensive than lower quality fuels due to the additional costs to suppliers of drying and quality management). • Original source material (fuels produced from materials such as virgin timber will tend to be more expensive than reclaimed materials or co-products; however, this will vary throughout the UK depending on the relative availabilities of certain materials). • Calorific Value (fuels richer in energy content will tend to be more expensive than those with lower energy content). 	<ul style="list-style-type: none"> • Contracting type – buying fuel by weight, volume, or energy. • Total annual contract volume. • Fluctuation in seasonal demand. • Local demand in relation to competing markets for materials.

⁶⁵ http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,15118&_dad=portal&_schema=PORTAL



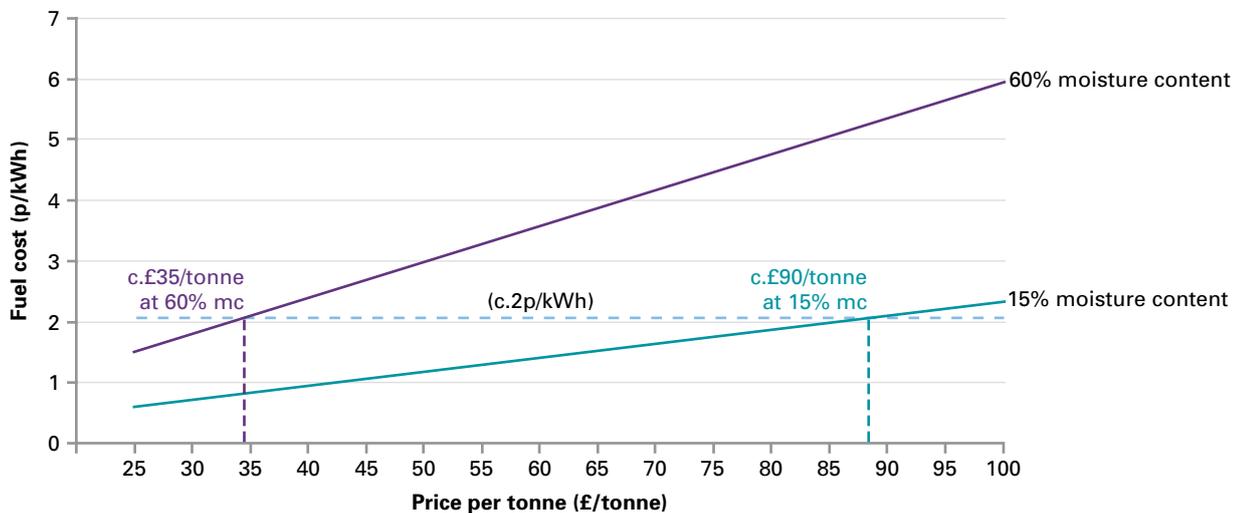
Figure 20 highlights the effect that moisture content can have on price, as this fuel characteristic is the key determinant of its energy content. Fuel purchased at a relatively low cost (c.£35/tonne) but which has a relatively high moisture content (60%) will have the same unit cost of heat energy (c.2p/kWh) as fuel purchased at a higher cost (c.£90/tonne) but which has a lower moisture content (15%).

O&M costs for biomass systems are usually higher than for fossil fuel systems, and generally include:

- **Labour.** Biomass systems can require more regular maintenance than fossil fuel boilers. A system can require between 0.5 and 1.5 days per month of attendance time.
- **Servicing.** Like fossil fuel boilers, biomass systems need to be serviced annually, and this may cost between £500-£1,500 plus parts. In addition, major overhauls are usually required at five-year intervals.
- **Electricity.** Compared to fossil fuel boilers, biomass systems require more electricity to operate their integral motors, fans and pump systems⁶⁶.

O&M costs can be minimised by specifying a biomass system for minimal attendance, for example by incorporating automatic ash extraction, automatic cleaning and remote monitoring systems. Several of these options come as standard on some biomass models. However, where they are optional they can add to the capital costs, so it is important to weigh up the benefit of reduced O&M costs against any additional capital costs.

Figure 20 Delivered fuel cost



Source: Carbon Trust/B&V market data

⁶⁶ However, even taking this additional electrical usage into account, biomass heating systems still provide significant carbon savings relative to conventional heating systems.

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Financial support measures for biomass heat

This box provides an overview of some of the financial support measures currently on offer and which have previously been available for installing biomass heating systems. The Government recently held a consultation about future support for renewable heating technologies (such as biomass) and details of some of the options can be found in the UK Renewable Energy Strategy consultation document⁶⁷.

Interest free loans

The Carbon Trust offers interest free energy-efficiency loans from £5,000 up to £200,000* for small or medium-sized enterprises (SMEs) throughout the United Kingdom to undertake eligible biomass projects. Loans are unsecured, interest free and repayable over a period of up to 4 years. There are no arrangement fees. All Businesses need to have traded for at least 12 months. Eligibility information, scheme terms and conditions, and other information including how to make an application can be found online at www.carbontrust.co.uk/loans

*Regional variations apply.

Grants for site owners

For several years, the UK government has awarded grants to project developers and other organisations to support the development of biomass heat and/or electricity projects. In England this has primarily been through the Bio-energy Capital Grants scheme. At the time of writing, a round of these grants is available until the 30th April 2009 with grants valued at up to 40% (subject to a maximum level cap of £500,000) of the difference in cost between installing a biomass system and a fossil fuel alternative⁶⁸.

While the Bio-energy Capital Grants scheme is for private and public sector organisations, support for households, public and charitable sector organisations is also available via the Government's Low Carbon Buildings Programme⁶⁹. Householders can benefit from grants up to £600 or 20% of the 'relevant eligible costs'⁷⁰ of automated wood pellet heaters/stoves, and up to £1,500 or 30% of the costs of woodfuel boiler systems. Meanwhile, public sector organisations can receive grants⁷¹ of up to £1.0m or 50% of the costs of these technologies.

The Bio-energy Capital Grants Scheme is for English sites only. The Low Carbon Buildings Programme is UK-wide. Other grant schemes include the Scottish Biomass Support Scheme⁷² (currently closed to applicants but with further rounds anticipated), the Wood Energy Business Scheme⁷³ in Wales and the Environment and Renewable Energy Fund in Northern Ireland, (sponsored by the Department for Enterprise, Trade & Investment⁷⁴).

Other support for site owners

In addition to grants, site owners may be able to benefit from other policy measures, including:

- The Enhanced Capital Allowance (ECA) Scheme provides businesses with 100% first year tax relief on qualifying biomass technology purchases. The energy technology list specifies which biomass technologies⁷⁵ are supported by the ECA scheme. Eligibility information, scheme terms and conditions, and other information including which biomass technologies are supported by the scheme can be found at www.carbontrust.co.uk/eca
- The Climate Change Levy. Generally, this is charged on the supply of energy to industry, commerce and the public sector, but along with other forms of low carbon energy, biomass is presently exempt from the charges. This has the effect of reducing the cost of using biomass compared to conventional fossil fuels.

⁶⁷ <http://renewableconsultation.berr.gov.uk/consultation/chapter-4/executive-summary/>

⁶⁸ See the DECC website for further details: <http://www.bioenergycapitalgrants.org.uk/>

⁶⁹ See: <http://www.lowcarbonbuildings.org.uk/> and <http://www.lowcarbonbuildingsphase2.org.uk/>

⁷⁰ See the scheme website for definition.

⁷¹ Other technologies – e.g. wind turbines – may be included in this total.

⁷² This is an initiative of the Forestry Commission Scotland. See: <http://www.usewoodfuel.co.uk/ScottishBiomassSupportScheme.stm>

⁷³ See: <http://www.woodenergybusiness.co.uk/>

⁷⁴ http://www.detini.gov.uk/cgi-bin/get_builder_page?page=2104&site=5&parent=21&prevpage=53

⁷⁵ For further details, see the Carbon Trust technology information leaflet ECA757, *Biomass boilers and room heaters*.

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Financial support measures for biomass heat (continued)

In addition, site owners may be able to take advantage of the following special circumstances:

- Using waste wood for biomass energy production and thereby diverting it from landfill. This will avoid the Landfill Tax⁷⁶, charged per unit mass of materials going to landfill sites. The current rate (set in April 2008) is £27/tonne.
- Installing a biomass CHP system (see box on page 42 and 43) and thereby generating renewable electricity in addition to heat. Such electricity may be eligible for subsidy under the Renewables Obligation⁷⁷, which is currently valued at around £45-50/MWh.

Wider policies affecting economics of the biomass industry

On top of the above, a range of other policies is supporting development of the biomass industry and may offer indirect yet still valuable financial benefits to organisations installing biomass heat systems.

For example, biomass fuels are zero-rated in the European Union Emissions Trading Scheme (EU ETS), which could affect a company's carbon dioxide abatement targets or compliance. In the UK, the same is true of the forthcoming Carbon Reduction Commitment⁷⁸. The Carbon Emissions Reduction Target (CERT) scheme, which obliges energy suppliers to reduce carbon emissions in the household sector⁷⁹, refers to biomass community heating and CHP as well as biomass microgeneration.

It is also worth mentioning policy measures intended to support the development of biomass fuel supply chains. For example, the Energy Crops Scheme offers grants to farmers in England for the establishment of miscanthus and short rotation coppice⁸⁰ and the Bioenergy Infrastructure Scheme⁸¹ offers grants to farmers, foresters, businesses, local authorities and charities in England to help with the costs of supply chain development (e.g. harvesting, processing, storage equipment). Other similar schemes operate in the devolved administrations.

The Renewable Heat Incentive

The Renewable Energy Strategy (RES) consultation⁶⁷ put forward two potential financial support mechanisms: one an obligation-type instrument similar to the Renewable Obligation for renewable electricity; the other a 'Renewable Heat Incentive' (RHI) – essentially a 'feed-in-tariff' (FIT) for renewable heat. The latter was stated to be the Government's emerging preference, and was also the preference of the majority of key respondents to the consultation.

The 2008 Energy Act (granted Royal Assent on the 26th of November) created enabling powers to allow the Government to establish a financial mechanism for stimulating the uptake of renewable heat (the RHI). As envisioned in the RES consultation, under the RHI, generators of renewable heat, including biomass heat, will be able to claim financial support for each measured unit of renewable heat (a MWh_{th}) they produce.

Using the powers in the Energy Act the Government intends to develop the detailed regulations and systems that will underpin the deployment of the RHI. Throughout this process, the Government intends to continue to work closely with key stakeholders who have already been involved in developing the detail of the policy.

Whilst the Government is working to introduce the RHI as soon as possible, as this is a new area of policy, there are some difficult challenges in design that will need to be addressed. The Government will conduct further analysis on the possible form of the RHI, how it can be administered and intends to consult on the details of the scheme later in 2009. The RHI is intended to bring a step change in renewable heat deployment and to make renewable heat sources (such as biomass) a significant part of the UK energy infrastructure.

⁷⁶ See the HMRC guide *Notice LFT1 A general guide to Landfill Tax*.

⁷⁷ See: <http://www.berr.gov.uk/whatwedo/energy/sources/renewables/policy/renewables-obligation/what-is-renewables-obligation/page15633.html>

⁷⁸ See: <http://www.carbontrust.co.uk/climatechange/policy/CRC.htm>

⁷⁹ See here for further details: <http://www.defra.gov.uk/environment/climatechange/uk/household/supplier/cert.htm>

⁸⁰ <http://www.defra.gov.uk/rural/rdpe/sectg.htm>

⁸¹ <http://www.defra.gov.uk/farm/crops/industrial/energy/infrastructure.htm>



Example economic appraisal

Organisations considering installing biomass heating systems are often interested in economic criteria, particularly:

- Total upfront capital costs (capital expenditure, capex).
- Ongoing operating costs, including costs of the fuel.
- The attractiveness of investments in simple payback and present value terms compared to fossil fuel systems.

This section describes how these criteria can be assessed by means of a simple worked example. The example employs data representative of current market conditions to indicate the scale of investment required.

The example concerns a 400 kW_{th} biomass heating system, which will act as lead plant at a new commercial site instead of a fossil fuel boiler. The biomass plant will deliver 1,600,000 kWh of heat a year, which represents a capacity factor of 46%. The boiler can run on either wood chips or pellets, and both are included in the example for comparison. Comparisons are also made to an equivalently sized fossil fuel boiler and fossil fuels this might use.

Total upfront capital cost

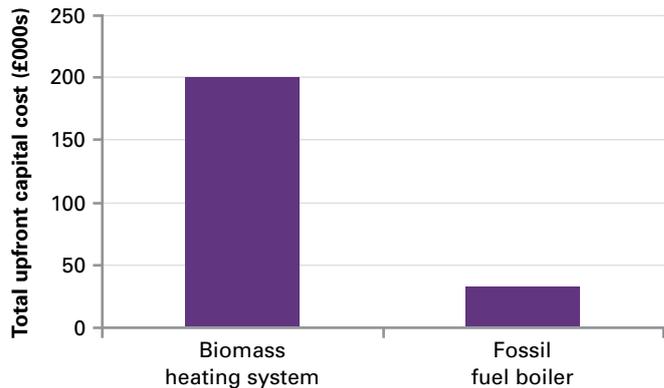
Firstly, the total cost per unit installed capacity of the boiler can be estimated using Figure 18, which indicates that a 400 kW boiler costs in the range £350/kW to £650/kW. Taking a mid-value of £500/kW and using the following equation, the total installed cost of the 400 kW boiler is £200,000 (see Equation A below).

If a grant is available, the total cost can be reduced by the grant amount. No grant is assumed in this example.

This equation can also be used to estimate the cost of an equivalent fossil fuel boiler, for comparative purposes. At a cost per installed capacity of £80/kW⁸², this is £32,000.

The difference between the capital investment options is illustrated in Figure 21 and is calculated to be £168,000 (the biomass capital cost premium).

Figure 21 Total upfront capital cost of biomass heating system



Equation A

$$\text{Total cost} \quad [\text{£}] = \text{Cost per unit installed capacity} \quad [\text{£/kW}_{\text{th}}] \times \text{Plant output at Maximum Capacity Rating (MCR)} \quad [\text{kW}_{\text{th}}]$$

⁸² The capital cost of fossil fuel was calculated from the *Spon's Mechanical and Electrical Services Price Book* 38th Edition (Davis Langdon, 2007).

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Annual operating costs

Annual biomass fuel usage

The first step in working out the ongoing annual operating costs is to assess the biomass fuel usage. This is a function of the energy required and the energy content of the fuel (taking into account the fuel's moisture content), as Equations B and C (below) show.

The constant 0.68 is the amount of energy required to drive moisture from the fuel (the evaporation enthalpy of water).

Tables 23 and 25 provide relevant data relating to biomass fuels and fossil fuels.

Table 23 Biomass fuel assumptions

	Chips	Pellets
Net CV of dry fuel [kWh/kg]	5.25	5.25
Moisture content [%]	35	8
Annual delivered heat	1,600,000 kWh	

The efficiency of the biomass plant is assumed to be 85%. This gives the results shown in Table 24.

Table 25 Fossil fuel reference assumptions

	Heating oil	Mains gas	Liquid Petroleum Gas (LPG)	Heavy Fuel Oil (HFO)	Light Fuel Oil (LFO)
Net CV of fuel	9.87 [kWh/litre]	10.13 [kWh/m ³]	6.52 [kWh/litre]	10.8 [kWh/litre]	10.7 [kWh/litre]
Cost per unit of fuel [£/litre] except gas which is given in [£/m ³]	0.50	0.30	0.40	0.35	0.40

$$\text{Equation B} \quad \text{Fuel usage [kg/year]} = \frac{\text{Delivered heat [kWh/year]}}{\text{Delivered heat per unit mass of fuel [kWh/kg]}}$$

$$\text{Equation C} \quad \text{Delivered heat per unit mass of fuel [kWh/kg]} = \frac{\text{Net CV of fuel as received [kWh/kg]} \times \text{Plant efficiency [%]}}{\text{Net CV of fuel as received [kWh/kg]}}$$

Where:

$$\text{Net CV of fuel as received [kWh/kg]} = \frac{\{\text{Net CV of dry fuel [kWh/kg]} \times (1 - \text{Moisture Content} [\%])\} - \{0.68 \times \text{Moisture Content} [\%]\}}{\text{Net CV of dry fuel [kWh/kg]}}$$

$$\text{Equation D} \quad \text{Fuel cost [£/year]} = \text{Fuel usage [tonnes/year]} \times \text{Unit fuel cost [£/year]}$$

Table 24 Calculating biomass fuel requirements

	Chips	Pellets
Net CV of fuel as received [kWh/kg]	3.17	4.78
Delivered heat per unit mass of fuel [kWh/kg]	2.70	4.06
Fuel usage [kg/year]*	593,000	395,000

*To the nearest 1,000 kg.

In summary, the biomass boiler would require 593 tonnes of chips or 395 tonnes of pellets per annum.

Annual fuel cost

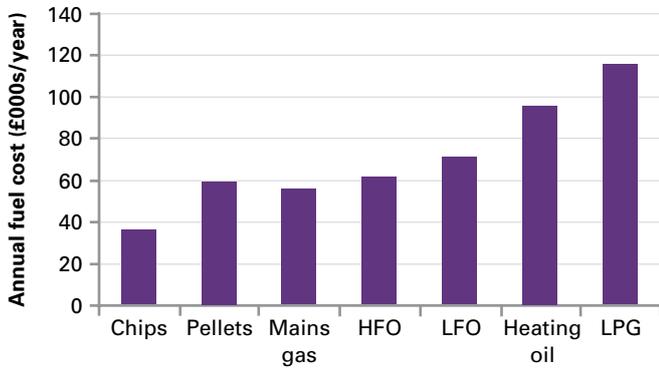
Currently in the UK, chips and pellets can be obtained for around £60/tonne and £150/tonne respectively⁸³. Applying equation D, the costs of using chips can be shown to be £35,600/year and the cost of pellets to be £59,200/year.

Figure 22 compares these costs to those of a range of fossil fuels which would be required by a fossil fuel boiler of equivalent capacity (400 kW_{th}) and identical efficiency (85%). Figure 22 is derived from the following data:

⁸³ http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,15118&_dad=portal&_schema=PORTAL



Figure 22 Annual fuel costs



From Figure 22, it can be seen that:

- The least cost of all fuel options is woodchips, offering a saving of almost £60,000 against oil.
- The annual cost of pellets is slightly more than that of mains gas and similar to that of heavy fuel oil. All the other fossil fuel options are more expensive.

Other annual operating costs

The costs of operating and maintaining a heating system need to be considered on top of the fuel costs. These can be considered in two parts:

- Annual maintenance cost (service & parts).
- Annual labour cost (labour).

Service costs are likely to be fixed prices and labour costs can be estimated using Equation E (below).

Using the following data, it can be shown that the total other annual operating cost of a chip-fired system is £1,500/year, and that of a pellet system is £960/year. The difference is due solely to the monthly labour requirement.

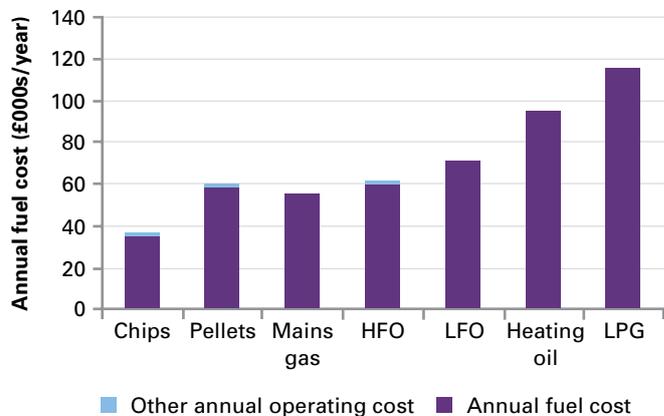
Equation E Annual labour cost [£/year] = Monthly labour requirement [days/month] × Annual plant duty [months/year] × Daily labour charge [£/day]

Table 26 Operating cost assumptions

	Chips	Pellets
Annual maintenance cost [£/year]	600	600
Monthly labour requirement [days/month]	0.75	0.30
Annual plant duty [months/year]	12	12
Daily labour charge [£/day]	100	100

For comparison, the annual maintenance costs of an equivalent fossil fuel boiler can be estimated at £300/year, and the annual labour cost £60/year, giving a total of £360/year. This is several times cheaper than either biomass fuel system. However, considered in context of overall annual costs, as shown in Figure 23, the differences are marginal, and the comparisons between the systems considering fuel costs alone still stand.

Figure 23 Annual operating costs including maintenance



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Attractiveness of investment

Although biomass systems have higher upfront costs than fossil fuel boilers, significant cost savings may be obtained over the lifetime of the equipment due to lower fuel costs. To assess the value of these savings, either a simple payback or discounted cash flow calculation can be made.

Simple payback

The simple payback can be estimated as shown in Equations F, G and H (below).

Considering the case of the biomass heating system being installed instead of a heating oil boiler, the data required to estimate this are as follows:

Table 27 Capital costs (from Figure 21)

	Biomass heating system	Fossil fuel boiler
Total capital cost [£]	£200,000	£32,000

Table 28 Operating costs (from Figure 23)

	Chips	Pellets	Heating oil
Annual operating cost [£/year]	£37,100	£60,200	£95,700

Extrapolating from the data in Table 27 and 28, it can be seen that:

- The biomass capital cost premium is £168,000.
- The biomass annual cost saving of using chips instead of heating oil is £58,600.
- The biomass annual cost saving of using pellets instead of heating oil is £35,600.

Equation F

$$\text{Simple payback [years]} = \frac{\text{Biomass capital cost premium [£]}^*}{\text{Biomass annual cost saving [£/year]}}$$

*Where the system is being installed on a **new-build**, this is the **additional capital cost** of the biomass system versus an alternative fossil fuel system. If the biomass system is being installed in an **existing building** (where a replacement boiler is not due), this will be the **total capital cost** of the biomass system.

Equation G

$$\text{Biomass capital cost premium [£]} = \text{Capital cost of biomass heating system [£]} - \text{Capital cost of equivalent fossil fuel system [£]}$$

Equation H

$$\text{Biomass annual cost saving [£/year]} = \text{Total annual cost of biomass heating system [£/year]} - \text{Total annual cost of fossil fuel boiler [£/year]}$$

This gives simple paybacks for chips of 2.9 years and pellets of 4.7 years.

For the range of fossil fuels considered in this example, the paybacks of using chip systems instead of fossil fuels range between 2 and 9 years, while the paybacks of pellet systems are between 3 years and more than 10 years. This underlines the economic advantage of using chips. Using pellets instead of mains gas does not give a positive payback because the total annual operating cost of pellets is slightly higher than that of gas, as seen in Figure 23.

Internal Rate of Return (IRR)

As an alternative to the simple payback assessment, a simple Internal Rate of Return (IRR) can be calculated and used to assess the project's economic viability.

The IRR is an annualised effective, compounded return rate which can be earned on the invested capital, i.e. its yield. As such, the advantage of an IRR calculation is that it can be used to compare the investment in a biomass system with other possible options, which are of a similar level of total investment and lifetime.

To calculate the IRR a simple cash flow needs to be created over the lifetime of the investment. In this worked example, the investment lifetime is 20 years – the lifetime of the plant. The annual cash flows are, in fact, savings in this case – the annual cost savings between the biomass plant and the existing fossil fuelled plant. To represent the capital cost of the biomass plant, its total capital cost is shown as a negative cash flow in year '0'.

The simplest method of calculating IRR of a biomass heating project is to use a spreadsheet program such as Microsoft Excel™. A simple set up is shown in Table 29:

To calculate the project's IRR enter the function (in Excel) in the relevant cell:

$$= \text{IRR} (\text{highlight the entire cash flow range in years 0-20, 0.1}^{**})$$

**Where 0.1 is the interest rate used as the initial guess required to allow the program to run calculation iterations.

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Comparison	Year 0	Year 1	Year 2		Year 20	IRR
Chip vs. Heating oil	-£200,000	£58,600	£58,600		£58,600	29%
Chip vs. LPG	-£200,000	£78,700	£78,700		£78,700	39%
Chip vs. Mains gas	-£200,000	£19,000	£19,000		£19,000	7%
Pellet vs. Heating oil	-£200,000	£35,600	£35,600		£35,600	17%
Pellet vs. LPG	-£200,000	£55,700	£55,700		£55,700	28%

A project is a generally good investment proposition if its IRR is greater than the rate of return that could be earned by alternative use of the capital (e.g. investing in other projects, putting the money in a bank account). It is common practice to compare a project's IRR with any 'cost of capital' or 'hurdle rate' which an organisation may have and to take into consideration an appropriate risk premium.

In this example, no account of the costs of decommissioning the plant at the end of its service life are included. These are usually very small and it is not uncommon to disregard them. Equally, the costs of a major system overhaul (for example after 10 years of full operational use) have not been included in the above worked example. However, if a good programme of annual maintenance is adhered to, these should also not be particularly excessive.

When constructing such cash flow models, no effect of the changes in prices of fossil fuels and biomass fuels is taken into consideration as these are very hard to predict and it is common practice to assume constant prices under such circumstances.

However, it is a good idea to perform some form of sensitivity analysis around key economic variables, which can impact on overall economic viability such as variations in fossil and biomass fuel prices and variations in capital costs.

Optimisation process

As discussed earlier, the full capital costs of a biomass system can vary considerably based upon a range of site-specific factors. It may be possible to conduct a 'value-engineering' exercise to optimise the economic performance of a system. For example, reducing the biomass plant's total specified capacity may reduce the amount of heat it will deliver in a year and thus the amount of fossil fuel it will displace (and thus the annual cost savings). However, the reduced capital outlay (due to smaller plant size) may mean that the payback period becomes reduced.

Also, it may be possible to reduce the size of the fuel store required to be constructed which will also reduce total capital cost. However, this would entail more frequent deliveries of fuel which may not be convenient. Biomass plant with lower levels of automation and sophistication tend to be lower cost. However, the additional levels of manual intervention required for normal operation (e.g. manual lighting, ash extraction etc.) may add to running costs and less sophisticated models may not have the desired level of functionality required of site owners.

Cost-effectiveness

As biomass heating systems require a higher level of capital investment than fossil fuel systems, it is worth taking steps to check that the project is cost-effective once commissioned. Three key areas to consider are:

- **Capital cost** – avoiding excessive expenditure by optimal sizing of the biomass plant component of system (vs. heat loads) and designing a fit-for-purpose fuel store/plant room/house may help to lower the initial capital outlay.
- **Capacity factor** – the higher the utilisation rate of the biomass plant component, the greater the quantity of delivered energy, and therefore, the lower the impact of the capital investment on the delivered heat cost is likely to be.
- **Fuel cost** – the lower the fuel cost, the more the fuel cost savings (against the fossil fuel alternative) may offset the capital investment (i.e. the faster the payback).

▲ Key milestone: Decision to purchase biomass heating equipment

Based on the results of the detailed feasibility assessment, a site owner should be in a position to understand the potential project's likely fuel requirements, equipment and fuel storage configuration, the necessary permits and consents required and its predicted financial performance. Based on the outcomes of this exercise, a decision is taken as whether or not to purchase equipment.



3.3 Procurement and implementation

This section of the guide goes through steps necessary to procure and install a biomass heating system, including commissioning and handover of the final plant. The activities are presented sequentially and typically occur in this order, although some projects may vary.

3.3.1 Apply for/acquire any necessary permits and consents required

If the feasibility study process identified that any specific permits and consents are required for the project (see section 3.2.5), these should be applied for at an early stage in project implementation as these can have significant lead times associated with them. Only after these have been secured should the project proceed. Note that local planning authorities may require specific information on the proposed installation (such as equipment emissions levels).

3.3.2 Establish preferred contract type

Biomass systems can be procured under a range of different contract structures, which vary by the way installation is undertaken and the balance of costs and risks in this process. In order to select the most suitable structure for a project, it is helpful to appreciate the range of structures before going to tender.

Range of contract structures

The main options typically used by the biomass industry are as follows:

- Contracts to install the biomass system:
 - Option 1** – In-house design, installation and commissioning.
 - Option 2** – In-house design with third party installation and commissioning.
 - Option 3** – Third party design, installation and commissioning (turnkey model).
- Contracts to install and operate the system or provide heat:
 - Option 4** – Third party design, installation and commissioning (turnkey model) with separate operating contract.
 - Option 5** – Third party design, installation, commissioning and operation with agreement to supply heat (Energy Supply Company (ESCo) model).

Option 1 – In-house design, installation and commissioning.

This approach is most appropriate where a site owner is reasonably knowledgeable about biomass systems, perhaps through prior experience. Here, the site owner takes responsibility for the entire project, undertaking work himself or placing contracts for individual pieces of work – e.g. boiler installation. This is likely to be least cost option. However, it may also be the riskiest, since the site owner must bear the costs of any incompatibility between his own work and the individual contracts, and between the individual contracts themselves; that is, it presents the greatest interface risks.

Option 2 – In-house design with third party installation and commissioning.

This option is appropriate in circumstances where the site owner is competent to design the system, and thereby leads the specification and purchasing of equipment. Thereafter the site owner appoints a main contractor to conduct the remainder of the work and take full responsibility for its completion – including any inherent interface risks should the contractor decide to sub-contract. A common variant of this approach is for the site owner to appoint an engineering firm to design the system (an “owner’s engineer”) and then take on a separate contractor to install it.

Option 3 – Third party design, installation and commissioning.

In the turnkey contract approach, the site owner appoints a single main contractor to take responsibility for the entire project – everything from design to commissioning and handover. This in principle offers the least risks to the site owner. However, in passing the risks to the contractor, it is also likely to be the most expensive approach.

Once the biomass system is built and commissioning tests are completed, the site owner faces the choice of either operating and maintaining the system himself or outsourcing these activities.

Option 4 – Third party design, installation and commissioning with separate operating contract.

Sometimes, turnkey installation suppliers offer operations and maintenance (O&M) deals as part of a package, but otherwise a contractor may be engaged separately. Outsourcing O&M is often preferable for large biomass systems, where the potential costs of unplanned outages can be significantly greater than the costs of the O&M service agreement.

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Option 5 – Third party design, installation, commissioning and operation with agreement to supply heat.

This final option is fundamentally different to the others in that the site owner has no direct involvement in the biomass system equipment from either an installation or operational perspective. Rather, a third party installs, owns, operates and maintains the system and sells the site owner heat. Typically the third party in this case is known as an energy supply company or ESCo. From the site owner's perspective, reasons to favour an ESCo model include the following:

- There is no capital project to finance, only a service agreement to be entered into and paid for.
- All technical risks fall to the ESCo, which takes on contractual risks obligations concerning the availability of heat.

However, a downside may be that the ESCo contract length may be fairly long (e.g. 10-15 years); from the ESCo's perspective this is necessary to finance the project. Note that the Build, Own, Operate and Transfer (BOOT) arrangement is very similar to an ESCo option, with the main difference being that it is always understood that the end user will purchase the asset at the conclusion of the operating agreement. Under the ESCo arrangement, there may only be the option for the site owner to purchase the asset.

Choice of contract structure and risk assessment

Essentially, the choice of contract structure for a site owner between these options usually depends on:

- Their availability in the local market; contractors may be more amenable to certain contract structures than others.
- The site owner's technical competence.
- The site owner's financial position, both to finance a capital project and enter into service agreements.
- The site owner's willingness to take risks.

At present in the UK, biomass systems are most often installed on a turnkey basis, because site owners tend to have no relevant technical expertise and little appetite for the risks associated with the other approaches.

In context of commercial and technical risks, it is possible to identify a range of typical uncertainties and measures to mitigate these. This is done in Table 30.

Table 30 Typical risks for biomass systems from a site-owner perspective

Type of risk	Risk	Mitigation
Commercial	Construction delay – installation is completed later than expected.	<ul style="list-style-type: none"> • Allow reasonable construction window, including time contingencies. • Use the contract terms to manage the timetable and deal with liability for delay.
	Capital overspend – total capital cost of installation exceeds that which was budgeted.	<ul style="list-style-type: none"> • Maintain contingency budget. • Enter contracts on fixed price basis, passing risk to contractors.
Technical	Immature technology – system breaks down due to shortfalls in design, manufacturing or installation.	<ul style="list-style-type: none"> • Choose well tested technologies and reputable installers backed up by customer references. • Include performance and reliability terms in contract.
	Unreliable fuel supplies – supplies insufficient to maintain required operation of the system.	<ul style="list-style-type: none"> • Choose system amenable to fuels from a range of potential suppliers. • Include fuel quality and timely delivery terms in contract.
	Plant mis-operation – system is not operated or maintained as required, causing outages and/or increased operating costs.	<ul style="list-style-type: none"> • If operated by in-house staff, ensure personnel are properly trained. • Enter into appropriate call-out support contract.

Note: This table is indicative only and not intended to be comprehensive.



The larger the biomass system, the greater the need to address these kinds of risks in detail in the contracts. This can include:

- To manage commercial risks, ensuring all technical and contractual interfaces are documented (e.g. by defining physical boundaries and termination points) and understood by all parties.
- To manage technical risks, ensuring design, installation and operation are conducted in accordance with pre-established quality control standards, perhaps independently verified. In addition, requiring guaranteed levels of performance (e.g. for combustion efficiency, reliability and availability) backed up by appropriate measures to deal with liability if the performance standards are not met.

These, of course, are general pointers and not intended as a substitute for legal advice on specific contracts.

Finally, it is worth noting there is a growing body of commercial experience in the industry to draw upon when considering contractual and risk assessment approaches. For example, the box on page 74 flags two problems which have occurred in previous biomass installation projects and could be avoided in future.

3.3.3 Prepare system specification

In preparing to go out to tender, it is worth spending time to prepare a good specification. This will enable potential contractors to deliver quotes more quickly and accurately and may also assist them to provide reduced or more 'firm' quotes due to the fact that a clear specification can reduce contractual uncertainties.

To aid the tendering process, the Carbon Trust has prepared a template Request For Proposal (RFP) proforma which are available on the Carbon Trust's website (www.carbontrust.co.uk/biomass). They are intended to provide a framework for the preparation of a suitably detailed specification that could be issued to potential contractors as part of a tendering process or to obtain budget quotes.

The detailed content of the specification should be informed by the conclusions of the feasibility study⁸⁴ and the required equipment functionality (which is covered in section 2.2.2). The RFP templates may not be suitable for all contracting structures as one single contractor may not be responsible for all items contained in them. However, site owners may choose to use these as a basis for their own tenders or as a form of checklist to ensure that the items have been covered.

Risks encountered in previous projects

Specification drift

In projects involving long contractual chains, such as large new-build developments, there has sometimes been a problem of 'specification drift'. This is that the required biomass system specification is diluted by contractors at intermediate links of the chain, with the result that the system ultimately installed does not meet the site owner's requirements. This can be avoided by ensuring that all contractors are aware of the site owner's original specification and all sub-contractors treat this as the primary technical reference.

Undue economy

Where projects are awarded on a fixed price basis, the main contractor and subcontractors naturally tend to minimise their costs. A key way of doing this is sourcing low cost parts and equipment, which is reasonable providing the specification is fully met. However, sometimes sub-contractors may make cost reductions without appreciating there is an associated performance penalty – in fuel supply automation, for example. It is therefore advisable to define such performance characteristics as completely as possible in the specification.

⁸⁴ It is worth noting that if local air quality issues have been flagged up as part of the detailed feasibility study (section 3.2.5), then certain emissions abatement equipment may need to be specified for the plant. At a basic level, this may take the form of a requirement to use a biomass appliance which is exempted for use in a smoke-controlled zone. However, if specific, low emissions levels have been specified by the local planning authority (e.g. because the proposed plant is situated in an AQMA), then some manufacturers may be able to offer abatement equipment such as fabric-filters, cyclones, electrostatic precipitators or catalytic blocks which can meet the specified emissions levels.

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3.3.4 Issue tenders for project

All public sector bodies seeking offers for the construction and/or operation of a biomass plant should consider the possible application of the Public Contract Regulations 2006 and any internal guidance and procedures governing tendering and contracts.

For any undertaking going out to tender seeking offers for biomass contracts there are a few helpful points to bear in mind, though these are not intended to be comprehensive nor are they intended to be a substitute for legal advice on specific tenders.

Pre-qualification

Prior to sending out invitations to tender, it is generally necessary to carry out a pre-qualification exercise. This is a set of minimum criteria against which companies can be selected and, thereafter, invited to tender more formally. A pre-qualification exercise might simply be a request to a range of potential tenderers to provide basic information on prior experience etc. A set of criteria might for instance include:

- An appropriate level of experience and track record on biomass projects similar in size and nature to that being tendered for.
- An appropriate standing as regards financial standing, insurance, quality assurance, and health and safety for the project being tendered for.
- The capacity to carry out the work required within the required timescale.

The site owner is then in a position to prepare and issue invitations to tender (ITT) to the pre-qualified vendors.

Due to the slightly higher level of complexity involved with a biomass heating project (as compared to a fossil-fuel heating system project), it is common for tenderers to visit the site during the tender period so that they are able to review all the aspects associated with the contract.

3.3.5 Review tender returns and select preferred bidder

In addition to the general considerations which might be expected to apply to any tendering process, there are a few specific considerations which are particularly relevant to a biomass project. These include:

- The need to ensure that received tenders are fully compliant with the specification laid out (note the issue of 'specification drift' that can occur and is discussed in the box on page 74). Alternatively, if variations are permitted, the reasons for the variation should be stated explicitly and should meet the minimum specification requirements.
- It is common practice for tenders to include a period of time validity on the price quote (e.g. 30 days). However, the time between the receipt of tenders and finally placing an order may exceed this validity period due to the length of time taken to investigate funding sources or gain final internal approval for example. If the time elapsed is significant, there may be a significant movement in price which could affect project economics.

It is important to note that biomass plant will generally have longer lead times for delivery upon placing an order than fossil fuel plant and this must be taken into consideration when project planning. The lead time depends on:

- The size of plant ordered: larger plant (>500 kW_{th}) will generally be made to order and so an allowance of several months should be factored in.
- The time of year: late summer/autumn represent peak periods of installation activity which may lengthen lead times.
- The manufacturer/supplier: different manufacturers and suppliers have different production schedules and order books, affecting speed of delivery.

Upon completion of this process of evaluation, a preferred bidder may be selected and notified.

3.3.6 Apply for external financial assistance if applicable

Recognising the benefits of biomass heating, but also the relative costs and early stages of the boiler installation and fuel supply markets, the UK Government and agencies are providing financial support to the biomass industry. This support varies in its applicability (type of organisations eligible, size of project and organisation, geographical location etc.). In the case of capital grant support, these are subject to varying application windows with varying levels of assistance. Potential financial support for biomass heating equipment is covered in more detail in the box on page 65.

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Health & Safety

Anyone contemplating the installation of biomass systems should make health and safety a priority. It is beyond the scope of this report to give detailed guidance on health and safety for biomass systems, and expert advice should be sought in relation to the end installation. This is only a brief introduction to relevant legislation and particular health and safety issues that it may be necessary to consider.

Relevant legislation

In the UK, over a dozen pieces of legislation are relevant to the installation, operation, maintenance and decommissioning of biomass systems, including for example, the Construction (Design and Management) (CDM) Regulations 2007, the Pressure Systems Safety Regulations 2000 and others. This reflects the fact that biomass system installation and decommissioning typically involve a combination of some construction/civil works and combustion plant installation.

From a health and safety perspective, the operation and maintenance of biomass systems are similar to fossil fuel plants, and therefore similar regulations are relevant – for example, the Control of Substances Hazardous to Health (COSHH) Regulations 2002.

Particular health and safety issues

Where biomass systems differ significantly to their fossil fuel counterparts and these differences raise different health and safety issues are in the respects of fuel storage and handling and fire safety.

Fuel storage and handling

Typically, biomass systems require delivery by road transport of the solid fuel and storage in a dedicated facility. Sometimes, this facility may be underground (a confined space) or above ground (requiring work at height), and the method of transferring the fuel from the delivery vehicle to fuel store may present other health and safety concerns (e.g. airborne dust, manual handling)⁸⁵.

Accordingly, the following may be relevant: the Confined Spaces Regulations 1997, the Work at Height Regulations 2005, and HSE occupational health and safety advice on wood dust⁸⁶. Also pertinent are the Provision and Use of Work Equipment Regulations 1998 and the Manual Handling Operations 1992.

Fire safety

Once delivered, the greatest risk associated with biomass systems is fire. This is largely addressed via the Building Regulations 2000 (Approved Document J – *Combustion Appliances and Fuel Storage Systems*). Also relevant are the Regulatory Reform (Fire Safety) Order 2005 and the Electricity at Work Regulations 1989. In basic terms, the fuel store and boiler house should not be built from or contain a readily combustible material. There should be appropriate fire escapes and some form of explosion relief should be provided. It should be noted that wood dust can present an explosion hazard, particularly during fuel deliveries. The Dangerous Substances and Explosive Atmospheres Regulations (DESAR) 2002⁸⁷ and ATEX Workplace Directive⁸⁸ are pertinent to this.

Fire and explosion risks in the fuel storage and plant flue system can occur as follows:

- In the fuel store, a fire could start due to 'burn back' from the combustion chamber via the fuel transfer system. Also excess carbon monoxide could be produced if water is used to douse a fire. These risks can be mitigated by the specification of a two, three or even four stage 'burn back' protection system (see section 2.2.2) and not attempting to tackle such a fire if it occurs without the Fire and Rescue Service.
- In the combustion chamber and flue system, an explosion could occur if combustion is incomplete and gives rise to gases (such as CO and H₂), which might be caused by a malfunction or operator misuse (e.g. overfeeding a low fire bed or the intentional/accidental cut-off of mains electrical power during high-load operation). This can be avoided by not allowing significant quantities of uncombusted fuel to build up in the retort/combustion chamber, following cleaning guidance and not switching off the electrical supply to the boiler without first having removed the load and allowed the boiler to burn residual fuel on the grate.

⁸⁵ Furthermore, wet fuel must not sit too long or it will begin to compost and can produce fungal spores which can be hazardous to health.

⁸⁶ See the Health and Safety Executive website at <http://www.hse.gov.uk/woodworking/dust.htm>

⁸⁷ Health and Safety Executive DSEAR pages – www.hse.gov.uk/fireandexplosion/dsear.htm

⁸⁸ Health and Safety Executive ATEX pages – www.hse.gov.uk/fireandexplosion/atex.htm

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Health & Safety (continued)

Further ways of avoiding the risk of explosive gases from incomplete combustion can be realised through aspects of the system design – typically already implemented in systems on the market today.

These include:

- Building into the design a mechanism by which the rate of release and build-up of volatile matter is matched by a suitable volumetric flow-rate of air, to ensure complete combustion can occur safely.
- Ensuring the ratio of secondary air (above the bed) to primary air (below the bed) is appropriate for biomass fuel firing. Ensuring the right flow-rate and pressure of secondary air will ensure emissions of carbon monoxide and smoke are minimised and combustion is efficient. Detecting carbon monoxide can be a way of identifying poor combustion conditions.
- When considering the entire design, installation and operation of the plant (from both manufacturing and installation perspectives), ensuring there are sufficient control interlocks and safeguards to prevent excessive charging of fuel and unwanted air supply as a result of incorrect operator usage.

Due to the variability in the nature of financial support, organisations considering installing biomass plant are advised to research which measures may be available to them as a background activity during a feasibility study⁸⁹. If a capital grant is available then the point at which to make an application for this funding is once a firm price quote for the total cost of the project has been established as it is this amount against which the funding allocation will be calculated.

The level of capital assistance secured (historically this has ranged from between c.15-35% of total project costs) cannot be assured until a firm decision is given by the funding body.

It is worth noting that some funding sources have specific policy objectives such as carbon savings or rural employment diversification. These may need to be addressed specifically in the application process.

The receipt of capital grant assistance and the firm prices obtained as part of the tendering exercise may affect the economics of the project (i.e. the total capital cost of the project may have gone up or down) and therefore it may be necessary to perform a brief re-evaluation of the economics at this point.

3.3.7 Specify and procure fuel

Based upon the results of investigations conducted in the detailed feasibility exercise, the site owner may have identified a preferred fuel supplier based upon a combination of factors such as: cost, quality assurance, credibility/reliability, proximity and appropriateness of delivery methods to the project.

The site owner⁹⁰ can then consult with the preferred fuel supplier to work on details such as delivery methods and vehicles to be used (which may have an impact on fuel storage system), as well as the specifics of fuel to be delivered (quality specification, type, quantities required, frequency of delivery and/or conditions that trigger a delivery). Such details should be referenced and incorporated into a formal agreement⁹¹.

Purchasing by energy content

Purchasing by energy content may be the best method of fuel procurement from the site owner's perspective as they will pay for the quantity of heat delivered and this encourages the fuel supplier to focus on supplying good quality fuel.

⁸⁹ Regional development agencies or organisations linked to them can be good sources of information. For example, in southwest England, consult Regen SW (<http://www.regensw.co.uk/>).

⁹⁰ If the preferred contracting model selected is an ESCo, then the responsibility for fuel procurement will lie with the ESCo operator.

⁹¹ The Carbon Trust has prepared detailed template fuel supply agreements that contain all the necessary provision to enable suitable fuel contracting and are available for download from the Carbon Trust website (www.carbontrust.co.uk/biomass). Further detailed guidance on fuel procurement procedures are also provided there.



In order to purchase biomass by its energy content (p/kWh), a reliable heat meter is needed (see section 3.4.2). Three factors need to be agreed within the supply contract:

- A schedule for reading the heat meter(s) – e.g. weekly, monthly.
- An agreed estimated efficiency of the plant (likely to be in the range of 75-90%).
- A schedule for reconciling any monies between the parties to account for the difference between the recorded efficiency of the plant and the agreed efficiency stated in the contract (including an assessment of the accuracy of these).

When purchasing by energy content, payments to the supplier are critically influenced by the operating hours of the plant and the efficiency of the system, both of which may fall beyond the control of the supplier. Consequently, to reduce the financial risk arising from plant downtime or loss of efficiency, it is recommended that the site owner purchases a minimum amount of heat per month to maintain financial viability of the contract from the supplier's perspective, while making provision for the system owner to request additional fuel/heat as required. It is also normal for the site owner to have a stand-by system, and for the supplier to pay the alternative heating bills if the biomass plant stops due to a lack of, or poor quality, fuel.

However, the supplier should not be financially disadvantaged due to any downtime of the plant which is not as a result of their activities or the quality of fuel they have supplied.

Calculating the pricing tariff will require discussions between the fuel supplier and the purchaser. A key factor will be the seasonal performance of the plant, which depends upon the efficiency of the plant at part load and the load the plant experiences in response to the seasonally varying heating demands. Since most biomass plants operate most efficiently at full capacity, then the longer a plant operates in this state, the higher the seasonal efficiency. While many biomass plants have a stated seasonal efficiency of 90%, this should be confirmed with operational data.

The pricing tariffs have three components and are often structured as follows:

- The first tariff component is a fixed (standing) charge to cover items such as the administrative overheads of the supplier. This is often based on the output rating of the plant (e.g. £X/MW_{th}).

- The second tariff component is that based on the amount of heat delivered from the boiler (e.g. £X/MWh). The amount of heat delivered is determined using heat meter(s). Arrangements are often structured such that payments are made on a monthly basis.
- The third component accounts for variations in plant operating efficiency. In some cases, the fuel supplier and site owner pre-agree on a boiler efficiency based on experience of operating the plant and/or information from the manufacturer (e.g. 85%). If both parties are confident that this level of efficiency could be maintained throughout the period of the fuel supply agreement, then it is relatively straightforward to take this into account when setting the price for delivered heat. For example, if the fuel supplier wishes to charge the equivalent of £20/MWh based on the net calorific value of the fuel as delivered and an efficiency factor of 85% has been agreed, then the price for heat delivered is £23.53/MWh (£20/85 X 100). The use of a pre-agreed/constant efficiency factor requires that there is corresponding agreement regarding plant maintenance schedules such that the plant efficiency is kept within acceptable limits.

In some cases it is not practical and/or possible to use a constant/pre-determined efficiency factor and this has to be determined. This is accomplished by monitoring the following over a set period:

- Heat output (kWh).
- Weight of fuel used (kgs).
- Net calorific value of fuel as received (MJ/kg – as determined by analysis).

Once these figures are collected for a set period, the following formula may be used to estimate the efficiency of the boiler plant:

$$\text{Boiler efficiency \%} = \frac{\text{Heat output (MJ*)}}{[\text{Weight of fuel used (kgs) X Net calorific value of fuel as received (MJ/kg)]}$$

*To convert kWh to MJ multiply by 3.6

Note: Net CV of fuel as received can also be calculated using the formulae in Appendix B.

This estimation may need to be repeated on a regular basis (e.g. upon changes in plant load factor, maintenance regimes and fuel types) to allow reconciliation of billing between supplier and site owner if there have been significant changes in measured efficiency over a period vs. the agreed efficiency.

Both the site and the supplier may consider it desirable to appoint the supplier responsibility for operating and maintaining the plant and associated plant. This will

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provide an incentive to the supplier to ensure the plant's operational efficiency is maintained. While fuel quality may be considered less important to the site owner in this instance, because it is the heat output that is being purchased, it should not be disregarded as it will have an effect on plant's successful operation and longevity.

Procuring and purchasing fuel on a weight or volume basis is more common and can be more straightforward than the above method. As biomass fuels are a bulk material, fuel suppliers will typically be more familiar with this approach.

It is important to note that purchasing fuel by weight or volume will mean that a combination of the biomass fuel as well as water and air (in the case of volume purchasing) will, in effect, be purchased. The relative quantities of these three components can vary with each load. This means that the amount of energy contained in each delivery of fuel can also vary.

If using this method, therefore, it is advisable to put in place a means of ensuring that each delivery contains fuel of the required energy content and that the other key physical and chemical parameters required for the specified plant to operate correctly are adhered to with each delivery.

A good working relationship with the fuel supplier and a clearly specified contract can help to achieve this. However, it is advisable for a site owner to establish some form of quality assurance process appropriate to their circumstances and agree this in the contract with the fuel supplier(s).

See section 3.4.2 for further detail on approaches to fuel quality assurance if procuring by weight or volume. Also see box on page 23 which discusses fuel quality standards and specifications.

3.3.8 Detailed system design

Depending on the exact contract type chosen, it is common for a main contractor and/or any subcontractors involved to work together, once selected as 'preferred suppliers', to refine the detailed designs for the project.

Successful projects rely on clear communication and specification between all participants with clear boundaries of responsibility. It is also very important that the preferred fuel suppliers are involved in the discussions and planning at this stage, as whatever fuel delivery and storage solution is arrived at on the site should take into account the capabilities and requirements of the fuel supplier (i.e. vehicle type used, delivery method etc.).

In order to build up their price, the specific contractor(s) involved will have done some preliminary design work.

At the commencement of the main contract, they may need to re-visit the site and carry out all necessary site surveys (a site investigation for civils, dimensional survey to allow the preparation of layout drawings, general assembly drawings and electrical survey to allow the connection of the plant into the existing system). With this information, the contractor(s) can prepare detailed drawings.

3.3.9 Installation/construction works

Upon commencement of the contract, the contractor will set up the site. For projects <1 MW_{th}, it is unlikely to be necessary to erect dedicated site huts. The contractor should agree the means of access and issues such as site security arrangements with the site owner prior to works commencing. At this point, it is possible for goods to be delivered to site, and construction and installation work may commence.

If the site is a green or brown-field site, the first works will comprise earth moving in readiness for the construction of building foundations (although if the plant is to be housed within an existing building this will generally not be required). This will be followed by civil engineering and building works.

As soon as the foundations/buildings have been prepared, and equipment has been delivered to site, mechanical and electrical equipment may be positioned. The next phase is to connect up all the mechanical equipment with piping and ducting and once done, the equipment may be grouted in. In general, electrical and control cabling is connected up once the mechanical equipment has been installed and connected mechanically. Piping and ducting that requires insulation will be lagged and clad.

3.3.10 Commissioning and training

Once the mechanical and electrical installation has been completed, each part of the plant should be checked mechanically and electrically. Once these checks have taken place, the plant will be deemed to be mechanically complete and process commissioning may commence. Process commissioning typically involves:

- Flushing and pressure testing of pipe systems.
- Electrical checks.
- Dynamic running checks of individual equipment/systems.
- Tests of all control and safety devices.
- Tests of all normal and alternative modes of operation.
- Plant performance and reliability trials.

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During the construction contract, the main contractor will collect all the relevant operating and maintenance instructions and add them to the Operating and Maintenance (O&M) Manual. These will form part of the Safety File to be handed to the client at the satisfactory completion of the job. The O&M manual and the safety file should include:

- Plant installation manual and drawings.
- Plant operation manual.
- Maintenance tasks and schedules.
- All drawings.
- Commissioning records.
- Relevant contact details.

Finally, to prepare for operation of the biomass system, arrangements should be made to train those people responsible for the systems operation. The following topics should be covered in this training:

- Plant operation.
- Performance monitoring.
- Troubleshooting.
- Planned maintenance (daily, weekly, monthly, etc.).
- Annual servicing and call-out conditions.

Commissioning and handover is a very important stage in a project and should not be omitted or rushed.

Key milestone: Handover

Following project implementation, a site owner should be in a position to formally accept the handover of a fully commissioned, correctly operating biomass heating system.

3.4 Operation and maintenance

Biomass heating systems have specific maintenance requirements that are different to those of gas or oil systems. This section provides an outline of some of the main requirements.

3.4.1 Standard operational maintenance regime

It is often possible to set up an O&M contract with the company that installed the biomass system. Alternatively, O&M responsibilities and duties may be contracted out to a third party facilities manager, the fuel supply company, or held by internal, onsite staff.

O&M requirements of biomass plant are similar to those of other solid fuel systems (e.g. periodic removal of ash and cleaning of heat exchanger surfaces).

Certain equipment specifications may, however, reduce the time required for general maintenance of biomass systems. These include:

- Automatic ignition may avoid the need to re-light manually.
- Automatic de-ashing may avoid the need to rake out ash manually; instead a periodic removal of an ash bin and disposal of the ash is required.
- Some types of plant have automated heat exchanger cleaning mechanisms.
- Remote system monitoring may enable the responsible O&M contractor to carry out simple maintenance tasks or performance adjustments before a major intervention is required.

Also, certain operational practices may minimise the time input required for maintenance of biomass systems:

- Use of high-quality fuel which is appropriately specified to the plant in use.
- Conducting regular checks and maintenance.
- Avoiding short-cycling (where the boiler turns on for only short periods before turning off).

However, it should be recognised that biomass systems do require a slightly higher degree of user input than oil or gas-fired systems. Typically, for a small-to-medium scale biomass system, the time requirement for on-site staff may initially be around 0.5 to 1.5 days per month but this can often be reduced as experience of the system is gained.

Maintenance activities will vary from plant to plant, and users should refer to any specific guidance or instructions issued by the biomass plant installer during the handover period of the plant.



A number of these activities do not necessarily require specialist skills and can, therefore, be performed by an on-site maintenance person if present. Where they are performed by personnel on-site, the training to undertake these activities should be provided by the installer in the commissioning and handover period of the system installation. Fuel deliveries may also require a presence from personnel at the site to provide access to the fuel store, to oversee delivery and to carry out any fuel quality-control checks/sign-offs as may be required in the fuel contract.

A schedule of maintenance tasks from a biomass equipment manufacturer's operation manual is outlined in Table 31.

Table 31 Example maintenance regime for a biomass plant⁹²

Daily	<ul style="list-style-type: none"> • Visual Inspection. • Clean any components where necessary.
Weekly	<ul style="list-style-type: none"> • Check gear motors for oil leaks. • Check ash level (empty if necessary).*
Monthly	<ul style="list-style-type: none"> • Scrape combustion chamber and remove bed ash. • Check conveyor grate.
3-Monthly	<ul style="list-style-type: none"> • Wipe flue gas sensor. • Clean Lambda probe. • Check grate.
6-Monthly	<ul style="list-style-type: none"> • Check (and clean) flue gas return (where applicable). • Inspect operational drives. • Check motors. • Clean heat exchanger. • Clean combustion chamber.
Annual (via O&M service contract with installer)	<ul style="list-style-type: none"> • Clean under-pressure controller. • Check seals. • Check combustion air blower fan and induced draught fan. • Check secondary air ducts (and clean). • Grease bearings. • Brush flue.

*Note that this can generally be disposed of by being used as a fertilizer. However, site owners should consult their local planning officer to confirm this.

3.4.2 Ongoing performance monitoring

Metering and logging the heat output is essential to be able to ascertain whether or not the installed biomass heating unit is performing correctly. If metering data is reviewed regularly, this may also provide a potential method for early detection of problems within a heating system (which may not necessarily be due to the biomass plant and could be another part of the system).

There are two main types of heat meter suitable for biomass systems:

- **Ultrasonic:** these are relatively cheap to purchase, and easy to install, but may not be sufficiently accurate for all purposes (typically $\pm 4\%$). This type of meter can be clamped onto an existing system without the need to drain down the system first, and without any cutting into pipework. This meter works by attaching two temperature sensors to the flow pipe, and establishing the density and specific heat capacity of the liquid. This means that it is possible to establish the heat flow between the inlet and outlet. On a new system, ultrasonic meters will work well initially but, as the pipe interior deteriorates, readings may not be as accurate and the meter cannot be relied upon to provide long-term accuracy. For retrofitting existing systems without heat metering, it may be more cost-effective to install this type of meter (to enable a site to switch to purchasing by energy rather than weight or volume).
- **Electromagnetic:** these meters are more expensive and require skilled labour to fit (they need to be cut into existing pipework), but are more accurate and most suitable if the site is to enter into a fuel supply contract based on heat delivered. Ideally, the heat meter will be installed at the same time as the biomass system so as to reduce installation costs as much as possible.

Key metering points include the heat output of the:

- Biomass plant.
- Buffer (if present).
- Fossil fuel stand-by/back-up plants.

Several types of biomass heating plant have a remote monitoring capability where performance data are transmitted regularly via a modem to a third party (e.g. the original installation contractor or O&M contractor), or the site owner's computers. Such remote monitoring can track plant performance and may be able to provide early warning of faults and alert staff to potential breakdowns.

⁹² Maintenance schedule taken from Fröling operating manual.

**Table 32** Estimated monitoring costs

Plant size	Physical meter cost	Logging equipment cost	Installation cost*
100-200kW	£720	£2,000	£1,700
200-400kW	£900	£2,000	£2,200
400-800kW	£1,900	£2,000	£2,500
>800kW	£2,500	£2,000	£3,000-£7,200

*The installation cost given here is for a retrofitted metering system. When metering is installed during installation of the plant, it can be assumed that installation costs specific to metering are marginal when taken within a full M&E scope of works.

Depending upon the type of fault, site attendance may be avoided by allowing the plant to be remotely reset. Plant variables can also be re-configured; for example, the speed of fuel auger rates can be changed to accommodate a change in fuel moisture content. Remote monitoring is not likely to replace all required physical operational checks, but may save time in the identification of problems and offer early warning if a fault occurs.

Fuel monitoring

Some method for measuring the consumption of biomass fuel is an important consideration for straightforward biomass system monitoring. Site owners should use a method best suited to their specific circumstances (fuel supply contract, staff availability, physical access). Options may include:

- By measurement or estimation of heat output.
- Low-cost webcams.
- A viewing window/hatch in the fuel store.

Solid biomass fuel quality is not always assured at present. Therefore, if the site owner has contracted directly with a fuel supplier for deliveries and has procured on a weight or volume method, it may be necessary to set up some form of sampling and testing regime to monitor fuel quality being delivered. This may include on-site testing of each delivery or random batch testing⁹³.

The CEN draft technical specifications⁹⁴ (see box on page 23) include a methodology for sampling fuels' key properties. However, these procedures may be unnecessarily complex for smaller operations and over time, site owners may gain an understanding of when fuel is likely to be unsuitable via simple inspection. Establishing a good working relationship with the chosen fuel supplier may minimise the need to perform regular or extensive sampling.

The key fuel characteristics to appraise are: moisture content, particle size and contamination (both chemical and alien particles). The following represent a range of relatively simple methods which may be employed by site owners:

Moisture Content

Simple

- 'Touch Test', does the delivery feel wetter than it should?

More Accurate

- Specialised 'bucket samplers'.⁹⁵
- Timber conductivity meters (c.£85-150).
- The 'oven-dry' method: oven-drying of fuel at 105°C and re-weighing until no further weight loss is detected (CEN/TS 14774-2:2004).⁹⁶

Particle Size

Simple

- Visual check for unacceptable level of oversized particles such as shards, slivers, unchipped wood or anything that may cause blockages in the fuel transfer system.
- Visual check for unacceptable level of undersized particles and dust content – (NB dust can also cause blockages).

More Accurate

- Put sample through handheld sieves to gauge the percentage of volume at each size (CEN/TS 15149-1:2006).

⁹³ In Austria, a small sample bag of fuel is provided with each delivery which may subsequently or randomly be sent to an independent test house for analysis.

⁹⁴ www.biomassenergycentre.org.uk/pls/portal/BIOAPPS.BSI_REGISTRATION_FRM.show

⁹⁵ http://www.schaller-gmbh.at/en/fs_3bio.php

⁹⁶ <http://www.bsi-global.com/>

Initial
assessmentDetailed
feasibilityProcurement and
implementationOperation and
maintenance

Contamination

Simple

- Visual check for foreign bodies, i.e. stones, plastic, nails, rubber etc.
- Visual inspection for chemical contaminants⁹⁷ evidenced by discoloration of material, e.g.:
 - Heavy metal compounds as a result of treatment e.g. Copperchrome Arsenate (CCA) (identified by green colour)
 - Halogenated organic compounds, e.g. Lindane (identified by yellow colour)
 - Creosote (identified by dark brown stain and smell)
 - Paint.

More Accurate

- Send a sample for laboratory testing at an independent test-house.

3.4.3 Annual maintenance

Typically, biomass boilers are serviced by the company which installed them. Service costs primarily depend on the parts required and the plant type and are likely to have a labour cost in the range of £400-£1,000/year for plants <1 MW_{th}. Charges will increase beyond this for systems in excess of 1 MW_{th} and reflect the scale and the complexity of those systems⁹⁸.

Table 33 provides an indication of the predicted parts replacement profile; this may vary, however, and plant installers should be consulted for specific replacement schedules. The cost of these components will also vary, but an allowance of £1,000 for a 5-year service and £6,000 for a 10-year service is a reasonable maintenance budget for a plant <1 MW_{th}.

Table 33 Example of potential parts replacement schedule

Component	Possible failure	Possible maintenance and frequency of parts replacement
Fire tubes	Fouling	Annual maintenance and 10+ years parts replacement
Burner unit	Clinkering	Weekly check and 10+ years parts replacement
Plant grate bars	Failure	Annual inspection
Refractory material	Corrosion	Annual inspection and infrequent parts replacement
Motors	Make sure adequate M&E protection is included in design	5-10 years (shorter depending on specific design)
Augers	Wearing due to grit in fuel	With abrasive feed, consider lining the troughs and adding weld reinforcement to flight tips and foot of flights. Typically 10+ years parts replacement
Seals on hydraulics for walking floor systems	Failure	5+ years
Seals on hydraulics on reciprocating grate	Failure	5+ years
Variable speed drives (mechanical and electronic)		5-10 years
Exhaust gas duct and stack	Rust if the plant suffers thermal cycling and fuel contains sulphur/ chlorine	Significant levels of corrosion would result in replacing the exhaust duct after 3 years

⁹⁷ However, it should be noted that chemical contamination may be hard to spot and a visual check cannot be relied upon – i.e. paint may be obvious but wood preservative won't be (source: Forest Fuels/RegenSW).

⁹⁸ For service contracts offering remote monitoring or a specified number of site visits, costs may be higher.

Glossary

Accumulator

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

Ash

The non-combustible, mineral content of biomass. During combustion, bottom (or bed) ash is left behind in or under the grate or combustion region. Ash that melts or fuses is known as slag or clinker. Very small particles of ash that are carried out of the system along with the flue gases are known as fly ash.

Auger

An Archimedean screw used to transfer biomass material (typically to move fuel from a store to the combustion chamber or to remove ash).

Balance of plant

Balance of plant consists of the remaining systems, components, and structures that comprise a complete heating plant that are not included in the prime boiler module (e.g. flues, pipework etc.).

Base load

The minimum heat demand from a system which is maintained throughout a defined period.

Capacity factor

The ratio of the actual output (of a heating plant) over a period of time and its output if it had operated at full capacity for the same period of time.

Clinkering

A hard deposit material which is produced through ash melting, and forming a mass of sticky material that cools hard.

Corn stover

The stalk, leaf, husk and cob remaining in the field following the harvest of corn for grain.

Display Energy Certificate (DEC)

Certificate showing the actual energy performance of a public building against its predicated use (using SBEM software).

Energy crops

Crops grown specifically for dedicated energy production purposes (e.g. miscanthus, hemp, rape).

Enthalpy

A description of thermodynamic potential of a system, which can be used to calculate the 'useful' work obtainable from a closed thermodynamic system under constant pressure and entropy.

Energy Supply Company (ESCo.)

Energy supplier who sells heat to the customer instead of a boiler and/or fuel. May install, own and maintain the boiler, or may sub-contract some or all of that.

EPC

Environmental Performance Certificate (EPC) – a certificate which gives a building an asset rating based on its energy efficiency (from A to G). An A rating shows it's very efficient, meaning lower fuel bills, while G is inefficient, meaning higher fuel bills. The certificate also shows the building's environmental impact by indicating its carbon dioxide emissions.

Feedstock

The raw biomass material subsequently used as a fuel.

IRR

The annualized effective compounded return rate which can be earned on the invested capital, i.e., the yield on the investment. The calculated IRR can be compared to any alternate costs of capital, or the internal investment hurdle rate to determine whether an investment will provide an acceptable return. The IRR is, effectively, the discount rate that makes the net present value of the investment's income stream come to zero.

kW_{th}

Kilowatts of thermal energy.

Million tonnes of oil equivalent (Mtoe)

A unit of energy: the amount of energy released by burning one million tonnes of crude oil (approximately 42M GJ).



Oven Dry Tonnes (ODT)

A metric tonne of biomass material at zero percent moisture content.

Oil cake

Coarse residue obtained after oil is removed from various oilseeds.

Particulate Matter (PM)

Also referred to as particulates – tiny (<10 µm) particles of solid or liquid suspended in a gas.

Seasonal efficiency

The ratio of delivered useful energy relative to the input potential fuel energy determined over a full heating season (or year), taking into account the efficiency of the heating equipment and system.

Short rotation coppice

Dense growth of small trees or bushes regularly trimmed back for re-growth.

Willow or poplar grown as an agricultural crop on a short (2-5 year) rotation cutting cycle and at a planting density of 10-20,000 cuttings per hectare.

Slabwood

The off-cuts from a sawmill, usually the edges of usable timber, or pieces of wood with large cracks or knots.

Slumber mode

Operation mode of a biomass plant when fuel is still lit, but not generating a significant amount of heat.

Stemwood

The wood of the stem(s) of a tree, i.e. of its main axis (or axes) as distinct from the branches (branchwood), stump (stumpwood), or roots.

Turndown ratio

The ratio of the maximum output of a boiler to its minimum output.

Volatile Organic Compounds (VOCs)

Also known as 'Volatiles' – carbon-based compounds that have high enough vapour pressures under normal conditions to vapourise into the atmosphere.

Appendix A – Conversion factors

Table 34 Commonly used conversions

Directions: multiply quantity in Unit a by conversion factor to determine quantity in Unit b.

Property	Unit a	Conversion factor	Unit b
Length	cm	0.3937	in
	m	3.281	ft
	km	0.6214	mi
Area	cm ²	0.155	in ²
	m ²	10.76	ft ²
	ha	2.471	acre
Volume	l	0.22	gal (imperial)
	m ³	6.289	bbl
	m ³	220	gal (imperial)
	m ³	35.315	ft ³
Mass	kg	2.205	lb
	kg	0.001	tonne
	tonne	2205	lb
Energy and power	MJ	0.2778	kWh
	MJ	239.01	kcal
	MJ	948.5	Btu
	kW	1.341	HP
	kWh	3414	Btu
Heating value	kJ/kg	0.4302	Btu/lb
	MJ/kg	239	kcal/kg
	MJ/L	4312	Btu/gal (imperial)
Density	kg/m ³	0.06244	lb/ft ³
	kg/m ³	0.01002	lb/gal (imperial)

Table 35 Conversion factors concerning units of energy

Measure	Units		Conversion unit
1 Newton metre	[N.m]	=	1J
1 kilojoule	[kJ]	=	1,000 J
1 megajoule	[MJ]	=	1,000 kJ
1 gigajoule	[GJ]	=	1,000 MJ
1 kilowatt-hour	[kWh]	=	3,600 kJ
1 megawatt-hour	[MWh]	=	3,600 MJ
1 gigawatt-hour	[GWh]	=	3,600 GJ

Table 36 Conversion factors concerning units of power

Measure	Units		Conversion unit
1 joule per second	[J/s]	=	1 W
1 kilojoule per second	[kJ/s]	=	1 kW
1 megajoule per second	[MJ/s]	=	1 MW
1 horsepower	[hp]	=	635 kcal/h
1 horsepower	[hp]	=	0.735 kW
1 kilowatt	[kW]	=	1,000 W
1 megawatt	[MW]	=	1,000 kW
1 gigawatt	[GW]	=	1,000 MW

Table 37 Conversion factors concerning quantities of wood chips^a and standard pellets

Volume and weight (based on a 50% unit of softwood and hardwood chips)
1m ³ of solid content of woodchips takes up approx. 2.8m ³
1m ³ of woodchips contains approximately 0.35m ³ of solid content
1m ³ of woodchips weighs approximately 250kg
1 tonne of woodchips fills approximately 4.0m ³
1 tonne of woodchips contains approximately 1.4m ³ of solid content
1m ³ of wood pellets weighs approximately 660kg
1 tonne of wood pellets fills approximately 1.5m ³

Table 38 Conversion factors concerning quantities of energy, and Calorific Value

Calorific value of fuels as received (based on softwood at 40% MC)					
1m ³ of woodchip	2.53 GJ	or	702.2 kWh		
1 tonne of woodchip	11.2 GJ	or	3,121 kWh		
1 tonne of fuel oil	41.5 GJ	or	11,528 kWh		
1 litre of fuel oil	40.9 MJ	or	11 kWh		
1,000 litres of oil	11,369 kWh	equivalent to	3.6 tonnes of woodchip	or	16.2m ³ of woodchip
1,000 m ³ of natural gas	10,948 kWh	equivalent to	3.5 tonnes of woodchip	or	15.6m ³ of woodchip

^a The calculations are based on woodchips of Norway spruce.

Appendix B – Basic calculations

Fuel requirements

To calculate the annual amount of biomass fuel required (in weight or volume), an assessment needs to be made on the amount of heat that will be delivered annually from the biomass boiler plant and also the 'effective heat' available from the fuel to be used. Tonnes are used here as this is the unit most commonly used by fuel suppliers.

$$\text{Fuel usage [tonnes/year]} = \frac{\text{Delivered heat [kWh/year]}}{\text{Delivered heat per unit mass of fuel [kWh/tonne]}}$$

Delivered heat from the biomass plant can be estimated as a function of its peak-rated capacity and its estimated annual load:

$$\text{Delivered heat [kWh/year]} = \text{Boiler peak-rated capacity [kW}_{\text{th}}] \times 8760^{\text{b}} \times \text{Estimated capacity factor}^{\text{c}}$$

The delivered heat per unit mass of fuel is dependent on the boiler efficiency and the CV of the fuel. It can be calculated using the following equation:

$$\text{Delivered heat per unit mass of fuel [kWh/tonne]} = \frac{\text{Net CV of fuel as received [MJ/kg]}}{\text{Boiler efficiency [%]}} \times 0.2778^{\text{d}} \times 1000^{\text{e}}$$

Where the Net CV of the fuel as received is calculated as follows:

$$\text{Net CV of fuel as received [MJ/kg]} = \left[\text{Net CV of dry fuel}^{\text{f}} \left[\frac{\text{MJ}}{\text{kg}} \right] \times \left(1 - \frac{\text{Moisture content}}{100} \right) \right] - \left(\frac{2.442^{\text{g}} \text{ [MJ/kg]} \times \text{Moisture content}}{100} \right)$$

^b The number of hours in a year.

^c For more information on capacity factors for biomass boilers see section 2.2.4.

^d This is the conversion factor for MJ to kWh.

^e To convert Kg to tonnes.

^f The Net CV of dry biomass fuel represents its net energy content assuming no moisture. It will vary between different types/species but a typical value used here is 18.9 MJ/kg.

^g This is the evaporation enthalpy of water.

Fuel storage volume

The volume required to store the fuel can be estimated as follows:

$$\text{Volume of fuel to be stored [m}^3\text{]} = \frac{\text{Number of days storage required [days]} \times \left[\frac{\text{Maximum daily boiler output [MJ]}}{\text{Boiler efficiency [\%]}} \right]}{\text{Energy density of fuel [MJ/m}^3\text{]}}$$

When estimating the size of actual fuel storage required, an allowance needs to be taken for any additional 'dead space' required in the fuel store (see section 3.2.4).

To calculate the maximum boiler output in MJ:

$$\text{Maximum daily boiler output [MJ]} = \text{Boiler peak-rated capacity [kW}_{\text{th}}\text{]} \times \text{Hours run in day at full load} \times 3.6^{\text{h}}$$

Note that the 'hours run in day' will be based on the estimated duty profile of the biomass boiler. So if a boiler is 'on' for eight hours in a day, this may not represent a continuous load at full capacity (e.g. start-up time). Some allowance should be made for this.

To calculate the energy density in MJ/m³:

$$\text{Energy density of fuel [MJ/m}^3\text{]} = \text{Net CV of fuel as received [MJ/kg]} \times \text{Bulk density [kg/m}^3\text{]}$$

^h Conversion factor for kWh to MJ.

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