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Project leader:	CT Pratt FEC Services Ltd, Stoneleigh Park, Kenilworth, CV8 2LS
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The results and conclusions in this report are based on an investigation conducted over a one year period. The conditions under which the experiments were carried out, and the results, have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

Authentication

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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Headline

Biomass heating equipment is sufficiently technically developed to be applied to protected horticulture in the UK. However, the economics are currently marginal. The best opportunities currently exist for ornamentals growers who do not use CO_2 enrichment and whose main heating fuel is gas oil.

Background and objectives

Alternative energy sources for greenhouse heating are attracting increasing interest because of the continued need to reduce costs and carbon emissions. Biomass, as an alternative to fossil fuels, is one way of meeting these pressures. This project has focussed on dry biomass fuels as they are most readily converted into heat by simple combustion.

The objectives of this project were to:

1. Provide guidance to the UK protected cropping sector on the suitability of biomass heating systems.
2. Identify different biomass fuels and heating technologies, and the technical and economic issues involved in their use.
3. Provide guidance regarding the sizing of heat store and boiler combinations using heat & CO_2 consumption data from commercial nurseries.
4. Make recommendations on any future work which might be required to advance biomass heating in UK protected cropping.

Biomass fuels

A variety of dry biomass fuels can be used. The cost of biomass fuels is highly variable and reflects their ease of use, quality and transport costs. The availability of local supplies is a key factor in their economic viability.

Figure 1 compares different biomass fuels at a range of prices with that of gas oil and natural gas. It should be noted that the net energy content of biomass fuels varies depending on their moisture content. It is therefore important to agree an acceptable range or pricing mechanism to reflect this with the fuel supplier.

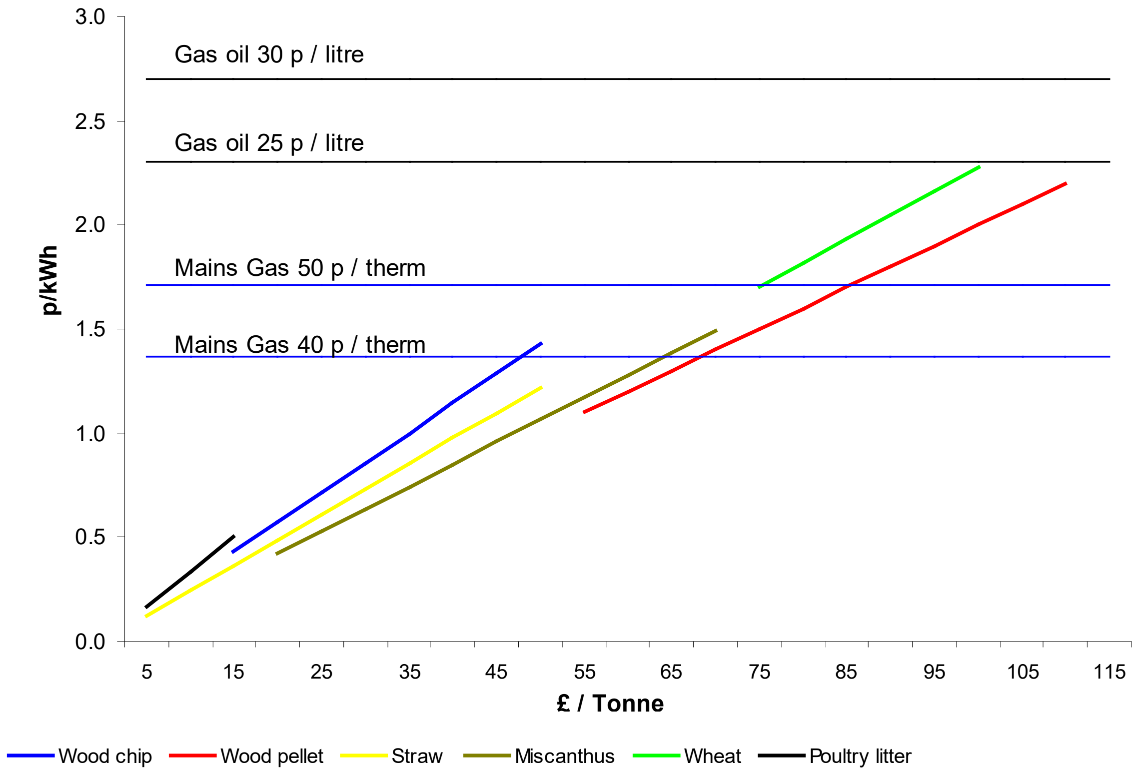


Figure 1 – Biomass to fossil fuel cost comparison

The physical size of the fuel particles is also important as the boiler and fuel handling equipment may not be able to handle a wide range. For example, a high proportion of sawdust may cause bridging in hoppers and fall through the boiler grate before it is fully burnt. Whereas logs may not burn cleanly and will block/damage feed systems. However, a tight fuel specification will increase fuel costs and restrict supply options. Although the equipment cost is likely to be higher, the ability to use fuel of a widely varying quality can deliver significant benefits.

Reliability of supply in the long-term and frequency of delivery are also important considerations. The latter has a major impact on the requirements for on-site fuel storage. Ease of fuel handling and automation should also be considered. Table 1 overleaf summarises the main characteristics of the commonly available fuels.

Table 1 – Biomass fuels reference guide

Fuel type	Energy content KWh / kg	Typical moisture content	Bulk density kg / m^3	Pro's	Con's
Wood chip	4	25 %	175 – 350	Easily fed into burners Easily transported and transferred Reliable supply available	Can be highly variable in energy content and moisture content Requires undercover storage Chip size can be variable if not tightly specified causing problems with handling & combustion
Wood pellet	5	10 %	600 – 700	Clean and easy to handle fuel Reliable High energy content	Expensive Few local supplies – increase transport cost
Straw	4.1	15 %	100 – 150	Very cheap where locally sourced Easily transported and handled Harvested immediately prior to winter use	Transport costs prohibitive if not local Needs to be chopped before burning requiring specialist equipment & increased labour input
Miscanthus	4.7	12 %	120 – 160	Dedicated energy crop not subject to other economic pressures Easily transported and handled	Difficult to source Not well established as a UK crop Requires 4 – 6 months storage before use Needs to be chopped before burning requiring specialist equipment & increased labour input
Grain	4.4	15 %	600 – 800	Easily handled and fed into burners High energy content Established supply chain	Highly volatile prices Specialised combustion systems required for large scale operation
Poultry litter	3	25 %	300 - 500	Very cheap where locally sourced	Can have high ash content Could be perceived as a waste and subject to stricter regulations

Technology, infrastructure and integration

Boiler technology

Biomass boiler technology is very similar to that found in coal boilers. Some myths to be dispelled regarding biomass boilers are:

- Biomass combustion is smoky – modern, automatically controlled biomass boilers do not produce smoke. If they do, they are not being correctly operated.
- Fuel feed is time consuming – this varies depending on the fuel used and the fuel supply system installed. However, a fully automated system should require less than one hour/day for daily checks and fuel supply.
- Ash removal is a manual operation – most boilers have automatic ash removal systems. A bin may need to be emptied twice/week.
- Heat exchange tubes need regular cleaning – many boilers include automatic cleaning systems reducing the need for manual cleaning to two or three times per year.

Fuel type and quality is the major consideration in choosing the appropriate boiler. Boilers with moving stepped grates can burn a wide variety of fuels and handle a wider range of moisture content. As discussed earlier a tight fuel specification allows the equipment costs to be reduced but may be at the expense of higher fuel costs.

Open buffer heat storage

The key questions/issues relating to boiler performance are:

- Speed of response – it can take 45mins for a biomass boiler to increase from 0 – 100% output
- Minimum fire – few biomass boilers operate reliably at below 25% of their rated output
- Smaller biomass boiler for base-load heating vs. a large one to satisfy all the heat demand.

The addition of open buffer heat storage solves many of these issues. It provides a reserve of heat to help satisfy sudden increases in heat demand giving the boiler time to respond. It can also help to satisfy short-term peak heat demands that are greater than the boiler capacity without the need for additional heat from a fossil fuel boiler. This helps to maximise the contribution of a smaller biomass boiler whilst minimising investment in boiler capacity that is rarely used. When the boiler is operating at minimum fire excess heat can also be stored for use later in the day.

Infrastructure

Short-term fuel storage will be required to hold up to two weeks supply depending on the reliability and frequency of deliveries. Longer-term storage facilities may also be required where fuel supply is seasonal or where lower fuel costs justify the additional investment required. Short term stores are usually bunkers, hoppers or portal frame building based. Long term storage can be as simple as an area of hard standing, however the effect of exposure to rain on the fuel quality should be carefully considered.

Site access should also be reviewed as biomass fuel is generally bulky and delivered in articulated lorries. Facilities that enable fast unloading can reduce transport costs and the nursery's own labour input. In most cases a materials handler will be required.

Case study calculations

A computer model was developed to calculate the economics of different configurations of biomass boiler, heat store and 'peak lopping' fossil fuel boiler combinations. Detailed heat and CO_2 demand profiles were downloaded from climate control computers on commercial nurseries to allow the realistic evaluation of a number of combinations.

Boiler & heat store capacity (assuming no CO_2 enrichment)

Two examples showing results from the model are detailed below. They demonstrate:

- The ability of open buffer heat storage to maximise utilisation of a small biomass boiler
- How much of the annual heat demand can be satisfied by a biomass boiler that is considerably smaller than the peak heat demand.

AYR chrysanthemum production – peak heat demand 1.77MW/Ha

- A 1MW biomass boiler with 200m^3 heat store would satisfy 100% of the heating demand
- A 0.5MW biomass boiler with a 100m^3 heat store would satisfy 80% of the heating demand - the existing fossil fuel boiler providing the remaining 20% during periods of high heat demand. This reduces to 60% when a heat store is not used.

Edibles crop nursery – peak heat demand 2.62MW/Ha, existing heat storage 200m^3/Ha

- A 1.5MW biomass boiler would satisfy 100% of the heating demand.
- A 0.6MW biomass boiler would satisfy 80% of the heating demand ($^1/_4$ of the size of the fossil fuel boiler).

The impact of CO_2 enrichment

The CO_2 in biomass boiler flue gasses cannot currently be used for greenhouse atmospheric enrichment. Where CO_2 enrichment is required the current best option is to burn natural gas producing heat as a 'by-product'. The cost of the alternative, pure CO_2, is greater than the savings delivered by using biomass fuel.

Moving from winter into summer the CO_2 demand increases and heat demand decreases to a point at which no additional heat from biomass is required.

Calculations for the same edible nursery as above have shown that this reduces the proportion of heat that can be supplied by biomass from 80% to 62%.

Economics

Due to the variable cost of both biomass installations and fuel it is difficult to make specific economic recommendations. Growers are advised to look closely at the following influences and consider the results from the sizing model in choosing the right fuel and boiler mix.

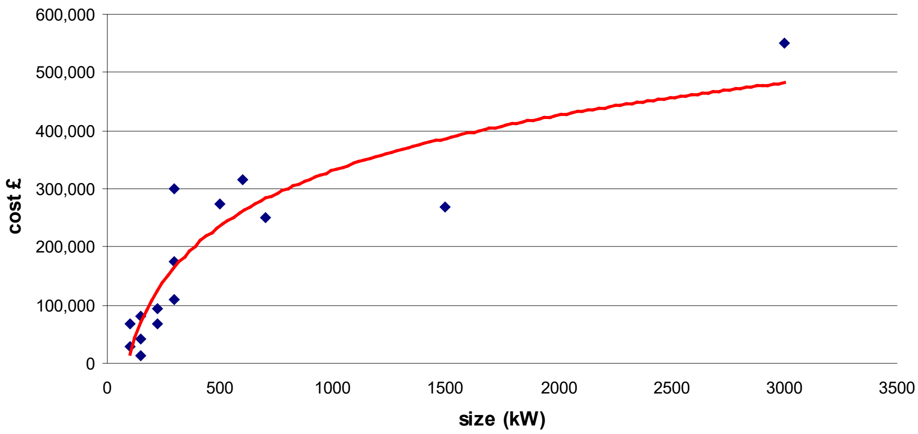
Capital costs

In addition to the heating capacity key factors are:

- Boiler plant - the type of fuel to be burnt and the degree of flexibility that is required in terms of fuel type & quality
- Heat storage – improves biomass boiler utilisation and operation but at a cost
- Fuel storage – regular deliveries may increase fuel costs but less investment will be required in storage facilities.

Each dot on the graph in Figure 2 below shows the total installed cost of a number of completed commercial greenhouse biomass heating installations in the UK. This demonstrates the significant effect of economies of scale.

Figure 2 – Capital costs



Operating & maintenance costs

The relatively limited experience with biomass heating systems in the UK and rapid development of more automated systems mean that this type of information is vague at best. Discussions with various operators in the UK & Europe suggest that an average labour requirement of one hour per day should be realistic almost regardless of the size of the installation. However, in every case the labour requirement during lengthy commissioning periods was high.

Ongoing repairs / replacement of wearing parts are an even greater unknown. Installations of the size required and rapid developments in technology mean that little long-term data is currently available. Growers wanting greater predictability of costs are advised to consider extended warranties / maintenance contracts with the supplier.

Simple payback

Wood chip and cereal straw represent the most widely available biomass fuels and are amongst the cheapest. The edibles nursery used 555kWh/m^2 p.a. whereas the ornamentals nursery used 346kWh/m^2. The fuel cost saving figures in the following tables are based on 1Ha and assume that the edible nursery uses natural gas for CO_2 enrichment whereas the ornamentals nursery does not use CO_2 enrichment.

Table 2 – Edible nursery fuel cost savings

	Cost of wood chip £/t		Cost of straw £/t	
Cost of natural gas p/kWh	25	30	25	30
1.2	£16,390	£11,580	£19,890	£15,780
1.4	£23,130	£18,320	£26,630	£22,520
1.6	£29,870	£25,060	£33,370	£29,620

Table 3 – Ornamental nursery fuel cost savings

	Cost of wood chip £/t		Cost of straw £/t	
Cost of natural gas p/kWh	25	30	25	30
1.2	£10,200	£7,200	£12,400	£9,840
1.4	£14,400	£11,360	£16,560	£14,040
1.6	£18,600	£15,600	£20,800	£18,240
Cost of gas oil gas p/litre*				
28	£39,420	£36,420	£41,620	£39,060
30	£43,300	£40,300	£45,500	£42,940
32	£47,180	£44,180	£49,380	£46,820

* excluding duty

In the case of the edibles nursery an optimistic view of the capital cost is £250,000. Therefore, ignoring the additional cost of labour etc, the simple payback (gas 1.6p/kWh, wood chip £30/t) would be 16 years. This is clearly an unrealistic proposition.

Due to its relatively high cost the best opportunities are where gas oil is the current heating fuel. On the ornamentals nursery the capital cost of a 0.5MW installation is expected to be around £230,000. The simple payback (gas oil 30p/l, straw £25/t) is therefore around five years. Which, once an allowance is made for labour and maintenance could increase to around six years.

However, it should be noted that the economies of scale are substantial as demonstrated in Figure 2. If the ornamentals nursery (gas oil) was 3Ha the payback (on fuel cost alone) would reduce to three years.

Biomass heating systems are not an immediately attractive investment to the majority of growers. However, there are niche situations where they are worth exploring in detail. Some grants are available and developments in the political / environmental arena may mean that added value in the form of marketing advantage and carbon credits could help to tip the balance. Additional benefits may be realised by the small number of nurseries that fall within the EU Emissions Trading Scheme through the release of carbon quota that can be traded on the open market.

Regulations

Three principle environmental / pollution regulations apply:

1. Clean Air Act 1993 (CAA) – covers the emission of smoke, dust/grit & fumes and applies to all commercial scale boiler plant whether biomass or fossil fuel
2. Waste Incineration Directive (WID) – determines whether a fuel is classified as a waste.
3. Pollution Prevention & Control (PPC) – applies when the fuel is classified as a waste.

The table below explains the scenarios most relevant to horticultural scale installations.

Table 4 – Summary of compliance requirements

Fuel not comprising waste	The Clean Air Act 1993 applies. Unregulated under PPC, no air pollution control permit is required for installations <20MW		
Boiler size	**< 400kW and < 50kg fuel used /hr**	**400kW - 3MW and 50 - 1000kg fuel used/hr**	**> 3MW and >1000kg fuel used/hr but <20MW**
Waste used as fuel for which an exemption from WID has been received	Same as fuel not comprising waste	Local Authority air pollution control permit is required (PPC regulations 2000 - 1.1 Part B)	PPC regulations 2000 - 1.1 Part A1
WID waste - non hazardous (for energy production)	WID applies, PPC regulations 2000 - 5.1 Part A2		WID applies, PPC regulations 2000 - 1.1 Part A1
WID waste - hazardous (for energy production)	WID applies, PPC regulations 2000 - 5.1 Part A1		WID applies, PPC regulations 2000 - 1.1 Part A2

Fuels derived from energy crops e.g. short rotation coppice and miscanthus and straw are not considered as waste. There is continued confusion over the status of clean waste streams such as forestry thinning and clean recycled wood. They are subject to ‘local interpretation’.

However, it is advisable in all cases to get written confirmation of the status of the fuel you plan to use from the Local Authority and the Environment Agency.

Conclusions

- At a technical level solid fuel biomass heating systems can be used to heat greenhouses in the UK.
- Choice of fuel type and supplier are the most important decisions when considering a biomass heating system.
- Continued support from the supplier is vital especially during the commissioning / learning phase which may last several months. In-house maintenance skills and continued attention to detail are required to ensure reliable operation.
- The ability to use a wide range of fuels / fuel quality will help to future proof the investment and allow more competitive fuel purchasing.
- Open buffer heat storage delivers wide ranging benefits and is a key component of any biomass heating installation.
- The inability to use the CO_2 from biomass boilers for greenhouse enrichment is a major barrier to adoption in the edibles crop sector.
- The best opportunities currently lie where CO_2 enrichment is not required and gas oil is the main heating fuel. As such this is likely to be dominated by the ornamentals sector.

Recommendations for growers

Fuel selection

- Quality – mutually acceptable quality criteria should be agreed with the supplier. Key criteria include particle size and moisture content
- Frequency of delivery – consider weekly deliveries vs. seasonal supply and the impact on fuel cost and the storage facilities required
- Storage & handling – consider the requirements of each fuel type and their impact on both capital & running costs
- Compliance issues – check the status of the proposed fuel.

Equipment & infrastructure

- Guarantees should be sought from the installer for ongoing support especially during the lengthy commissioning process. The equipment is not 'fit & forget'
- The range of fuel type / quality that a boiler can use should be closely investigated. A greater range will help with fuel supply options, cost and reliability of operation
- Open buffer heat stores have wide ranging benefits. Excluding them on the grounds of capital cost should be questioned and performance guarantees obtained
- Consider the economics of a small boiler to satisfy the base-load heat demand compared to the higher capital cost of going 100% biomass.
- Fuel storage & handling – consider fuel flexibility, capacity relative to fuel deliveries and ease / speed of unloading
- Take account of space & access requirements – biomass heating systems (boiler, fuel storage & vehicle access) require considerably more space.

Recommendations for further work

Long-term data detailing the total cost of ownership of biomass heating systems continues to be lacking. This presents additional risk / uncertainty to the limited number of businesses considering investment.

- The few UK installations currently in operation should be closely monitored on a case study basis to identify their true running cost.

The use of CO_2 from biomass systems for greenhouse atmospheric enrichment is the biggest single technical barrier to their use in edible crop production.

- The quality of flue gasses from biomass fuels should be assessed to identify the challenges faced.
- The technology available to deliver satisfactory flue gas quality should be investigated.

Science Section

1 Introduction and Background

High energy costs continue to challenge the UK greenhouse industry. Concern about global warming and the effect of burning fossil fuels has already resulted in the introduction of the Climate Change Levy (CCL) and energy targets through Climate Change Agreements (CCA's) and the European Emission Trading Scheme (EUETS). Similar economic and legislative pressure is also affecting growers in other northern European countries. As a result growers are looking for methods to reduce their current dependence on fossil fuels. One solution being considered is the use of alternative fuels such as wood and straw.

At present growers are hampered by a lack of reliable information on biomass heating systems and their integration with their existing heating infrastructure. This, combined with a lack of large scale, commercially proven installations in the UK, greenhouse sector, has meant that businesses have not been able to fully explore the opportunities offered by biomass heating.

There is, therefore a requirement for a clear, comprehensive overview of biomass fuels and technology to help growers make well informed decisions about the suitability of biomass heating systems for their business.

1.1 Specific questions & concerns

Economics

The true cost of heat produced by a biomass heating installation is sometimes difficult to determine.

- What are the likely costs and energy content of the fuels?
- What are the additional running costs of biomass heating compared to fossil fuelled systems?

Fuel type and quality

Unlike the majority of fossil fuels the quality and ease of use of biomass fuels varies widely.

- What are the key considerations when assessing different fuels?
- What standards exist / what specifications should be used when buying biomass fuels?
- What are their characteristics and how do they impact on storage / handling & combustion system selection?

Infrastructure and technology

Unlike mains gas boilers biomass heating systems require fuel storage and fuel handling facilities. The boilers themselves tend to be less flexible in terms of output and speed of response and there are a variety of combustion systems to choose from.

- What are the options on boilers and how do they impact on fuel selection and ease of use?
- How are they integrated with an existing fossil fuel system?

- What size boiler should be chosen? Is a heat store necessary and how big should it be?

CO_2

There is currently no proven way to allow the CO_2 in the flue gasses produced by a biomass heating system to be used for greenhouse enrichment.

- If CO_2 continues to be produced by burning natural gas what impact will this have on the utilisation & viability of a biomass heating system?
- What are the other options for CO_2 enrichment and how much is required?

Rules & regulations

Flue gases from biomass installations can be 'dirtier' than say those from a mains gas boiler.

- What legislation applies?
- What fuels does the Waste Incineration Directive apply to?

2 Objectives

The objectives of this project were to:

1. Provide guidance to the UK protected cropping sector on the suitability of biomass heating systems.
2. Identify different biomass fuels and technology and the technical and economic issues surrounding their use.
3. Provide guidance regarding the sizing of heat store and boiler combinations using example commercial nurseries.
4. Make recommendations with regard to any future work which might be required to further advance biomass heating in the UK protected cropping sector.

These objectives were met by gathering and assessing information from a variety of sources including:

- Commercial nurseries
- Equipment suppliers
- Scientific publications/papers
- The horticultural press
- Visiting biomass installations and interviews with people in the biomass industry
- Government strategic publications and guidance notes.

3 Biomass fuels

3.1 Overview

The most recognisable biomass fuel resource which we all know of is wood. However biomass fuels include many other materials such as straw, poultry litter, wheat etc.

Biomass fuels can be categorised as, **dry biomass** which can be burnt e.g. wood and straw, and **wet biomass** which has to be processed in other ways to produce energy e.g. animal slurry or food waste in anaerobic digesters. This report covers only the dry fuels. These include;

1. Wood fuel in chip and pellet form.
2. Cereal straw and rape straw.
3. Miscanthus.
4. Cereal grain.
5. Poultry litter.
6. Rape meal.

3.2 Wood chips

3.2.1 Sources and supply

Wood for wood chip fuel is commonly taken from three established sources and occasionally from one further source where regulations allow.

1. Forestry/arboriculture co-products and thinnings.
2. Short rotation coppice willow.
3. Timber processing by-products.
4. Wood waste (depending on regulations).

Forestry residue is material that remains after logging in woodland. Historically this material had little or no value and was left to rot. However it is now recognised as a valuable energy resource. These residues are best chipped at source because they have a low bulk density and are difficult to load and haul.

Arboriculture waste is made up of material that has been taken from trees that have been removed or prunings from trees that require management. As with forestry residues this wood is generally chipped at source for ease of loading and transportation. Wood chip produced from these sources requires some time to dry before being used; usually 6 – 8 weeks. If the material is left any longer than this it begins to compost because of its initial high moisture content and the inability of cool dry air to naturally penetrate the heap.

Short rotation coppice is a crop grown specifically for energy use. The most common species is Willow, although Poplar has also been shown to be suitable. Coppices are established and are harvested every three years over a 30 year plus life cycle. Short rotation coppice can either be harvested as billets or chipped at harvest. Billets require longer storage than chips as they take longer to dry. Short rotation coppice is an emergent energy source with approximately 390 hectares planted in the UK in 2006. Unlike forestry and arboriculture residues, short rotation coppice resource can be easily increased to meet energy demand through new establishment.

Timber processing by-products are a good source of clean dry timber for wood chip or pellets, 30 – 45% of the wood in a trunk is typically discarded as waste. The waste material is usually in the form of off-cuts or slab wood and requires chipping

before use. Moisture content tends to be less than other sources because the material has undergone air or kiln drying before processing and hence requires only short term storage once chipped.

Wood waste is an emerging fuel resource. However, it must be free from contaminants that could either damage the chipping machine or cause the wood to be classified as a hazardous waste. Common sources of this type of wood are untreated pallets, packaging and clean construction industry reclamation timber. Burning wood waste offsets its landfill cost and it can be possible to charge a 'gate fee' for this material, enhancing its financial viability as a heating fuel. The use of wood waste is dependant on obtaining an exemption from the Waste Incineration Directive (see further section on regulations).

Wood chip is a well recognised fuel for biomass boilers and new suppliers enter the market on a regular basis. Numbers of suppliers are however not a measure of the quality of fuel and this is variable. Larger suppliers will enter into a guaranteed supply contract for a fixed period either supplying chip or, to guarantee quality, metered heat. Wood chip costs can vary significantly depending on the proximity of the source wood and the amount of processing it requires.

3.2.2 Processing and standards

Whatever the timber source it must undergo some processing before being suitable for use in biomass energy plants. The easiest and cheapest method of ensuring high levels of uniformity and consistency is to pass the material through a chipper. Industry has traditionally used the long established Austrian Onorm standard to define wood chip quality but there is now a European wide set of standards being introduced – CEN TC335. These standards are similar in design and implementation and are shown in Table 5 below.

Table 5 – Woodchip standards

Parameter	Austrian Onorm	EU Standard CEN TC 335
Type of material	Material	Origin
Cross sectional area (cm^2*10)	G30, G50, G100	P15, P30, P50, P100
Moisture content %	W15, W20 W25 etc	M15, M20, M25 etc
Ash content %	N/A	A0.5, A1, A1.5 etc

(Sources: http://www.usewoodfuel.co.uk/Fuel%20Quality%20and%20Standards.stm
http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,19836&_dad=portal&_schema=PORTAL)

Hence a $3cm^2$ chip of moisture content 25% and resulting in an ash content of 1% will have a nomenclature of G30:W25 in Austrian standard and P30:M25:A1 in the European standard.

The most important factors in the consideration of wood chip as a fuel are its particle size and moisture content. Particle size must be considered because it determines the type of fuel feed system that can be used. Deviations from the defined size can cause problems with feed system operation and boiler combustion efficiency.

3.2.3 Energy content

The moisture content of all biomass fuels is important because it affects the net amount of energy available. The higher the moisture content the more energy is wasted driving off the water. The absolute calorific value of dry wood (0% moisture content by weight) is 19GJ / tonne (5.3kWh / Kg). As the moisture content rises the absolute calorific value remains at 19GJ / tonne but the net calorific value (the resulting energy value available for providing useful heat) reduces. The way in which the net calorific value is related to the moisture content is expressed using the following formula:

$$CV_n = (CV_d \times (100 - MC) - (2.442 \times MC))/100$$

Where: CV_n is net calorific value (in GJ / Tonne)

CV_d is dry calorific value (19 GJ / Tonne)

MC is the % moisture content per total weight

Figure 3 below shows this in terms of kWh / Kg of wood fuel. It can be seen that there is no useful energy available above 85% moisture content. Most biomass systems are designed to operate with wood of between 15 and 40% moisture content.

Figure 3 – Energy value of wood fuel, variation with moisture content

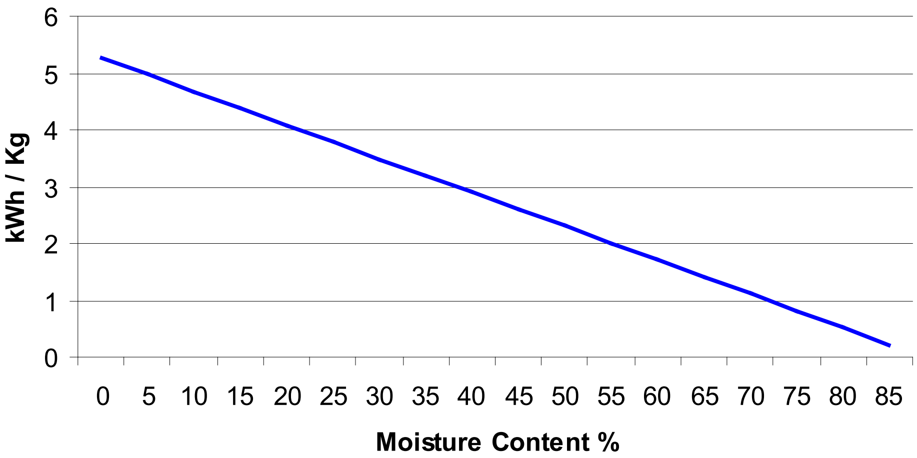
(Source: http://www.ruralgeneration.com/Willow%20as%20wood%20fuel.doc)

A tabulated version of the graph above appears in the appendix for more accurate reference.

It may be necessary to establish some long term storage facilities so natural drying can take place. Timber in slab and log form prior to being chipped can be stored outside. To do this it is advised that it is covered and kept off the ground. Enabling air to flow through the stack aids the drying process and can give final moisture contents of 30 – 35%. Green wood (that is timber just cut from the living tree) requires one year per 25mm of thickness to reach these moisture contents.

3.2.4 Storage and handling

Wood chip needs different storage facilities to slab and log wood. It is best kept in a



portal frame building which allows good air movement to prevent composting. Wood chip dries faster than slab or log wood so where fresh chip is produced on-site this will reduce the amount of longer-term covered storage required.

Short term storage is only required for the fuel in chipped form. This storage should be integral with the feed system of the biomass boiler to keep handling to a minimum. Wood should be able to be chipped directly from the outside store or easily transferred using a materials handler. A walking floor is commonly specified for short term storage to keep operator time to a minimum. Portal frame buildings lend themselves very well to this type of fuel store but underground bunkers or hoppers can also be used. Storage facilities should ideally have concrete floors which prevent the ingress of moisture and foreign bodies to the fuel.

Both wood chip and slab wood in long term storage will require handling facilities. The most versatile way of handling these materials is with a materials handler or similar vehicle. This can be fitted with forks or a bucket depending on the material being moved and can be used for many other jobs not associated with the biomass installation.

3.2.5 *Combustion characteristics*

Wood chip can be a very clean burning fuel requiring the least amount of tending of any of the biomass fuels. In order for this to be the case burners must be set up correctly to allow optimum combustion conditions. Production of clinker is possible and more prevalent with wood chip derived from waste streams because of reduced material quality. Ash is typically in the region of 0.5 – 1% by mass of the input fuel, the more bark there is on the wood the greater the ash content will be.

3.3 Wood pellets

3.3.1 *Sources and supply*

Wood pellets are a popular alternative to wood chip, especially for the domestic biomass sector but are less common for large biomass installations. Pellets are formed from saw dust and other wood fines from the timber processing industry or pulverized wood that cannot be used for any other purpose. Pellets are created by forcing this material at high pressure through a set of cylindrical dies. The temperatures that result causes the natural glues in the wood to bind the material together.

Wood pellets are a relatively new form of fuel having only been commercially available for about five years in the UK. Consequently the supply chain is not as well established as with some of the other forms of fuel. There are a small number of manufacturers in the UK but a significant proportion of pellets are imported from Europe specifically Scandinavia. Supply in bulk is by covered trailer and pellets can either be pumped or tipped into the storage facility.

3.3.2 *Standards*

Pellets are manufactured to close tolerances because of the method in which they are produced. Usual dimensions of pellets are 20mm long and 6mm or 8mm in diameter. Typical moisture content range of wood pellets is 6 – 10% and they have a high bulk density. This means they are a very consistent and reliable form of wood fuel. British BioGen has recognised that standards must be maintained to ensure wood pellet quality and have set some out in their Code of Good Practice for Biofuel Pellets and pellet burning appliances shown in Figure 4 below.

Figure 4 – British BioGen wood pellet standards

9.0 Physical and chemical attributes of pellets
9.1 SUMMARY OF COGP STANDARDS FOR PELLETS

Class	Feedstock	Size	Ash	MC	Calorific value	Bulk density	S	Cl
Domestic	Virgin & clean wood	>5mm-<20mm	1%, 3% or 6%	<10%	>4.7kWh/kg	600kg/m^3	300ppm	800ppm
Commerical	Clean wood waste <15% MOB	>10mm-<20mm	1%, 3% or 6%	<10%	>4.2kWh/kg	500kg/m^3	300ppm	800ppm

Pellet length shall not exceed five times the diameter.

9.2 The only additives that may be used in COGP pellets are lignin as a binder and trace amounts of vegetable oil as a die lubricant. The use and amount of any additive shall be disclosed.

9.3 The amount of ash resulting from burning any fuel must be taken into account in the design of the appliance and all COGP pellets shall be clearly labelled as follows:
<1% ash, "Premium" <3% ash, "Standard" <6% ash, "High Ash"

Source: The British BioGen Code of Good Practice for Biofuel pellets and pellet burning appliances <25kW Version 1 April 2000

3.3.3 Energy content

Wood pellets have the same net energy to moisture content relationship as woodchips. They have a greater net calorific value than most wood chips because of their reduced moisture content. The moisture content of wood pellets is in the range 6 – 10% giving a net calorific value of
4.7 – 5kWh/kg. In addition to this they have a greater bulk density so take up less storage space than the equivalent energy value of wood chip.

3.3.4 Storage and handling

Long term storage of pellets for drying is not necessary. The amount of on-site storage required is determined by the reliability and frequency of deliveries. Any storage facility should have concrete floors, retaining walls and weather protection. As with wood chip, portal frame buildings and bunkers work well for this type of storage. Hoppers are more suitable for wood pellets than wood chip because of their increased energy density. However the size of hopper can be prohibitive for large installations.

Wood pellets are most commonly delivered directly into short term storage meaning that extra handling facilities are unnecessary.

3.3.5 Combustion characteristics

Wood pellets are a very clean burning fuel requiring the least amount of tending of any of the biomass fuels. Pellet burners can be easily matched to fuel as it has the most consistency of any biomass fuels. Clinker is not a problem with wood pellets as they tend to be made from timber product waste that has few impurities. Ash is typically in the region of 0.5 % by mass of the input fuel.

3.4 Cereal and rape straw

3.4.1 Sources and supply

Straw is a by-product of arable farming. It is most commonly supplied in large square bales weighing approximately 500kg each. Straw suppliers are well established in the arable regions of the UK to supply the livestock industry. Therefore supplies for heating should be readily obtained. However, the production season is restricted to July – September so long-term storage facilities are required. Straw suppliers can provide this and deliver straw on a regular basis throughout the year. However, there are cost implications.

3.4.2 Standards

There are currently no defined standards for the quality of straw for combustion in biomass boilers. The moisture content is highly dependent on the weather conditions during harvest. A maximum moisture content of 20% should be easily achieved with levels as low as 15% possible. Straw must be harvested in dry conditions otherwise damp bales will deteriorate and become difficult to shred prior to combustion.

3.4.3 Energy content

The dry matter energy content for cereal straw and oil seed rape straw is 15.7GJ/tonne (or 4.4kWh/kg). As with wood fuels moisture content has a big influence on the net calorific value. At 16% moisture content (typical average figure) the net calorific value of both straw types is 13.5GJ/tonne (3.75kWh/kg).

Source: ***A TRIAL BURN OF RAPE STRAW AND WHOLE CROPS HARVESTED FOR ENERGY USE TO ASSESS EFFICIENCY IMPLICATIONS*** – *DTi November 2003*

3.4.4 Storage and handling

Baled straw is a self supporting material and hence easy to transport and stack. Straw will typically be delivered on flat bed trailers which carry approximately 36 bales. These will need to be offloaded on-site and transferred to a storage facility. A materials handler capable of carrying up to 1 tonne will be required for this.

Long term storage can be carried out externally in large stacks without cover but the top layer of bales will be unusable for energy. Covered storage is best in portal frame buildings that do not necessarily have to have retaining walls. However walled buildings to provide drier storage are advisable.

Bales are loaded onto a conveyor where they are automatically fed to a shredder. A blown air transport system is commonly used to deliver the shredded straw to the boiler. The length of the conveyor is critical as it dictates how often bales have to be loaded onto it.

3.4.5 Combustion characteristics

Straw can be a difficult fuel to burn because of the inherent variability in the way in which it is grown and harvested. Straw has a high ash content up to 5% by mass and can cause difficulties in the combustion chamber because of its silica content.

3.5 Miscanthus

3.5.1 Sources and supply

Miscanthus (or Elephant grass) is grown and harvested specifically for energy use. Miscanthus is a rhyzomic crop which, once established, can be harvested for up to 20 years. The grass is cut annually at the end of winter / beginning of spring. Because of this miscanthus requires time in storage to dry out - typically six months. Miscanthus can be left to dry loose but for energy purposes it is commonly baled. Loose miscanthus can also be pelleted but for large scale use this is usually too costly both in terms of energy and money. Supply in the UK is currently limited but areas of miscanthus grown are increasing each year.

3.5.2 Standards

As with straw there are no known miscanthus production standards related to combustion in biomass installations. At harvest the moisture content averages 50% and it must subsequently be dried to reach the more desirable moisture content of 15% for burning.

3.5.3 Energy content

The energy content of miscanthus is 18GJ/tonne when dry (5kWh/kg), at a moisture content of 15% the net calorific value reaches 16GJ/tonne (4.4kWh/kg).

3.5.4 Storage and handling

Miscanthus is a relatively new crop to the UK and greater experience is required to establish the best conditions for long term storage. It is recommended that baled miscanthus should be stored under cover to ensure quality of fuel. Covered areas should allow good airflow to help the drying process. Short term storage should be in portal frame-like buildings as with straw.

3.5.5 Combustion characteristics

Miscanthus has similar combustion characteristics to straw and should be dried as thoroughly as possible before use as a fuel to minimise problems in combustion. Miscanthus can have ash contents varying from 1.5 % to 4.5 % by mass.

3.6 Cereal grain

3.6.1 Sources and supply

Cereals such as oats, wheat and barley are well established agricultural crops that are sown and harvested on an annual basis. More usually used for food production, low cereal prices in the summer of 2005 caused farmers to look at other markets and some was used as an energy source.

Grain is reasonably well suited to use as a fuel because of its high energy content and ease of handling. The supply infrastructure of grain is well established and the moving and handling of the fuel is well understood. Recent price increases have seen its projected popularity as a combustible biomass fuel fall. Grain futures prices are being driven by the demand for bioethanol, a premium fuel, and the demand for this is likely to soak up surplus grain production in the UK in the future.

3.6.2 Standards

Grain has to achieve many tight standards for food production but there are no known standards pertaining to its use as a biomass fuel. However, a target moisture content of 15% is one standard that is relevant which ensures a consistent net energy content. In the main the quality of grain for use as a fuel is very consistent and should present few problems in comparison to wood chip or straw.

3.6.3 Energy content

Cereal grain has an energy content of 17GJ/tonne on a dry matter basis (4.7kWh/kg) which reduces to 15.5GJ/tonne (4.4kWh/kg) at 15% moisture content; the threshold at which it is stored for food production.

3.6.4 Storage and handling

Grain is a very easy fuel to handle because it has flow properties which enable it to be blown or moved through screw augers. Moving grain from source to installation is done in grain trailers which have hydraulic tipping mechanisms to aid emptying. Bucket based materials handlers can also be used to move grain if required.

Long term grain storage is a well established technology and includes large bins or portal frame buildings with concrete floors and retaining walls. Although a nursery could invest on their own many farmers & grain suppliers have long-term storage facilities. The well established supply chain also means that regular deliveries are almost guaranteed. Therefore investment in long-term storage facilities is less important with grain than any other biomass fuel.

3.6.5 Combustion characteristics

Grain appears to be a very convenient fuel because of the way in which it free flows and is easily moved into the combustion system. Grain husks are incombustible and have a propensity to 'bulk' clogging up the combustion chamber. Ash content is similar to straw – approximately 5 %.

3.7 Rape meal

3.7.1 Sources and supply

Rape meal is a by-product of the crushing of oil seed rape for oil extraction. The oil is used in the chemical industry and in the food industry. In more recent years it has been used for the production of biodiesel. Rape meal has been traditionally used as a mixer in animal feed but increases in biodiesel demand are likely to lead to the saturation of this market and therefore it may become a good source of combustible biomass fuel.

3.7.2 Standards

There are no defined standards for rape meal as a combustible fuel because its use in this manner is very new. As with all biomass fuels the moisture content is critical and defines the calorific value and hence quality.

3.7.3 Energy content

It is difficult to find information about the energy content of rape meal however early indications are that it has a calorific value, slightly higher than other biomass fuels due to its residual oil content at 22GJ/tonne (6.1kWh/kg).

3.7.4 Storage and handling

Rape meal requires handling in a similar manner to grain. Bulk trailers capable of tipping into dedicated hoppers are the most suitable form of transport.

3.7.5 Combustion characteristics

Rape meal has high energy content but also has high silicon and potassium content that can lead to difficulties in burning and cause clinkering.

3.8 Poultry litter

3.8.1 Sources and supply

Poultry litter is a by-product of the poultry industry and describes the material left over on the floor of the shed from meat bird production. There are poultry farms scattered throughout the UK and many have difficulty in disposing of this material. Poultry litter is available all year round. Obtaining poultry litter tends to be through dealing direct with the poultry producer who is unlikely to be set up with transport and handling & storage facilities. Taking poultry litter as a fuel can help offset producer costs and therefore is generally inexpensive to purchase.

3.8.2 Standards

Standards do not exist for poultry litter as a biomass fuel. Quality is very batch dependant and litter can have a high moisture content.

3.8.3 Energy content

The energy content of poultry litter is typically less than that of most other biomass fuels. The calorific value is approximately 11GJ/tonne (3kWh/kg) at 25% moisture content. Litter can have a moisture content of up to 40% and may require some drying before use.

3.8.4 Storage and handling

The handling of poultry litter can be difficult. This is because it is a mildly hazardous substance so care must be taken to ensure proper safeguards are in place for all workers who come into contact with it. Litter should ideally be stored in covered buildings that allow good airflow to aid the drying process. The buildings should be capable of storing the quantity available from the supplier at any one time as they are unlikely to have storage facilities of their own. The fuel is transported in bulk trailers. A materials handler will also be required.

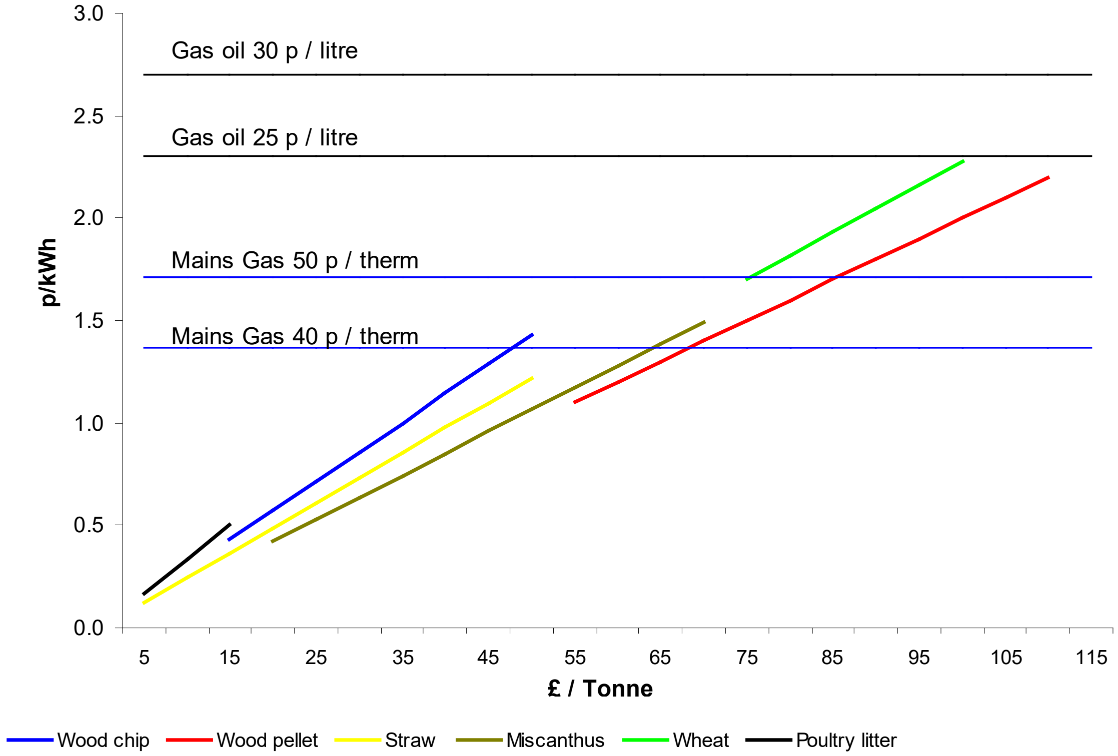
3.8.5 Combustion characteristics

Poultry litter will need to be dry (25 % moisture content) before burning in order to make the combustion as easy as possible. Details on its combustion characteristics are not readily available as it is not a widely used fuel.

3.9 Biomass fuel financial comparisons

The graph (Figure 5) below compares the costs of biomass fuels as purchased £ / tonne with the equivalent pence / kWh energy value, with summary reference guide, Table 6.

Figure 5 - Biomass fuel price comparisons



The lines for each fuel denote the likely cost range (£/tonne) for the fuel. The graph shows that even the most expensive fuels (wheat and wood pellets) can be cheaper than gas oil. Many of the biomass systems that have been installed are on sites where the fuel substitution is being made from oil to biomass. At current natural gas prices biomass fuels compare less favourably. The economic case for biomass fuels as a substitute for natural gas is strongest with the least processed and hence cheapest fuels. Further detail on cost comparison of biomass fuels and fossil fuels can be found in tabulated form in the Appendix.

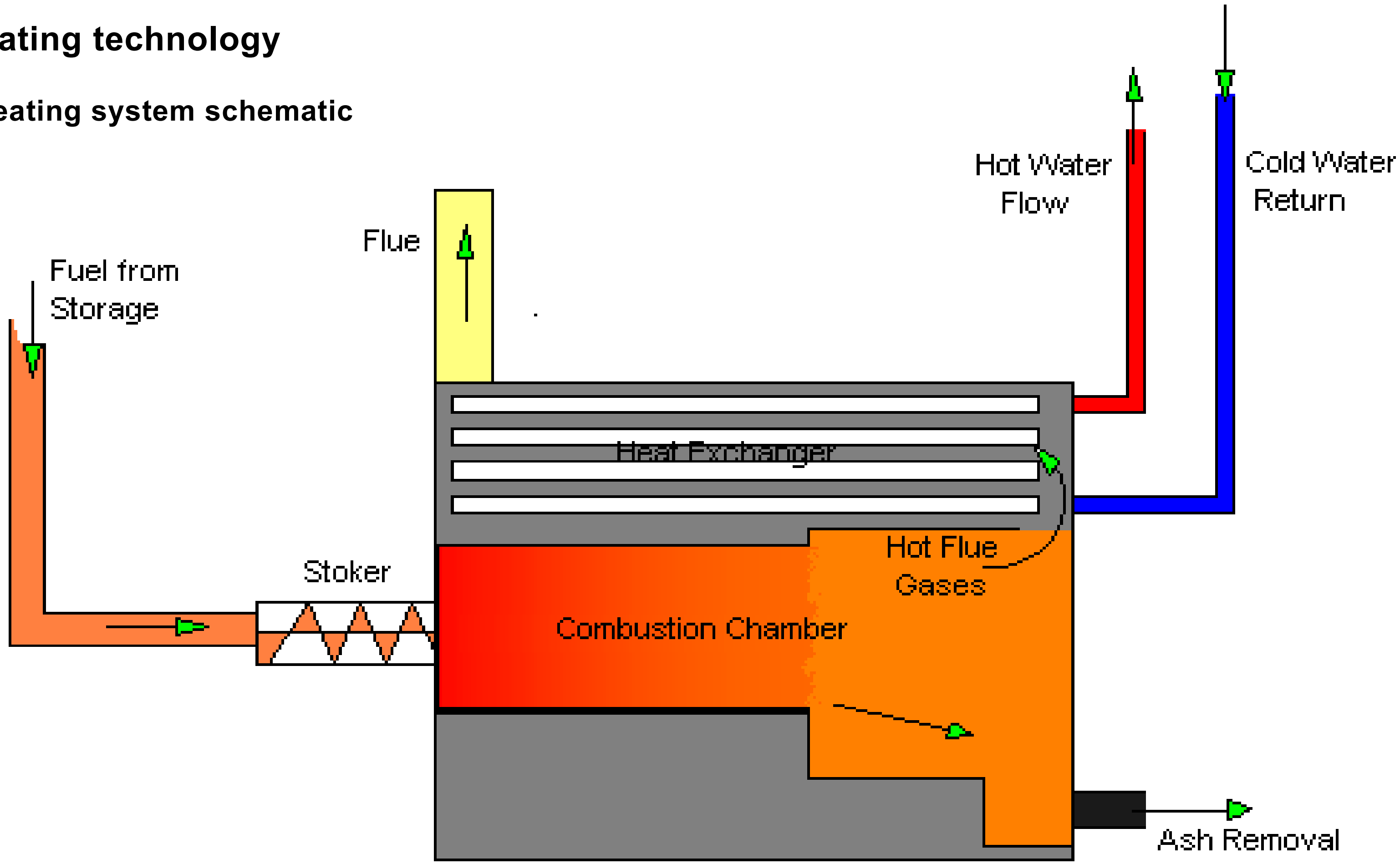
The final delivered cost of biomass fuels depends heavily on the level of processing and the distance transported from supply to point of use. For example, wood pellets tend to be expensive as they are a uniform highly processed product. There is also limited production in the UK and a large proportion is imported from Scandinavian countries. In comparison straw is a by-product of cereal growing and is simply baled in the field and delivered to the end user in that form. However, it is a bulky product and transport costs per kWh of heat produced can be higher.

Table 6 Biomass fuels reference guide

Fuel type	Energy content KWh / kg	Typical moisture content	Bulk density kg / m^3	Pro's	Con's
Wood chip	4	25 %	175 – 350	Easily fed into burners Easily transported and transferred Reliable supply available	Can be highly variable in energy content and moisture content Requires undercover storage Chip size can be variable if not tightly specified causing problems with handling & combustion
Wood pellet	5	10 %	600 – 700	Clean and easy to handle fuel Reliable High energy content	Expensive Few local supplies – increase transport cost
Straw	4.1	15 %	100 – 150	Very cheap where locally sourced Easily transported and handled Harvested immediately prior to winter use	Transport costs prohibitive if not local Needs to be chopped before burning requiring specialist equipment & increased labour input
Miscanthus	4.7	12 %	120 – 160	Dedicated energy crop not subject to other economic pressures Easily transported and handled	Difficult to source Not well established as a UK crop Requires 4 – 6 months storage before use Needs to be chopped before burning requiring specialist equipment & increased labour input
Grain	4.4	15 %	600 – 800	Easily handled and fed into burners High energy content Established supply chain	Highly volatile prices Specialised combustion systems required for large scale operation
Poultry litter	3	25 %	300 - 500	Very cheap where locally sourced	Can have high ash content Could be perceived as a waste and subject to stricter regulations

4 Heating technology

4.1 Heating system schematic



The schematic above shows how a typical biomass boiler is configured and the various components that are required, as well as defining the nomenclature used in this section.

4.2 Short term fuel store

4.2.1 Size

All fuels will need to be stored for short periods of time before use. The amount of storage required depends on the frequency of delivery but should hold at least one weeks stock of fuel. These stores also need to house the primary fuel feed mechanism that starts the automatic fuel delivery to the burner. Table 7 below gives an indication of the sizes of store required for a range of biomass fuels at varying weekly energy consumptions.

Table 7 - Fuel store sizing

Energy use per week		$8kWh/m^2$	$10kWh/m^2$	$12kW/m^2$	$15kWh/m^2$
MWh / hectare / week		80	100	120	150
Tonnes required per week	Wood chip	23	29	34	43
	Wood pellet	16	20	24	30
	Straw	20	24	29	37
	Grain	18	23	27	34
Store size needed (m^3)	Wood chip	87	109	131	163
	Wood pellet	25	31	37	46
	Straw	156	195	234	293
	Grain	26	32	39	49

4.2.2 Type

The volume and type of fuel to be used dictates the type of store that is most suitable. There are four commonly used short term store types for biomass.

1. Trailer bins – volume of biomass contained is limited by the size of trailer capable of being hauled on the road. This storage is suitable for small systems and flowing bulk fuels only i.e. not straw or miscanthus.
2. Hoppers – fuel is pumped from the delivery vehicle to the hopper. This storage is most suitable for wood pellet and grain and is used for small to medium size biomass systems.
3. Bunkers – these are built underground or using the natural contours of the site to enable fuel to be tipped in directly from the delivery vehicle. These stores tend to have their own integral fuel feed systems and are only really suitable for pellets, grain and wood chip.
4. Portal frame building – this is the most versatile type of store enabling material to be loaded directly into the store and easily handled once there. Straw can be kept covered and moved to the feed system when required and fuels such as pellets and chip can be moved using a walking floor system.

4.3 Feed systems

As with short term storage the installation of the feed system is dependant on the type of fuel. There are three stages to the feed system of most biomass systems, store feed, primary fuel feed and the stoker.

4.3.1 Store feed

The store feed transports the fuel from the short term store to the primary feed mechanism. For loose bulk fuels (wood chip, pellets etc.) a 'walking floor' is the most commonly used system. Walking floors use hydraulic rams to push the fuel forwards. Augers are occasionally used mostly for bunkers. Augers work less well because oversize fuel (large chips etc.) can cause bridging and prevent free flow of fuel. This can be overcome by having fuel stirrers that operate occasionally to ensure the fuel is evenly distributed.

Bales are loaded onto a conveyer by materials handler. This is obviously more labour intensive than augers or walking floors used for other fuels. Bales are usually loaded once a day and the conveyer needs to be sized accordingly.

4.3.2 Primary feed system

Once the fuel reaches the primary feed system entry point, it needs to be transferred to the stoker. Most commonly the primary feed system consists of a number of screw augers. These screw augers are suitable for a wide range of fuels especially for those that flow well (chip, pellet, grain etc.).

Straw tends to be treated differently. After being conveyed to the primary feed system it is then chopped, the chopped straw has little mass and can be blown. Some primary feed mechanisms for straw use a vacuum to suck the straw to the stoker.

4.3.3 Stoker

The stoker is the entry point of the fuel to the burner. Fuel supply is controlled by screw augers as these have proved to be the most robust solution for high temperature conditions. Stokers can have single or multiple points, multi point stokers give a more even distribution of fuel in the grate.

4.4 Boilers

4.4.1 Grates

The grate of a biomass boiler is where the fuel is burnt. There are numerous different types available which are both manufacturer specific and dependant on the type of fuel being burnt. Typical types of grate and their applications are shown in Table 8 overleaf. Optimum combustion can only be achieved through using the correct type for the particular application. The type of grate is dictated by the type and quality of the fuel (lower moisture content is a typical indicator of better quality fuels).

Simple grate systems rely on the fuel being added to move the combusting fuel towards the ash box. Whilst this work well with reliable clean burning fuels, fuels that have a propensity to clinker or bulk up in the combustion chamber will not produce good results and incorrect combustion settings could lead to serious difficulties.

More advanced systems use series of moving steps or similar systems which sweep the grate clean periodically. This adds complexity and cost to biomass boilers but can help to ensure reliable operation with a wider range of fuel types / quality.

Table 8 – Grate types

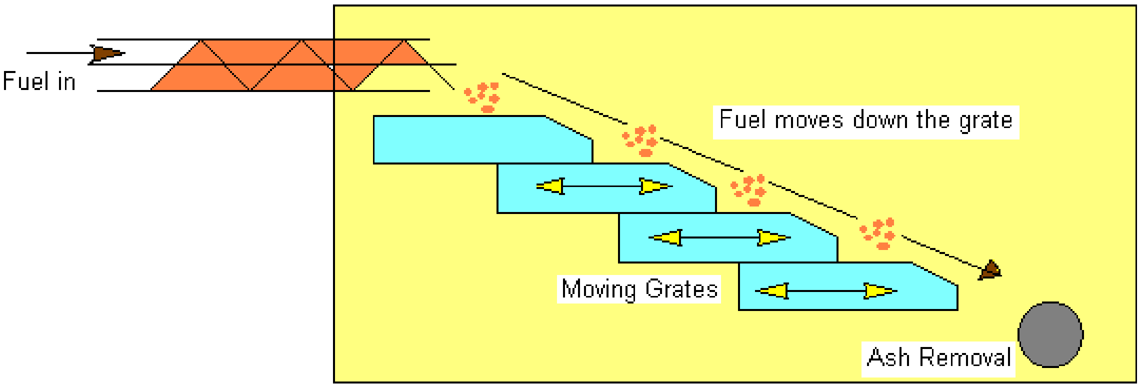
Type of Grate	**Fuel Characteristics**	**Suitable Fuels**	**Typical Moisture contents**
Underfed	Medium size particles such as G30 Chip	Wood chip, Pellets	< 30 %
Overfed Flat	Small and medium sized fuels	Wood pellets, chopped Straw	< 30 %
Stepped	Clean burning fuels with varying particle sizes	Straw, Wood chip,	30 % - 60 %
Moving stepped	Wide range of fuels can deal with high levels of impurities	All biomass fuels	30 % - 60 %

Underfed grates have the fuel augured or blown in from below the burn area and are typically used with wood based fuels with moisture contents of less than 30%. Overfed grates are not widely used in large boilers and tend to be limited for use for smaller wood pellet burners.

Step grates are capable of handling fuels with moisture contents as high as 60% and of varying physical size. Fixed stepped grates can be a source of difficulty; if the fuel has a high ash content there is a propensity to clinker.

Moving step grates (see Figure 6 below) are by far the most versatile and can be used for a large variety of fuels and with most of the feed systems. Moving step grates are self cleaning and can reduce the amount of time required for ongoing checks / maintenance.

Figure 6 – Moving stepped grate schematic



4.4.2 Boiler shell and heat exchanger

The boiler shell and heat exchanger are very similar to conventional fossil fuel type boilers. They can comprise single or multi pass water jackets. For larger systems multi tube heat exchangers are favoured. The heat exchange efficiency in biomass boilers is close to that of conventional systems operating at efficiencies of 80 – 90%.

Fly ash from the combustion process can build up in the heat exchange tubes and reduce their efficiency. They therefore require regular cleaning. Although this can be done manually automatic systems are available. The most common method is to blast compressed air down the tubes at set intervals when the boiler is operational. This prevents build up of fly ash and hence stops the clinkering of this over time. Manual cleaning is still required 2-3 times per year.

4.4.3 Firebreaks

Because of the nature of the way in which fuel is fed into the burner there is a risk of combustion creeping back into the feed system. To comply with insurance regulations biomass fuel feed systems should have fire breaks built into them. These can be either extinguishing systems or mechanical breaks or a combination of the two.

4.4.4 Ash removal

Combustion of any biomass fuel produces ash which can be as little as 0.5% of the raw material by volume or as great as 10%. The ash will usually be removed from the boiler through an auger and sent to a steel bin which will require regular emptying.

Larger biomass installations also have flue gas particulates cyclones to remove more ash from the flue gas before it goes to atmosphere. These also require regular emptying.

4.5 Biomass infrastructure

Conventionally fuelled heating systems tend to be very simple in terms of how the fuel input process and boiler integrates. Biomass systems by contrast require a much greater degree of handling and processing of the fuel.

4.5.1 Fuel Logistics

Biomass is a bulk fuel that cannot be piped to where it is required and so will need to be delivered to the site in bulk. Consideration of this is paramount when designing a biomass system.

Areas for consideration are:

- How many deliveries of fuel will be required? Will this increase heavy haulage traffic and require approval from the local authority?
- How far is the fuel travelling and therefore what sort of vehicle will be used? i.e. agricultural tractor or articulated lorry – can the site be developed to allow this?
- How will the fuel be stored and how will it be transferred from the haulage vehicle to the store?
- How will the fuel be moved around the site? i.e. from store to boiler.

4.5.2 Combustion by-products

Ash will need to be disposed of once it has been removed from the boiler; the ash is suitable for use as a fertiliser and can be spread on agricultural land. Until a suitable time for this spreading, the ash will need to be stored, preferably on hard standing and under cover. Moving of the ash may necessitate suitable machinery for movement and loading.

4.5.3 Boiler housing

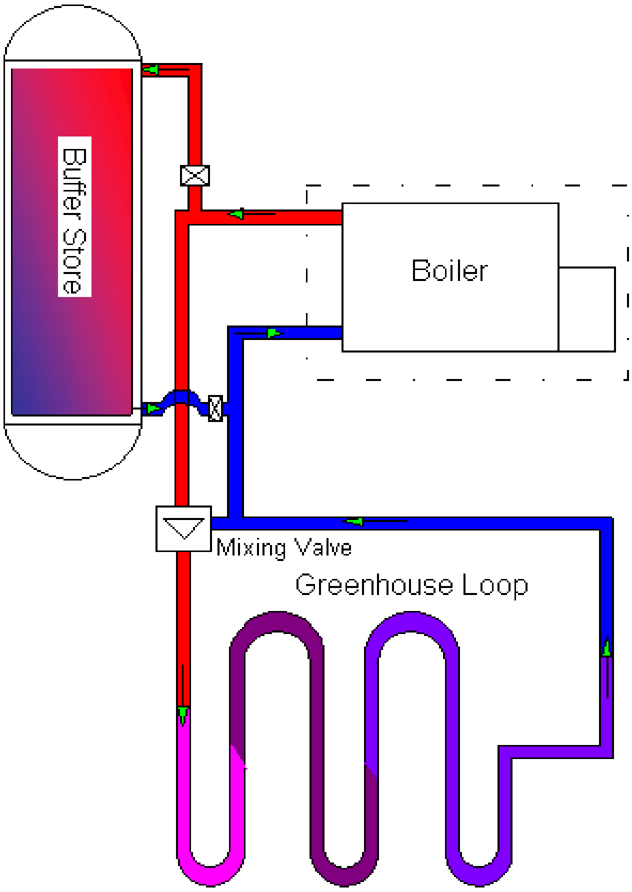
Biomass boilers usually have a larger footprint than their equivalent size fossil fuel boilers. Because of this and because it may be necessary to keep the fossil fuel system for backup, housing the biomass system in a dedicated building is advised. Portal frame buildings are generally suitable as are glasshouse structures. The building should be large enough to allow easy access for daily maintenance and be able to cope with seasonal strip down and cleaning.

5 Integration into greenhouse heating systems

5.1 Heat storage

Biomass boilers have a minimum fire level of approximately 30% compared to 15% for natural gas boilers. It can also take up to 45mins from kindle fire (0%) to maximum output compared to just a few minutes for a gas boiler. It is therefore desirable to have buffer storage with biomass systems. This allows the boiler to work constantly for long periods with changes in heating demand being handled by the buffer store.

Figure 7 – Closed buffer heating system



5.1.1 Closed buffer

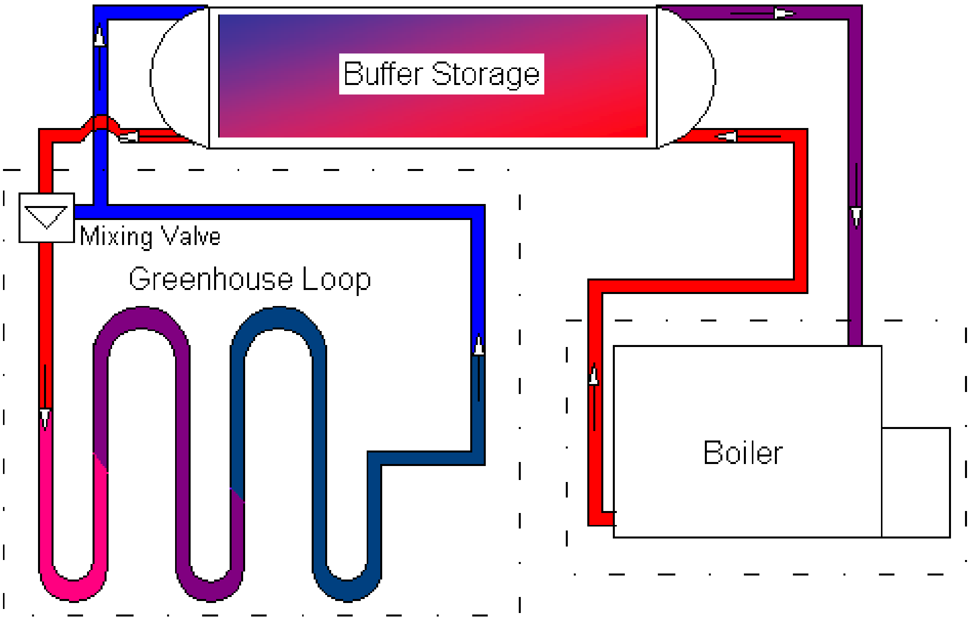
Many edibles nursery heat stores are operated in closed buffer mode (see Figure 7). Here the boiler is used as the primary heat source heating the greenhouse directly during the day. When there is spare capacity available from the boiler or when it is operating to meet CO_2 demand any surplus heat is diverted to the heat store. This heat can then be used overnight.

The underlying limitation of closed buffer heat storage is that the greenhouse can only be heated by the boiler OR the heat store. Not a combination of them both.

5.1.2 Open buffer

Open buffer storage is different to closed buffer storage in that the buffer is the primary heat source passing hot water to the greenhouse when it is required. The boiler operates simply to keep the heat store at the required primary feed temperature. Should there not be enough capacity in the heat store then the boiler water passes directly through and supplies the heating water directly.

The open buffer system is best for biomass systems because it cuts down cycling of the boiler. This is because heat is being drawn from the buffer rather than the boiler. The buffer therefore handles the hour to hour changes in heating demand. Open buffer is also particularly suited to smaller capacity boilers as it allows the build up of heat



reserves over long boiler operational periods.

Figure 8 – Open buffer heating system

Backup boilers can also be easily accommodated into open buffer operation to supply the extra heat capacity when the biomass system can not cope.

5.2 Heating system calculations

The operation of an open buffer system and biomass boiler was simulated using heat and CO_2 demand data from three commercial greenhouses. This allowed the impact of a range of biomass boiler and heat store size combinations to be trialled. In addition to modelling for heat demand the simulation allowed the effect of CO_2 demand to be considered and the effect this had on the operation of the biomass system.

Data was taken from three nurseries as 5 minute records for a year. The data used were:

1. Measured greenhouse temperature - used in conjunction with calculated pipe temperature to ascertain the heating demand on the nursery at any one time.
2. Calculated pipe temperature – used in conjunction with measured greenhouse temperature to give required heat demand.
3. CO_2 demand – to establish when CO_2 was required in the greenhouse.
4. Actual boiler demand – combined with CO_2 demand this allowed the amount of CO_2 delivered to the greenhouse to be determined.

The model was run with various different combinations of boiler and buffer sizes. A table showing the most relevant combinations is given for each grower type. All the models were run for a 1ha greenhouse block and the boiler sizes quoted are the delivered heat capacity to the greenhouse (as opposed to their fuel use capacity) and as such independent of any system efficiencies.

The important values calculated by the model were;

1. **Biomass boiler utilisation** – given as a percentage value this describes the relationship between the actual boiler energy output in a year compared to the theoretical maximum output it could achieve if it operated continuously. This is a typical measure used by heating system designers to ascertain how hard the boiler works.
2. **Biomass boiler contribution to heat** - the value of the greenhouse heat requirement supplied by the biomass boiler both as percentage of total heat requirement and as kWh/m^2.
3. **Fossil fuel heat energy requirement** - the value of the heat energy supplied by the fossil fuel top up boiler both as percentage and as $kWh\ m^2$.
4. **Thermal capacity rating of the auxiliary fossil fuel fired boiler** (kW) – where the biomass boiler is not capable of supplying all the greenhouse heat demand.

5.3 Nursery overviews

5.3.1 Nursery 1

This is an ornamentals nursery producing cut flowers which are grown at 20 – 22 degrees C. The glasshouse environment is enriched with CO_2 using flue gasses from the mains gas boiler. The site is of recent construction with blackout and shade screens. Supplementary lighting and insulated buffer storage are also installed. Table 9 below gives an overview of the heating installation.

Table 9 – Nursery 1 details

Boiler details	2.1MW/ha gas boiler
Buffer capacity	150m^3/ha insulated
Heating system type	Low level plastic and high level steel pipes

The maximum heat requirement over any one hour period in the year was 1771kW and the annual heat demand for the greenhouse was 346kWh/m^2.

5.3.2 Nursery 2

This was an edible crop nursery that has seen significant investment in energy saving measures over the last seven years. Thermal screens, insulated buffer tanks and improved boiler control have all allowed the energy use to be optimised. Heat is occasionally destroyed for CO_2 purposes but the data used was from an area that did not have heat destruction during the season.

Table 10 gives an overview of the heating installation.

Table 10 – Nursery 2 details

Boiler details	3.3MW/ha gas boiler
Buffer capacity	240m^3/ha insulated
Heating system type	Low level pipe rails

The maximum heat requirement over any one hour period in the year was 1429kW and the annual heat demand for the greenhouse was 428kWh/m^2.

5.3.3 *Nursery 3*

This nursery was a high temperature edibles nursery. The glasshouse is a modern (six years old) Venlo type. Thermal screens and insulated buffer stores were installed. The model was run at two different CO_2 levels; high CO_2 demand and low CO_2 demand. The CO_2 data was collected from other nurseries where the detailed heat demand was not available or where heat was regularly destroyed to aid CO_2 availability. This was done to establish the effect of two CO_2 levels on the operation of a biomass system.

Table 11 below gives an overview of the currently installed heating system.

Table 11 – Nursery 3 details

Boiler details	2.88MW/ha gas boiler
Buffer capacity	230m^3/ha insulated
Heating system type	Low level pipe rail

The maximum heat requirement over any one hour period in the year was 2,623kW and the annual heat demand for the greenhouse was 597kWh/m^2.

5.4 Heating system model results

5.4.1 *Nursery 1*

The heating system simulation was run using a variety of boiler sizes with different buffer store combinations. The simulation was also run for two scenarios – with & without the need for CO_2 enrichment.

Case 1 - Without CO_2 enrichment

Buffer store sizes of 50, 100 and 150m^3 were chosen to reflect the likely size of store for this type of operation. The results appear in the Table 12 overleaf.

Table 12 – No CO_2 demand results from Nursery 1

Biomass boiler size (kW)	**Buffer size (m^3)**	**Biomass boiler utilisation %**	**Heat from biomass**		**Heat from fossil fuel**		**Fossil fuel boiler size (kW)**
			%	**(kWh/m^2)**	**%**	**(kWh/m^2)**	
1764	0	22	100	346	0	0	0
800	50	47	94.39	326	5.61	19	971
800	100	48	96.91	335	3.09	11	971
800	150	49	98.02	339	1.98	7	971
600	50	56	84.23	291	15.77	55	1171

600	100	59	88.43	306	11.57	40	1171
600	***150***	***60***	***90.12***	***312***	***9.88***	***34***	***1171***
400	50	66	66.75	231	33.25	115	1371
400	100	71	71.04	246	28.96	100	1371
400	150	72	72.41	250	27.59	95	1371

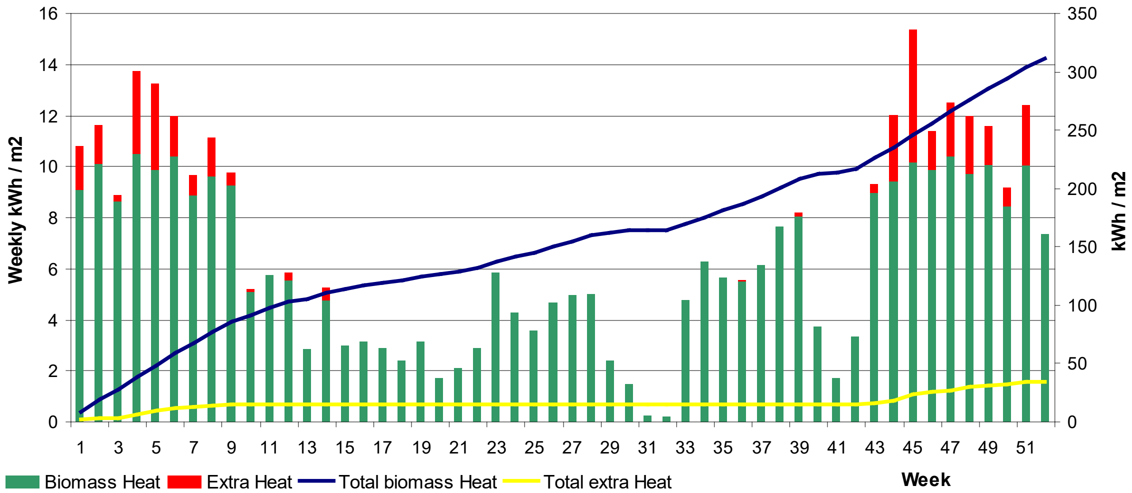
The values in the table suggest that in order to optimise boiler utilisation and heat supplied from biomass the site would be best served by a 600kW boiler and 150m^3 buffer store. This represents a boiler only 34% of the size of the peak heat demand.

A buffer store size of 50m^3/Ha still gave good results - only reducing the amount of heat supplied by the biomass system by 6%. With no buffer storage at all the amount of heat supplied by a 600kW boiler reduced by 20%.

A graph of the heating profile for the 600kW, 150m^3 scenario is shown in Figure 9 below.

Figure 9 – No CO_2 demand Nursery 1 heating profile

The graph shows that between weeks 11 and 46 the biomass boiler satisfies virtually all the heating demand with only weeks 12, 14 and 39 requiring fossil fuel top up.



Case 2 - With CO_2 delivery

Figure 10 below shows the amount of CO_2 as kg per m^2 per week delivered to the greenhouse in the form of flue gasses from the nursery's existing mains gas boiler. This represents a total of 157 tonnes per Ha over a complete year.

As it is not currently possible to use the flue gasses from burning biomass fuels for CO_2 enrichment it must be provided by other means. The options considered were:

1. Continue to burn mains gas to satisfy the CO_2 demand
2. Use pure CO_2

Option 1 produces 'waste' heat that can be used to heat the greenhouse thereby reducing the amount of biomass fuel required. Option 2 allows utilisation of the biomass boiler to be kept as high as possible but incurs the additional cost of buying pure CO_2. The economics of these approaches are discussed for each nursery in section XX

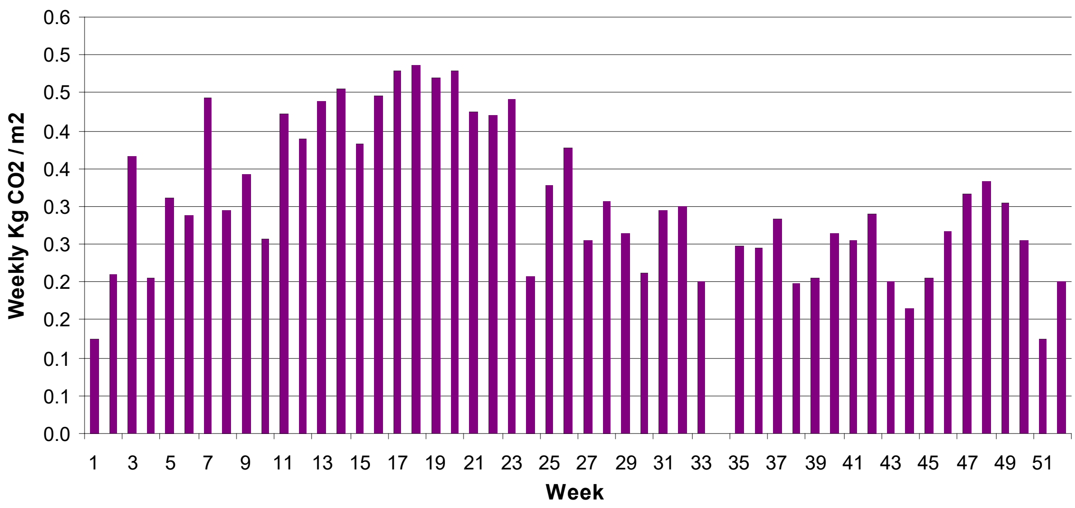
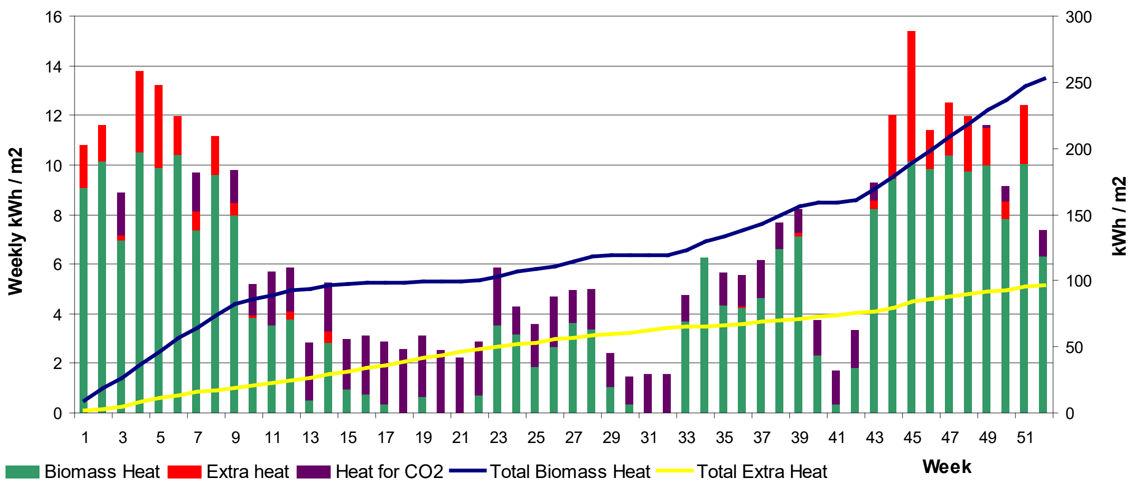


Figure 10 – Nursery 1 CO_2 requirement

Figure 11 below shows the effect that burning mains gas for CO_2 enrichment has on biomass heat utilisation. The fossil fuel boiler is required to operate over and above that required to meet periods of peak heat demand. This is most significant between weeks 15 – 22 when CO_2 demand is highest. This reduces the biomass component of the heat delivery from 90% to 73% of the total.

Figure 11 - Nursery 1 showing the CO_2 effect on heating requirement



5.4.2 Nursery 2

Case 1 - without CO_2 delivery

The values in Table 13 suggest that a boiler supplying 500kW to the greenhouse backed up with the existing buffer storage capacity of 240m^3/Ha will maximise both boiler utilisation and biomass energy supply. It can be seen from the tables that any increase in the size of the buffer store above 150m^3 has only a marginal effect on the quantity of heat supplied by the biomass installation. The heat demand profile for this site is shown below (Figure 12).

Table 13 – Nursery 2 no CO_2

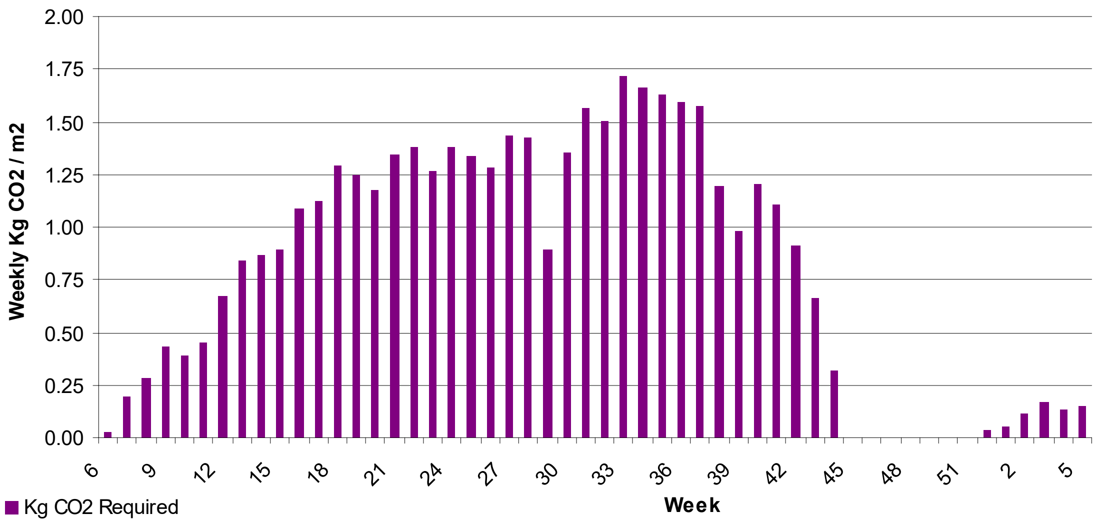
Delivered capacity boiler size (kW)	**Buffer size (m^3)**	**Biomass utilisation %**	**Heat from biomass %**	**Value (kWh/m^2)**	**Heat from fossil fuel %**	**Value (kWh/m^2)**	**Fossil fuel boiler size (kW)**
1420	0	34	100	428	0	0	0
800	150	61	99.23	424	0.77	3	629
800	200	61	99.41	425	0.59	3	610
800	250	61	99.56	426	0.44	2	610
600	150	74	90.82	388	9.18	39	829
600	200	74	90.88	389	9.12	39	829
600	250	74	90.89	389	9.11	39	829
500	150	82	83.78	358	16.22	69	929
500	200	82	83.95	359	16.05	69	929
500	***250***	***83***	***84.05***	***359***	***15.95***	***68***	***929***
400	150	90	73.21	313	26.79	115	1029
400	200	90	73.43	314	26.57	114	1029
400	250	90	73.61	315	23.39	113	1029
200	150	99	40.41	173	59.59	255	1229
200	200	99	40.51	173	59.49	254	1229
200	250	99	40.56	173	59.44	173	1229

Figure 12 – Nursery 2 no CO_2 requirement

The graph shows that very little fossil fuel 'top up' heat is required between weeks 16 – 40.

Case 2 - With CO_2 delivery

Figure 13 below shows the amount of CO_2 as kg per m^2 per week delivered to the greenhouse in the form of flue gasses from the nursery's existing mains gas boiler.



This represents a total of 423 tonnes per Ha over a complete year.

Figure 13 – Nursery 2 CO_2 requirement

The impact of satisfying the CO_2 requirement using a mains gas fuelled boiler is shown in Figure 14. It is likely that the biomass boiler would simply be turned off between weeks 18 – 38. Compared to the 'no CO_2' scenario this reduces the amount of heat provided by biomass from 84% to 42%.

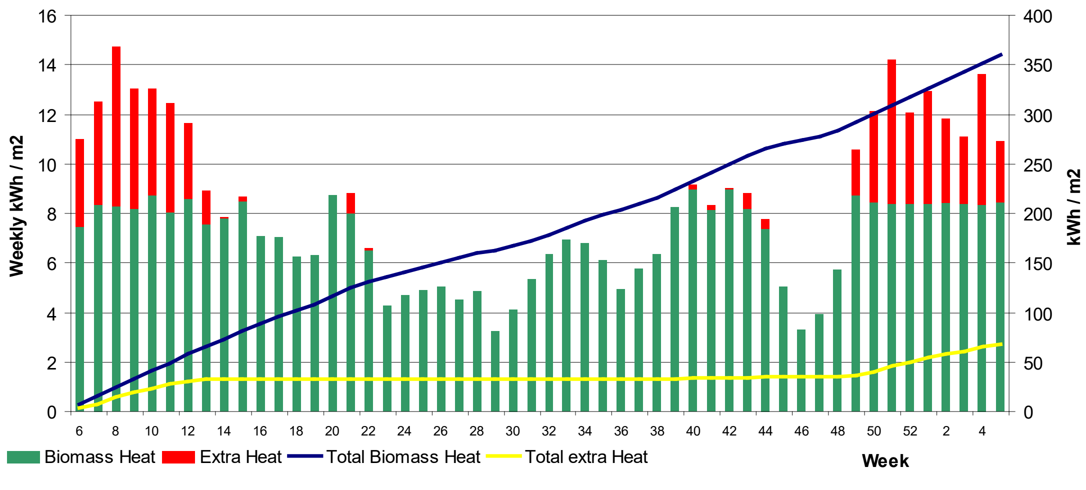


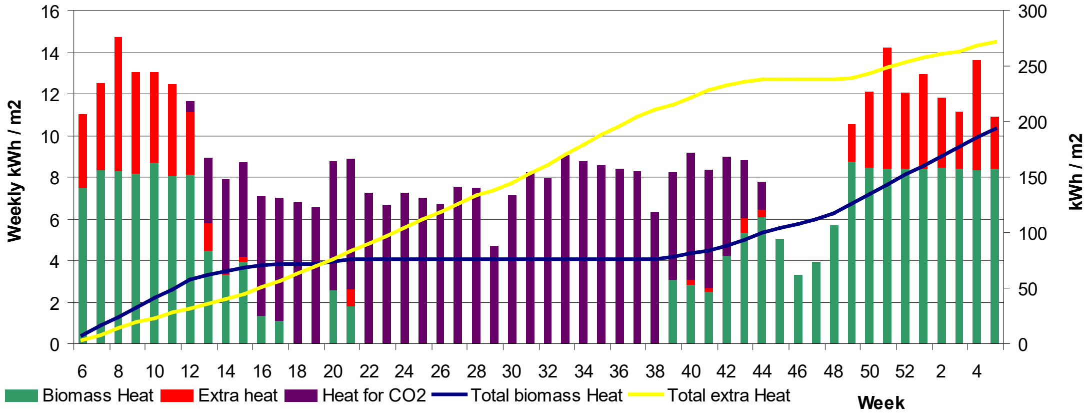
Figure 14 – Effect of CO_2 demand on the heating requirement of Nursery 2

5.4.3 Nursery 3

Case 1 – No CO_2 requirement

Table 14 shows the results of the model for Nursery 3 excluding the CO_2 requirement.

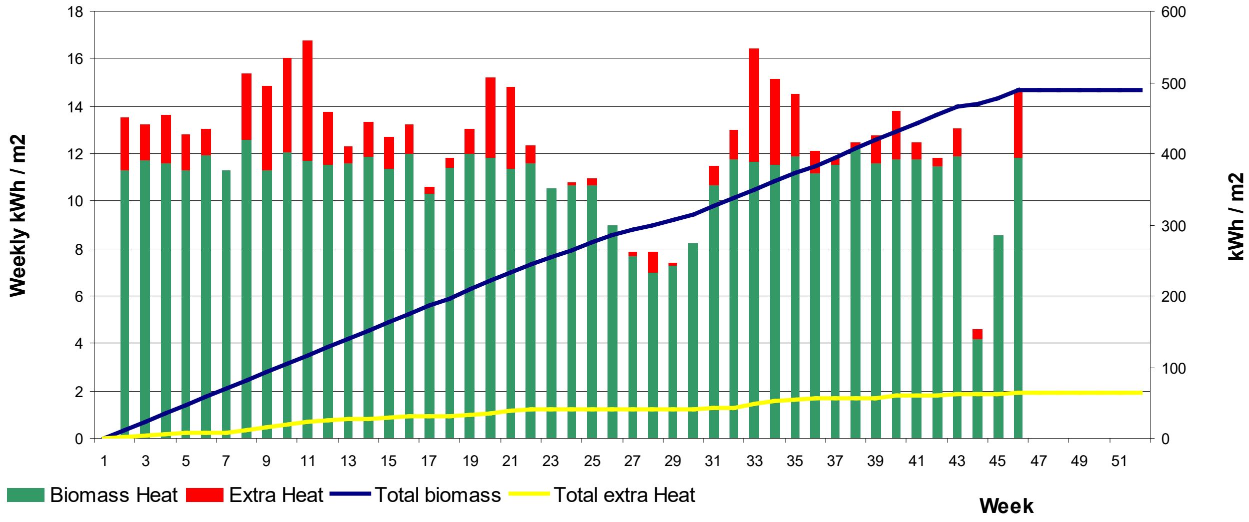
Table 14 – Nursery 3 without CO_2 requirement



To optimise boiler utilisation and the amount of heat obtained from the biomass system, a boiler capable of delivering 700kW to the greenhouse with a buffer tank of 250m^3 appears to be the best option. The table shows the small effect that changes to the buffer size have in the range 150 – 250m^3 on the amount of energy being delivered. The heat profile graph obtained with this scenario is shown in Figure 15 overleaf.

Delivered capacity boiler size (kW)	**Buffer size (m^3)**	**Biomass utilisation %**	**Heat from biomass %**	**Value (kWh/m^2)**	**Heat from fossil fuel %**	**Value (kWh/m^2)**	**Fossil fuel boiler size (kW)**
2623	0	24%	100%	555	0%	0	0
1300	150	49%	100%	553	0%	2	1323
1300	200	49%	100%	553	0%	2	1323
1300	250	49%	100%	553	0%	2	1323
1000	150	63%	99%	551	1%	4	1623
1000	200	63%	99%	551	1%	4	1623
1000	250	63%	99%	552	1%	3	1623
800	150	75%	94%	524	6%	31	1823
800	200	76%	95%	527	5%	28	1823
800	250	76%	95%	529	5%	26	1823
700	150	80%	88%	486	12%	69	1923
700	200	80%	88%	488	12%	67	1923
700	**250**	**81%**	**88%**	**490**	**12%**	**65**	**1923**
600	150	82%	77%	430	23%	125	2023
600	200	83%	78%	431	22%	124	2023
600	250	83%	78%	432	22%	123	2023
500	150	84%	66%	365	34%	190	2123
500	200	84%	66%	366	34%	189	2123
500	250	85%	66%	367	34%	188	2123
400	150	85%	53%	296	47%	259	2223
400	200	85%	53%	297	47%	258	2223
400	250	86%	54%	297	46%	258	2223

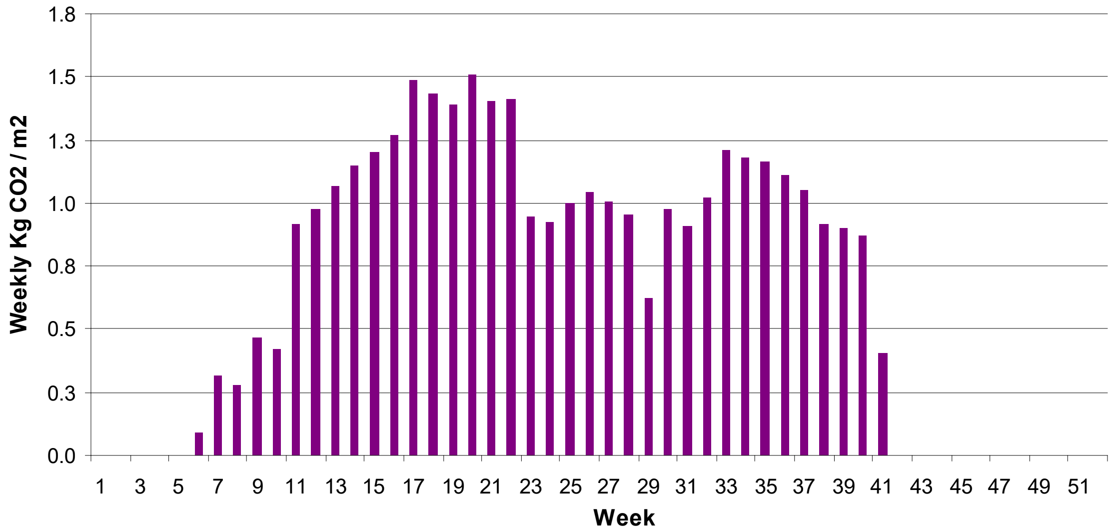
Figure 15 – Nursery 3 with no CO_2 requirement



Case 2 – Nursery 3 with low CO_2 demand

Figure 16 below shows the amount of CO_2 as kg per m^2 per week delivered to the greenhouse in the form of flue gasses from the nursery's existing mains gas boiler. This represents a total of 350 tonnes per Ha over a complete year.

Figure 16 – Low CO_2 demand profile



The effect of satisfying this CO_2 demand using mains gas is shown in Figure 17 below. The amount of heat supplied by the biomass boiler (700kW, 250m^3) reduces from 88% to 64%.

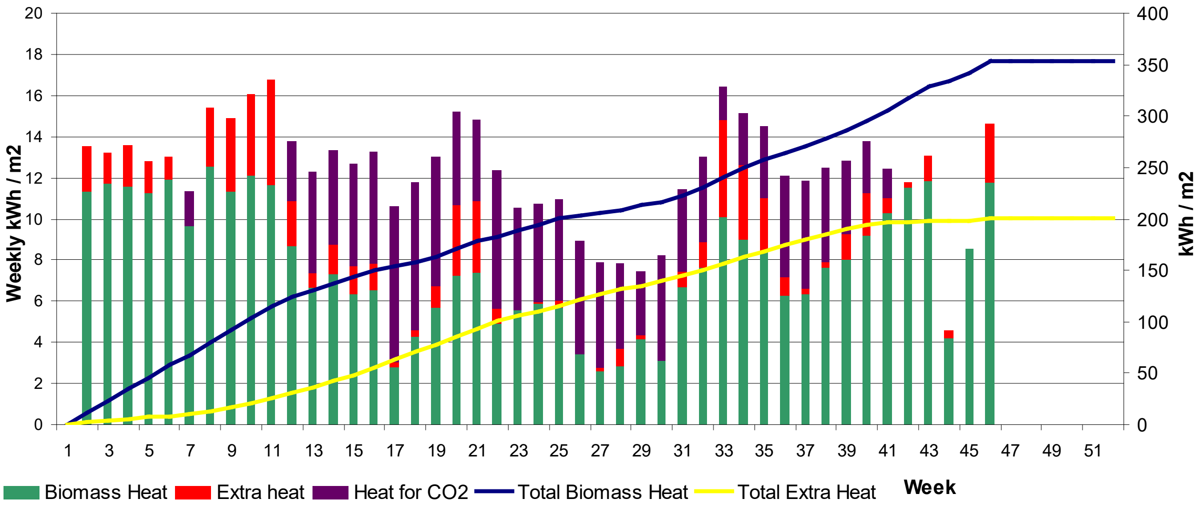


Figure 17 – Effect of optimised CO_2 demand on Nursery 3

Case 3 - Nursery 3 with high CO_2 input

Figure 18 below shows the amount of CO_2 as kg per m^2 per week delivered to the greenhouse in the form of flue gasses from the nursery's existing mains gas boiler. This represents a total of 697 tonnes per Ha over a complete year.

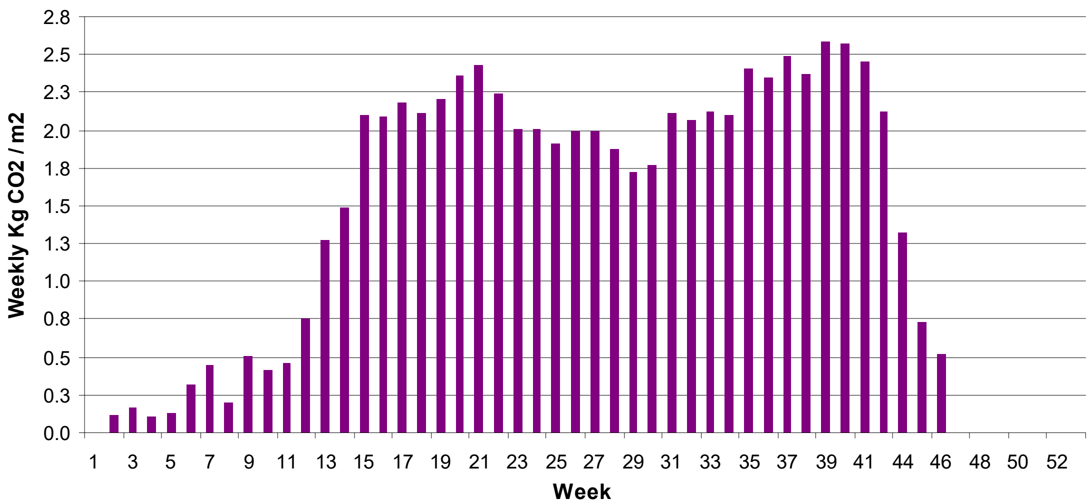


Figure 18 – High CO_2 demand profile

The effect of satisfying this CO_2 demand using mains gas is shown in Figure 19 below. The amount of heat supplied by the biomass boiler (700kW, 250m^3) reduces from 88% to 31%.

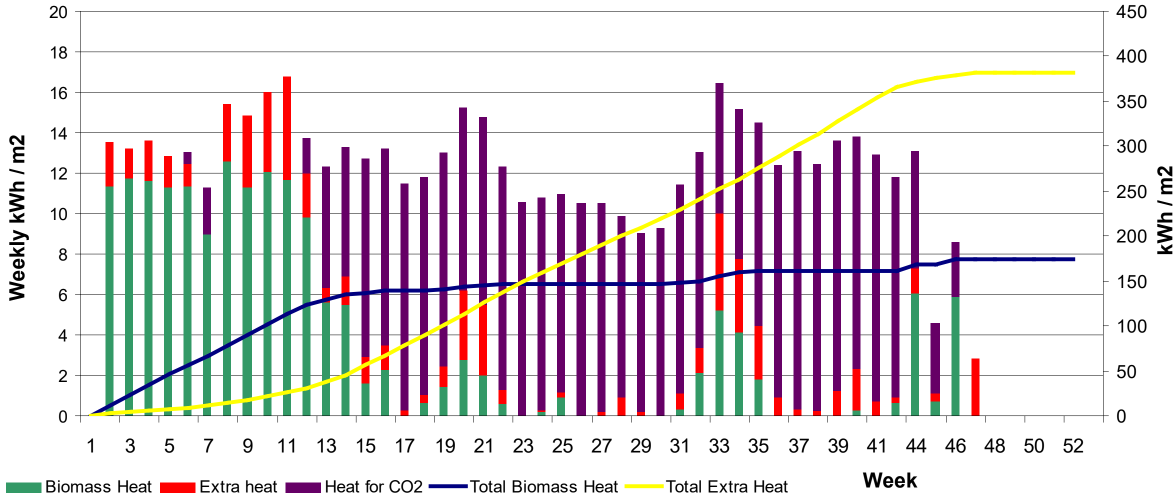


Figure 19 – Effect of high CO_2 demand on the heating requirement of Nursery 3

5.4.4 *Heating model summary*

Table 13 – Simulation results summary

Summary table heat only						
	Biomass boiler size (kW)	Buffer store size (m^3/Ha)	Total heat required (MWh)	% from biomass	% from fossil fuel	Fossil fuel boiler size (kW)
Nursery 1	600	150	3460	90	10	1171
Nursery 2	500	250	4280	84	16	929
Nursery 3	700	250	5550	88	12	1923
Summary table incorporating CO_2						
	Biomass boiler size (kW)	Buffer store size (m^3/Ha)	Total heat required (MWh)	% from biomass	% from fossil fuel	Fossil fuel boiler size (kW)
Nursery 1	600	150	3460	73	27	1171
Nursery 2	500	250	4280	42	58	929
Nursery 3 low CO_2	700	250	4280	64	36	1923
Nursery 3 high CO_2	700	250	4280	31	69	1923

5.4.5 Heating system model conclusions

Running the model for the four scenarios highlights some considerations when moving to biomass heating.

1. Open buffer operation is best suited to biomass operation. It allows a smaller boiler to be used than with a closed buffer. In all cases modelled, the size of boiler that would be required to supply 90% of the heat energy was approximately half that of the currently installed conventional boiler.
2. Looking at the size of the actual buffer stores installed on the sites considered in the model, optimising these would not have a large effect on the utilisation and efficiency of the biomass heating system. Therefore, it's likely that where buffer stores are already in existence it would not be economically viable to extend them to improve the performance of a biomass heating system. For sites with no existing buffer storage a store of $50m^3$ per hectare for ornamentals nurseries and $150m^3$ per hectare for edible nurseries will deliver good results whilst avoiding excessive cost.
3. CO_2 demand has a significant effect on the utilisation factor of biomass systems because, when a fossil fuel boiler has to be used to supply this, the heat energy by-product from the fossil fuel boiler displaces heat that could have been supplied by the biomass boiler. Where the CO_2 demand is high a smaller biomass boiler may be better matched to ensure maximum use is made of it. CO_2 could be supplied from pure sources and in this case the boiler buffer combination suitable would be the same as that in the non CO_2 consideration cases
4. The size of the supplementary fossil fuel boiler is dependant on a few short periods of high heat demand during the year. In practice it is likely that the existing fossil fuel system would be kept as backup and would be more than capable of supplying these peaks. If no existing fossil fuel system exists the economics of installing a fossil fuel fired reserve would need to be compared to the cost of a larger biomass boiler.

6 Economic analysis

6.1 Installation costs

Costs of biomass installations can vary greatly depending on the type of installation and amount of additional infrastructure that may be needed. Typical costs to be considered are shown in Table 14 overleaf.

Figure 20 overleaf shows the spread of cost versus kW for some of the 'turnkey' biomass heating installations recently completed in the UK.

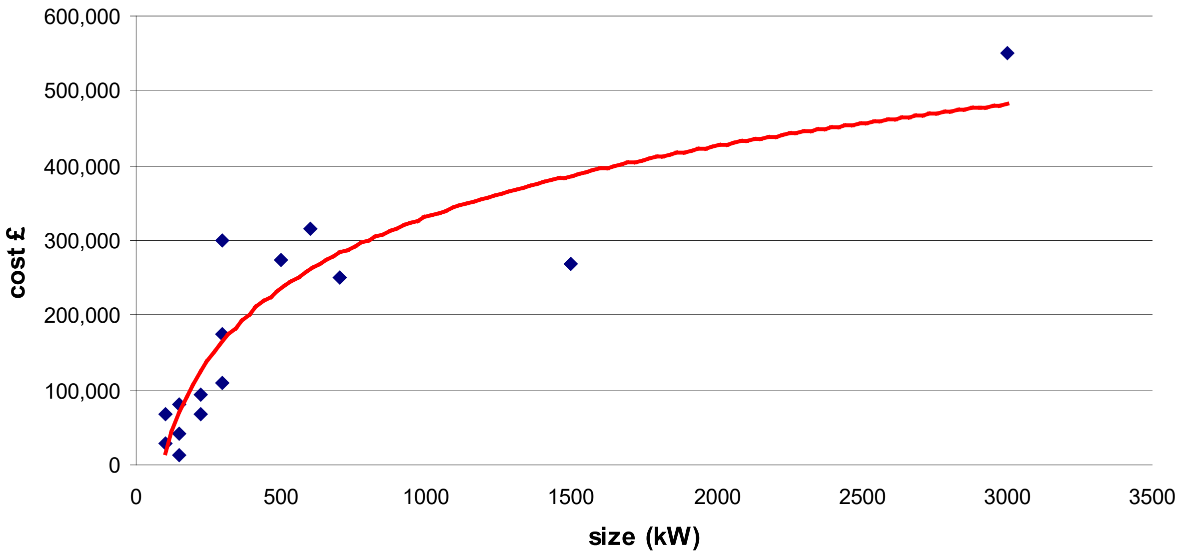


Figure 20 – Installed biomass system costs

The red line gives an approximation of cost to installed size that can be used to budget for biomass installations. The graph demonstrates the economies of scale that can be achieved. A 500kW installation cost approx. £500/kW whereas the 3,000kW installation cost only £167/kW. This has a massive influence on payback calculations demonstrating the need for growers to carry out their own detailed costs if considering biomass heating.

Table 14 – Typical biomass installation costs

Component	Comments	Type of cost	Amount [1]
Biomass boiler *and* Fuel feed system	May be housed in existing boiler house or require additional building Walking floor, augers ram feed etc	Capital Capital – usually included with the boiler	up to 500kW installed £150 - £200 per kW over 500kW installed £100 - £180 per kW
Buffer storage	Should be insulated – likely to be already installed	Capital	£140/m^3 (second hand) £300/m^3 (new)
Fuel store	Large easily accessible building close to boiler house	Capital	£120 - £190/m^2
Hard standing	Area for longer term fuel storage and for vehicles to turn	Capital – unless already existing	£10/m^2
Materials handling	Materials handler, lorries, trailers etc.	Capital – can be used for other jobs around the site	£10,000 - £25,000
Fuel processing equipment	Wood chipper, straw chopper etc.	Capital or ongoing if hired from existing contractor	£5000 - £12,000 purchased or £150 - £250 per day hire
Fuel	Location and type cause great variability in cost	Ongoing	See fuel section for greater detail
Labour	Day to day checks, loading feed systems, alarm calls	Ongoing	£4000 (1 day a week)
Maintenance	Parts, regular servicing	Ongoing	£2 -5 / kW

1 - Caution must be exercised when using these values as they are extremely variable depending on installation type, size and location.

6.2 Cost / benefit analysis

6.2.1 Fuel cost saving & payback

The following figures have been based on the results from section 6 combined with:

- Natural gas – 1.5p/kWh
- Gas oil – 30p/litre. Excluding duty
- Woodchip at £30/tonne which is a mid range cost.

Table 15 below shows the value of the fuel cost saving per Ha excluding any operation & maintenance costs.

Table 15 – Fuel cost savings

CO_2 accounted for	Boiler size (kW)	Buffer size (M^3/Ha)	Fuel cost saving p.a./Ha
Nursery 1 (with gas)	600	150	£20,050
Nursery 1 (with oil)	600	150	£59,900
Nursery 2 (with gas)	500	250	£12,470
Nursery 3 (with gas)	700	250	£11,190

If nursery 1(with gas) was only 1Ha Figure 20 suggests the investment required would be approx. £250,000 giving a payback of 12.5 years. However, if it was 3Ha requiring a 1,800kW boiler the investment would only increase to £400,000 (60% more). The payback would then reduce to 6.7 years.

The best possible scenario of nursery 1 heated with gas oil has a payback of 4.2 years for a 1Ha nursery and 2.2 years for 3Ha. Note that this is based on fuel cost alone and excludes increased operation & maintenance costs.

A more detailed breakdown of the economics appears in Appendix 3. This includes an estimate of the operation & maintenance costs including labour. The value of the carbon saved has also been calculated to give an indication of its value in specific circumstances.

The cost associated with using pure CO_2 and 100% biomass instead of natural gas has also been provided. However, at current prices this increases in total costs compared to using 100% mains gas.

7 Regulations covering burning of biomass

7.1 Legislation affected through installation of biomass heating plant

7.1.1 EU Emissions Trading Scheme (EU ETS)

Sites covered by EU ETS will be affected by the installation of a biomass boiler. Biomass installations must be included in the sites heat capacity limit calculations. However the CO_2 emissions from the burning of biomass are zero rated under the scheme rules and will therefore not count towards the emissions targets set under the EU ETS. This may help the site achieve the set targets or result in lower than target emissions. This will allow the site to either sell surplus carbon allowances or avoid the cost of buying additional allowances. The current price for a tonne of EU carbon is £12 - £15.

Any site not on EU ETS whose thermal capacity exceeds 20MW after installing a biomass installation will need to register on the EU ETS scheme and demonstrate full compliance thereafter.

7.1.2 Climate Change Levy (CCL)

The climate change levy is a charge imposed on the business for the use of coal, gas, LPG and electricity. Biomass fuels do not have the climate change levy applied to them. The cost of the climate change levy for these fuels is shown below in Table 16.

Table 16 – Climate Change Levy costs

Fuel type	Cost
Electricity	0.441pence/kWh
Gas	0.154pence/kWh
Coal	1.201pence/kg
LPG	0.985pence/kg

The horticulture industry has been granted an 80% exemption from the levy providing growers join the climate change levy discount scheme and demonstrate compliance with the scheme requirements. One of the requirements is to reduce energy consumption by set targets on a biennial basis.

Biomass fuels are considered as carbon neutral under the climate change levy discount scheme rules. The substitution of fossil fuels by biomass and therefore their use does not need to be declared as part of the energy consumption of the site. However the scheme operators (NFU Energy) should be informed of the change. Over performance in the CCL scheme can be traded as carbon on the UK emissions trading scheme (UK ETS). Current UK carbon prices are £2 - £3 per tonne.

A fuel type having a biomass and non biomass component can be exempt from climate change levy providing the non biomass component is less than 10% of the whole. If it is greater than this the biomass component of the fuel can still be considered carbon neutral and hence exempt from climate change levy but the non biomass fraction must be reported as an energy use.

7.1.3 Clean Air Act 1993

Any boiler installation up to 20MW that burns clean fuels is covered primarily by the Clean Air Act 1993 which requires operators to burn smokeless fuels. Manufacturers of equipment apply to Defra for exemptions to this Act subject to satisfactory testing. This testing will be required to prove that the appliances are capable of burning fuels or waste as fuels without emitting smoke. This is a basic requirement that any biomass boiler installation should be able to satisfy.

If the Pollution Prevention and Control regulations apply to the installation (see section 8.1.4 below) the Clean Air Act does not.

7.1.4 Pollution Prevention and Control (PPC) and Waste Incineration Directive (WID)

PPC applies to any installation where the combined capacity of the boiler plant on a site is greater than 20MW regardless of the fuel type. Where the installed capacity is less than 20MW the PPC may still apply to a biomass installation depending on a number of criteria.

If the PPC applies a permit to operate is required. The permit obliges the operator to meet certain emissions criteria and comply with any inspections that may be required. This is no different to the requirements for fossil fuel boilers >20MW.

The Waste Incineration Directive (WID) is a European Union directive. Its purpose is to control potentially harmful emissions from the incineration or co-firing (incineration for the purposes of disposal and energy production) of waste without the proper guidelines and technology being applied. Waste is described in the Waste Incineration Directive as

- *…any substance or object……which the holder discards or intends or is required to discard.*

WID and its definition of waste is important because it determines whether a biomass heating system falls within the remit of PPC even when it is <20MW. Table 17 below provides a guide as to which substances are not considered waste and therefore do not come under the jurisdiction of WID. The notes explain under which circumstances these apply.

Table 17 – WID explanations

Fuel	Comment
Forest thinnings and residues (lop and top etc)	*Note 1*
Forest products (including, inter alia, sawdust, co-products including chip and bark)	*Note 1*
Clean recycled wood	*Note 2*

Wood pellets	*Note 2*
Straw	*Note 1*
Energy crops (i.e. any crop purposely grown for energy, including, inter alia, annual and perennial crops, short rotation coppice and grasses such as Miscanthus etc).	*Note 3*
Notes:	
1. If the material is waste from agriculture or forestry and not contaminated with non-vegetable waste	
2. If the material is not contaminated with halogenated organic compounds or heavy metals as a result of treatment with wood-preservatives or coating.	
3. If the crops were grown specifically for energy, then they would be considered a fuel and not a waste, and the WID would not apply.	

Source: **Regulation of Energy from Solid Biomass Plants**, *A report produced for the Environment Agency by AEA Technology May 2006*

Fuels not comprising waste of any sort i.e. energy crops, are unregulated under PPC up to combined plant installation size of 20MW thermal capacity. Above 20MW and less than 50MW the plant is regulated under Section 1.1 B(a) of the PPC regulations 2000.

Waste can be exempted from WID and therefore have less stringent restrictions imposed on it providing the user can satisfy the Environment Agency and their local authority that the waste is clean i.e. free from harmful contaminants and is suitable for the purpose. The most common exemptions are paragraph 5 and paragraph 29 of the WID.

Paragraph 5 Exemption

This allows the burning of waste so long as the net rated thermal input is less than 400kW (if more than one appliance the total must be less than 400kW). The fuel must be neither tyres nor hazardous waste. Hazardous waste is defined in the WID guidance as:

> *…a waste included in the European Waste Catalogue (Commission Decision 2000/532/EC, published in OJ L 226, 6.9.2000, p3) and marked there with an asterisk (*).*

This is a very comprehensive list. Guidance should be sought from the Environment Agency when the constituents of the waste stream are known to establish whether they are classified as hazardous or not. A paragraph 5 exemption should be registered with the Environment Agency

Paragraph 29 Exemption

This allows the disposal of waste at the place where it is produced by the person producing it by burning in an incinerator which is exempt under section 5.1 of the PPC regulations (this means the incinerator must have a capacity less than 50kg/hour by mass of fuel input).

Some wastes are not permitted to be burnt even under this exemption. They are: clinical waste, sewage sludge, sewage screenings, municipal waste, any hazardous waste.

A paragraph 29 exemption is regulated by the Environment Agency and must be registered with them.

Substances classified as waste under the WID can be burnt as fuel in combustion plant however they will require the correct permits and should be burnt under the correct conditions as specified in the waste incineration directive. These conditions are not necessarily the same as the conditions required for burning materials for heat generation. These conditions are sufficiently stringent as to make this process untenable for many growers.

If a waste resource is thought to be a suitable fuel then an exemption from the waste incineration directive can be sought under Article 2 Section 2A of the directive which seeks to classify the material into one of the types shown in the Table 17. For fuels comprising waste that are exempt from the WID:

- PPC does not apply if the rated maximum fuel input of the system is <400kW.
- Section 1.1 Part B of the PPC applies from 400kW to 3MW.
- Section 1.1 Part A of the PPC applies from 3MW to 50MW.

Any installation with a combined thermal input >50MW falls within the remit of the Large Combustion Plant Directive.

Advice from the Environment Agency is that they are contacted to discuss the classification of any potential fuel. Specific recommendations for each case can then be more accurately given.

Table 18 overleaf summarises the information in this section.

Table 18 – WID and PPC regulations as applied to biomass installations

	Plant Size				
Material	**< 400kW**	**400 - 3000kW**	**3 - 20MW**	**20 - 50MW**	**> 50MW**
Fuel not comprising waste	Unregulated under PPC, covered by the Clean Air Act 1993			Local Authority air pollution control (PPC regulations 2000 - 1.1 Part B)	Large Combustion Plant directive applies (PPC regulations 2000 - 1.1 Part A1)
	< 400kW and < 50kg fuel used/hr	**400kW - 3MW and 50 - 1000kg fuel used/hr**	**> 3MW and >1000kg fuel used/hr**	**20 - 50MW**	**> 50MW**
Waste used as fuel exempt from WID	Unregulated under PPC, covered by the Clean Air Act 1993	Local Authority air pollution control (PPC regulations 2000 - 1.1 Part B)	PPC regulations 2000 - 1.1 Part A1		Large Combustion Plant directive applies (PPC regulations 2000 1.1 Part A1)
WID waste - non hazardous (for energy production)	WID applies, PPC regulations 2000 - 5.1 Part A2		WID applies, PPC regulations 2000 - 1.1 Part A1		WID applies, Large Combustion Plant directive applies (PPC regulations 2000 - 1.1 Part A1)
WID waste - hazardous (for energy production)	WID applies, PPC regulations 2000 - 5.1 Part A1		WID applies, PPC regulations 2000 - 1.1 Part A2		WID applies, Large Combustion Plant directive applies (PPC regulations 2000 - 1.1 Part A1)

8 Discussion

The potential for biomass is evidenced by the number of growers who have installed such systems recently. All of these recent installations have been for lower energy ornamental sites. Where CO_2 enrichment is required these growers rely on direct-fired fuel burners installed in the greenhouse for CO_2 enrichment rather than back-of-boiler CO_2 recovery. Biomass has been more popular as a replacement for gas oil based heating systems because of the bigger difference in fuel costs.

This project sought to investigate whether biomass heating could be applied to the higher energy use growing systems such as cut flowers and edible salads. Results show that biomass systems could replace a significant proportion of the heating requirements and that the size of boiler required is significantly smaller than currently installed fossil fuel boilers.

The inability to use the flue gases from biomass boiler for enrichment is a significant barrier to its uptake. At current prices the cost of pure CO_2 is much higher than producing CO_2 by burning mains gas. The 'waste' heat produced by burning mains gas for CO_2 reduces the amount of heat required from biomass and therefore makes the economics less favourable. However, biomass heat could still satisfy 30-60% of the total heating requirement without affecting the availability of CO_2.

The type and quality of fuels is of paramount importance. Moisture contents up to 50% can be acceptable for some fuels but when specifying fuels, moisture contents less than 25% will deliver the best results. Cheap biomass fuels may be a reflection of their local availability and poor quality. Fuels should be chosen with cost, quality, ease of use and reliability of supply in mind.

Boiler technology has advanced significantly from the days of log burners. Modern integrated controls and automatic operation mean that manual intervention is minimised. It must be recognised however that all biomass systems will require greater input compared to gas or oil based systems.

Regulations governing the use of biomass are at best complicated to understand and at times can be impossible to apply. Generally energy crops present the easiest fuel stream to gain approval followed by clean forestry and agricultural residues. Any fuel regarded as a waste by-product will need to be closely scrutinised and it is likely to fall under the jurisdiction of the Waste Incineration Directive. Whilst exemption from WID is possible it is by no means an easy process and failure in the quality of the fuel could result in removal of the exemption.

9 Conclusions

This report has shown that biomass heating is applicable to UK protected horticulture.

- Fuel type & supplier selection is the single most important decision when considering a biomass heating system
- Continued support from the supplier is vital especially during the commissioning/learning phase which may last several months. In-house maintenance skills and continued attention to detail are required to ensure reliable operation
- The ability to use a wide range of fuels/fuel quality will help to future proof the investment and allow more competitive fuel purchasing
- Open buffer heat storage delivers wide ranging benefits and is a key component of any biomass heating installation
- Combined with an open buffer heat store a biomass boiler rated at 35% of the peak heat demand can provide 80% of a nursery’s annual heat demand
- Biomass boilers can supply as much as 60% of the heating demand even on a site where CO_2 enrichment is provided by a natural gas boiler
- The inability to use the CO_2 from biomass boilers for greenhouse enrichment is a major barrier to adoption in the edibles crop sector. Pure CO_2 could be used instead however the cost is prohibitive.
- The best opportunities currently lie where CO_2 enrichment is not required and gas oil is the main heating fuel. As such this is likely to be dominated by the ornamentals sector.

10 Recommendations and further work

This project has shown the applicability of biomass heating to UK protected horticulture. The natural progression of this work would be to monitor some of the recent biomass installations to obtain long-term commercial information regarding their technical and economic performance.

Further work is also required on the release of CO_2 from the flue gases of biomass boilers to improve the viability of biomass heating, especially in the edibles sectors which rely heavily on CO_2 enrichment to improve yields.

Fuel type and quality is of paramount importance to the success of burning biomass as a heating fuel. There is scope for a recognised quality standard for all common biomass fuels, not just woodchip. In addition there is a need for simplification of the rules regarding the combustion of some biomass fuels.

Appendix 1 - moisture content vs. net calorific value of wood

Dry wood i.e. 0 % moisture content			19	**GJ/tonne**
Example cost			40	**£/tonne**
Moisture content	**Net energy value**			**Actual cost**
%	**GJ/tonne**	**kWh/kg**	**kWh/tonne**	**pence/kWh**
0	19.00	5.28	5278	0.76
5	17.93	4.98	4980	0.80
10	16.86	4.68	4682	0.85
15	15.78	4.38	4384	0.91
20	14.71	4.09	4087	0.98
25	13.64	3.79	3789	1.06
30	12.57	3.49	3491	1.15
35	11.50	3.19	3193	1.25
40	10.42	2.90	2895	1.38
45	9.35	2.60	2598	1.54
50	8.28	2.30	2300	1.74
55	7.21	2.00	2002	2.00
60	6.13	1.70	1704	2.35
65	5.06	1.41	1406	2.84
70	3.99	1.11	1109	3.61

Appendix 2 - Biomass fuel cost comparison tables

Air dried log wood		Oil	LPG	Gas	Kiln dried log wood		Oil	LPG	Gas
£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm	£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm
5	0.13	1.35	0.93	3.66	20	0.36	3.93	2.69	10.65
10	0.25	2.70	1.85	7.33	25	0.45	4.91	3.36	13.32
15	0.38	4.05	2.78	10.99	30	0.55	5.89	4.04	15.98
20	0.50	5.40	3.70	14.65	35	0.64	6.87	4.71	18.65
25	0.63	6.75	4.63	18.31	40	0.73	7.85	5.38	21.31
30	0.75	8.10	5.55	21.98	45	0.82	8.84	6.05	23.97
35	0.88	9.45	6.48	25.64	50	0.91	9.82	6.73	26.64
40	1.00	10.80	7.40	29.30	55	1.00	10.80	7.40	29.30
45	1.13	12.15	8.33	32.96	60	1.09	11.78	8.07	31.96
50	1.25	13.50	9.25	36.63	65	1.18	12.76	8.75	34.63
55	1.38	14.85	10.18	40.29	70	1.27	13.75	9.42	37.29
60	1.50	16.20	11.10	43.95	75	1.36	14.73	10.09	39.95
65	1.63	17.55	12.03	47.61	80	1.45	15.71	10.76	42.62
70	1.75	18.90	12.95	51.28	85	1.55	16.69	11.44	45.28
75	1.88	20.25	13.88	54.94	90	1.64	17.67	12.11	47.95
80	2.00	21.60	14.80	58.60	95	1.73	18.65	12.78	50.61
85	2.13	22.95	15.73	62.26	100	1.82	19.64	13.45	53.27
90	2.25	24.30	16.65	65.93	105	1.91	20.62	14.13	55.94
95	2.38	25.65	17.58	69.59	110	2.00	21.60	14.80	58.60
100	2.50	27.00	18.50	73.25	115	2.09	22.58	15.47	61.26

Wood chip		Oil	LPG	Gas	Wood pellet		Oil	LPG	Gas
£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm	£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm
20	0.57	6.17	4.23	16.74	30	0.60	6.48	4.44	17.58
25	0.71	7.71	5.29	20.93	35	0.70	7.56	5.18	20.51
30	0.86	9.26	6.34	25.11	40	0.80	8.64	5.92	23.44
35	1.00	10.80	7.40	29.30	45	0.90	9.72	6.66	26.37
40	1.14	12.34	8.46	33.49	50	1.00	10.80	7.40	29.30
45	1.29	13.89	9.51	37.67	55	1.10	11.88	8.14	32.23
50	1.43	15.43	10.57	41.86	60	1.20	12.96	8.88	35.16
55	1.57	16.97	11.63	46.04	65	1.30	14.04	9.62	38.09
60	1.71	18.51	12.69	50.23	70	1.40	15.12	10.36	41.02
65	1.86	20.06	13.74	54.41	75	1.50	16.20	11.10	43.95
70	2.00	21.60	14.80	58.60	80	1.60	17.28	11.84	46.88
75	2.14	23.14	15.86	62.79	85	1.70	18.36	12.58	49.81
80	2.29	24.69	16.91	66.97	90	1.80	19.44	13.32	52.74
85	2.43	26.23	17.97	71.16	95	1.90	20.52	14.06	55.67
90	2.57	27.77	19.03	75.34	100	2.00	21.60	14.80	58.60
95	2.71	29.31	20.09	79.53	105	2.10	22.68	15.54	61.53
100	2.86	30.86	21.14	83.71	110	2.20	23.76	16.28	64.46
105	3.00	32.40	22.20	87.90	115	2.30	24.84	17.02	67.39
110	3.14	33.94	23.26	92.09	120	2.40	25.92	17.76	70.32
115	3.29	35.49	24.31	96.27	125	2.50	27.00	18.50	73.25

Straw		Oil	LPG	Gas	Miscanthus		Olil	LPG	Gas
£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm	£/tonne	pence/kWh	pence/litre	pence/litre	pence/therm
5	0.12	1.32	0.90	3.57	15	0.32	3.45	2.36	9.35
10	0.24	2.63	1.80	7.15	20	0.43	4.60	3.15	12.47
15	0.37	3.95	2.71	10.72	25	0.53	5.74	3.94	15.59
20	0.49	5.27	3.61	14.29	30	0.64	6.89	4.72	18.70
25	0.61	6.59	4.51	17.87	35	0.74	8.04	5.51	21.82
30	0.73	7.90	5.41	21.44	40	0.85	9.19	6.30	24.94
35	0.85	9.22	6.32	25.01	45	0.96	10.34	7.09	28.05
40	0.98	10.54	7.22	28.59	50	1.06	11.49	7.87	31.17
45	1.10	11.85	8.12	32.16	55	1.17	12.64	8.66	34.29
50	1.22	13.17	9.02	35.73	60	1.28	13.79	9.45	37.40
55	1.34	14.49	9.93	39.30	65	1.38	14.94	10.23	40.52
60	1.46	15.80	10.83	42.88	70	1.49	16.09	11.02	43.64
65	1.59	17.12	11.73	46.45	75	1.60	17.23	11.81	46.76
70	1.71	18.44	12.63	50.02	80	1.70	18.38	12.60	49.87
75	1.83	19.76	13.54	53.60	85	1.81	19.53	13.38	52.99
80	1.95	21.07	14.44	57.17	90	1.91	20.68	14.17	56.11
85	2.07	22.39	15.34	60.74	95	2.02	21.83	14.96	59.22
90	2.20	23.71	16.24	64.32	100	2.13	22.98	15.74	62.34
95	2.32	25.02	17.15	67.89	105	2.23	24.13	16.53	65.46
100	2.44	26.34	18.05	71.46	110	2.34	25.28	17.32	68.57

Wheat		Oil	LPG	Gas	Poultry litter		Oil	LPG	Gas
£/tonne	**pence/kWh**	**pence/litre**	**pence/litre**	**pence/therm**	**£/tonne**	**pence/kWh**	**pence/litre**	**pence/litre**	**pence/therm**
30	0.68	7.36	5.05	19.98	2	0.07	0.72	0.49	1.95
35	0.80	8.59	5.89	23.31	4	0.13	1.44	0.99	3.91
40	0.91	9.82	6.73	26.64	6	0.20	2.16	1.48	5.86
45	1.02	11.05	7.57	29.97	8	0.27	2.88	1.97	7.81
50	1.14	12.27	8.41	33.30	10	0.33	3.60	2.47	9.77
55	1.25	13.50	9.25	36.63	12	0.40	4.32	2.96	11.72
60	1.36	14.73	10.09	39.95	14	0.47	5.04	3.45	13.67
65	1.48	15.95	10.93	43.28	16	0.53	5.76	3.95	15.63
70	1.59	17.18	11.77	46.61	18	0.60	6.48	4.44	17.58
75	1.70	18.41	12.61	49.94	20	0.67	7.20	4.93	19.53
80	1.82	19.64	13.45	53.27	22	0.73	7.92	5.43	21.49
85	1.93	20.86	14.30	56.60	24	0.80	8.64	5.92	23.44
90	2.05	22.09	15.14	59.93	26	0.87	9.36	6.41	25.39
95	2.16	23.32	15.98	63.26	28	0.93	10.08	6.91	27.35
100	2.27	24.55	16.82	66.59	30	1.00	10.80	7.40	29.30
105	2.39	25.77	17.66	69.92	32	1.07	11.52	7.89	31.25
110	2.50	27.00	18.50	73.25	34	1.13	12.24	8.39	33.21
115	2.61	28.23	19.34	76.58	36	1.20	12.96	8.88	35.16
120	2.73	29.45	20.18	79.91	38	1.27	13.68	9.37	37.11
125	2.84	30.68	21.02	83.24	40	1.33	14.40	9.87	39.07

Appendix 3 - Economics

The tables below detail the cost where CO_2 for enrichment is supplied from the flue gases of a mains gas fuelled boiler and from pure CO_2 (Second table).

- Heat demands are based on the nursery case studies
- Installation costs are taken from Figure 20 using the boiler size to establish cost
- Heat storage is assumed to be already installed
- Carbon savings are calculated assuming the biomass fuel is carbon neutral and that the value of reduced carbon emissions can be realised
- Pure CO_2 costs are based on nursery CO2 requirements for 1 hectare

Annual heat demand (MWH)	Gas cost (pre installation)	Oil cost (pre installation)	Biomass installation cost	Biomass fuel required (MWH)	Cost of biomass fuel (after installation)	Total cost of fuel (after installation)	Fuel cost saving	Labour and maintenace	Carbon saving (tonnes)	UK carbon value @ £2/tonne	EU carbon value @ £15/tonne
3460	£ 51,900		£ 260,000	2,972	£ 25,258	£ 32,585	£ 19,315	£ 6,400	565	£ 1,129	£ 8,469
3460		£ 96,111	£ 260,000	2,972	£ 25,258	£ 41,088	£ 55,023	£ 6,400	743	£ 1,486	£ 11,143
4280	£ 64,200		£ 235,000	2,115	£ 17,976	£ 50,454	£ 13,746	£ 6,000	402	£ 804	£ 6,027
5550	£ 83,250		£ 280,000	3,787	£ 32,190	£ 58,634	£ 24,616	£ 6,800	720	£ 1,439	£ 10,793

Biomass installation cost breakdowns with CO_2 from fossil fuel

Biomass installation cost breakdowns using pure CO_2

Annual heat demand (MWH)	Gas cost (pre installation)	Biomass installation cost	Biomass fuel required (MWH)	Cost of biomass fuel (after installation)	Total cost of fuel (after installation)	Fuel cost saving	Labour and maintenace	Carbon saving (tonnes)	Cost of pure CO_2 (£80/t)	UK carbon value @ £2/tonne	EU carbon value @ £15/tonne
3460	£ 51,900	£ 260,000	3,114	£ 26,469	£ 31,659	£ 20,241	£ 6,400	592	£ 12,560	£ 1,183	£ 8,875
4280	£ 64,200	£ 235,000	3,595	£ 30,559	£ 40,831	£ 23,369	£ 6,000	683	£ 33,840	£ 1,366	£ 10,246
5550	£ 83,250	£ 280,000	4,884	£ 41,514	£ 51,504	£ 31,746	£ 6,800	928	£ 28,000	£ 1,856	£ 13,919

Appendix 4 - Sources of information

Sources used in this report have been quoted where used. The following list a number of further sources. However, their inclusion should not be taken to imply any recommendation by the authors of this report or the HDC. The opposite applies to organisations / suppliers not included.

Information

The Biomass energy centre run by The Forestry Commission – a good source of general information.

http://www.biomassenergycentre.org.uk/

Rural Energy – a well established installer of biomass systems and fuel suppliers. Also provides biomass consultancy.

http://www.ruralenergy.co.uk/

National non food crops centre – provides information and advice on energy crops such as rape seed and Miscanthus.

http://www.nnfcc.co.uk

Renewable Energy Association – general advice regarding renewable energy procedures and policies as well as registering renewable energy sites.

http://www.r-p-a.org.uk/

IEA Bioenergy Task 29 – educational website devoted to explaining practical and technological matters regarding biomass equipment.

http://www.aboutbioenergy.info

Biomass equipment manufacturers

http://www.vyncke.com/

http://www.crone.nl/

http://www.binder-gmbh.at/Englisch/Heizanlagen1/auswahlkriterien.html

http://www.linka.dk

http://www.viessmann.co.uk/

http://www.talbotts.co.uk/

Biomass suppliers

http://www.wood-fuel.co.uk/

http://www.mancoenergy.com/

http://www.talloil.se/english.html