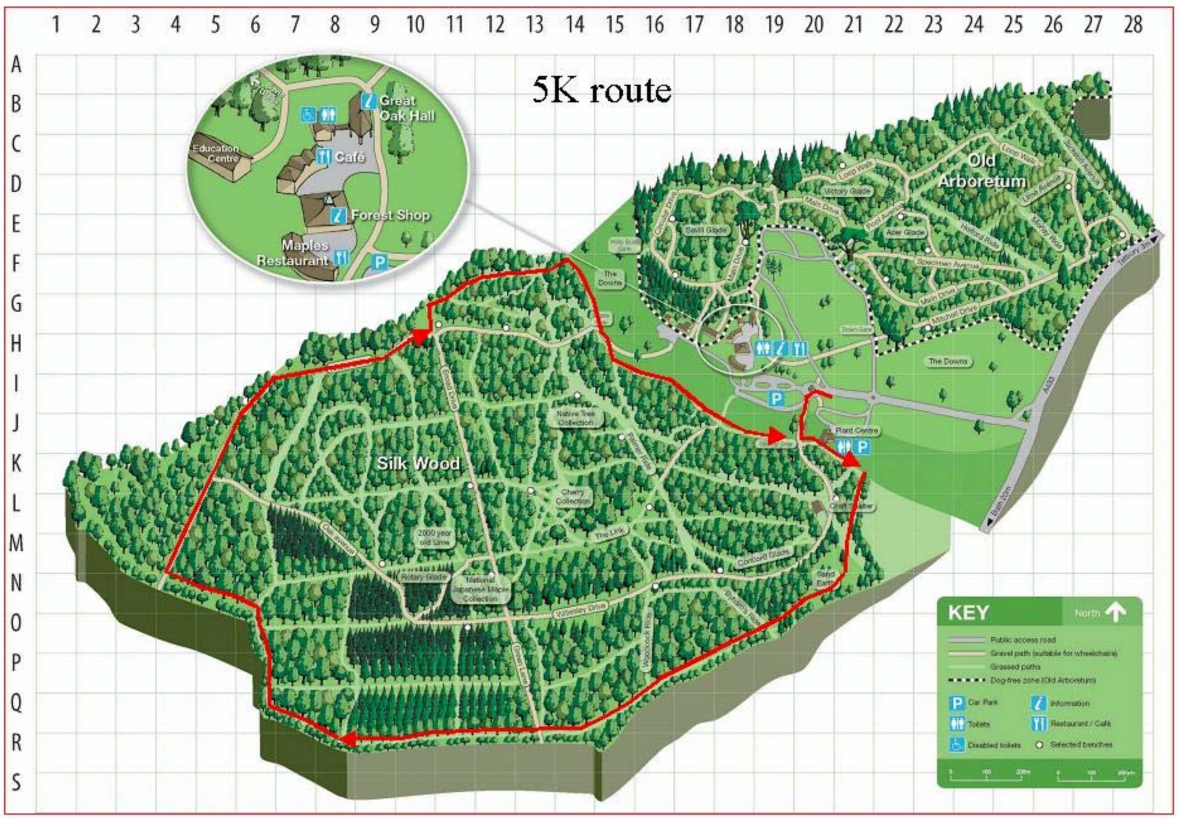
Potential woodfuel CHP plant at Westonbirt Arboretum
Initial feasibility study and technology assessment



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EXECUTIVE SUMMARY

There are a number of commercially available woodfuel CHP systems available with heat output in the range required for this project. It would not yet, however, be appropriate to regard these as commodity items that can be installed in the “fit and forget” manner of a fossil fuel heating system. In order to offer high efficiency at this small scale a range of innovative technology solutions have been developed. Although there are a number of systems of one design or another in operation around the world, any organisation installing such a system must consider itself an early adopter.

The Forestry Commission has a role in supporting and promoting the use of woodfuel in the UK. If this project to install a biomass CHP system were to be undertaken it would have to be in the expectation that this is a pre-commercial system and a certain amount of input and commitment will be required to ensure trouble free operation and that this would be something in the class of an RD&D project for the benefit of the UK biomass market. It is to be expected that there will be financial savings on fuel costs, compared with LPG, gas or electrical heating, also on generated electricity used on site. If an export meter is installed excess electricity generation may even yield an appreciable income. The true value of the undertaking, however, would be far wider in providing a public exemplar of the technology for the benefit of future UK biomass heating and CHP. This project is therefore envisaged as a technical evaluation, rather than as a measure to be justified on purely economic grounds. It can therefore only be undertaken with the assistance of significant grant support.

It has been suggested that a nominated member of Westonbirt staff should be assigned to the installation, though not necessarily full time, and that a part of this person's role would be to document fully operation and performance to allow lessons to be learned from the installation, and make this information publicly known. There should also be visitor access to appropriate parts of the system and quality interpretation of the issues associated with biomass as a low carbon, renewable fuel for heat and power, the woodfuel supply chain and the technologies involved.

There is a small number of different technology choices applicable to the scale of heat required by this project. It is suggested that the optimum choice will depend as much on the details of the specific manufacturers and systems available as on any general consideration, and this can only be assessed by visiting examples of each system in operation, and discussing its operation with those responsible for day to day running. The systems available vary considerably in the ratio of heat output to electricity and fuel requirements for a given heat output.

With a site connected to the UK electricity Grid there is no need for electrical output to match demand on either a moment by moment or annual average basis as the Grid can accommodate any shortfall or excess production. Heat, however, must be used on-site as produced, and consequently specifying the system should be driven by heat requirement, not electricity. Heat is always co-generated with electricity and if not required on site must be dumped somehow, which is environmentally questionable and requires additional equipment.

According to Austrian best practice the system should be specified to meat the heating requirement of average cold winter days, so that it is operating at maximum output, and efficiency, most of the time during winter. The peak demand from the few coldest days should be met by a supplementary, fossil fuel powered boiler(s), which can also provide backup in case of emergency.

It is suggested that operation be restricted to the heating months and, for the sake of calculations this has been assumed to be 5 months at full output, with two months in Autumn and Spring at 50%. Some biomass systems may be operated simply during the working day and shut down at night. Others can be reduced to a low output slumber mode over night to reduce thermal cycling of components.

Depending on which CHP system is chosen, and how it is operated, the annual fuel requirement could be anything from 200 tonnes at 35% MC to over 600. If this were bought in as small round wood (SRW) from the Forestry Commission at £22 per green tonne, dried on site and chipped by a contract chipper, this would correspond to an annual fuel cost of £7,700 to £23,700.

The current total energy spend for the site, based on LPG, oil and electricity, is around £27,000, however, allowing for future development projects this could be expected to rise to £35,000. Most of the biomass CHP systems would be able to meet this entire demand, and there would also be additional income from sale of ROCs (Renewable Obligation Certificates – around £6,000 p.a.) and excess electricity (£28,000 or more p.a., depending on system and annual hours of operation).

In addition, around 200 tonnes of CO_2 would be saved per annum on-site, with additional savings associated with electricity exported of up to 189 tonnes.

The quoted capital cost of the CHP systems vary from €200,000 (about £140,000) to £350,000, however these figures vary considerably in what is included, and all will require significant additional expenditure on building for the boiler and fuel storage, hard standing for drying SRW prior to chipping, salary for an operator, Grid connection, a heat distribution main, project management etc., as well as potentially fuel handling, project planning, a maintenance contract, operator training, installation costs, etc., depending on what is included in the quote. These are likely to lead to a full project cost of between £250,000 and £600,000. It may be decided, as an alternative to making use of local contract chipping and haulage services, to purchase a suitable wood fuel quality chipper of sufficient capacity, suitable agricultural tractor and crane loader, which might add approximately a further £80,000.

It is suggested that the Forestry Commission should take an active role in the fuel supply process both to ensure consistent specifications are maintained and minimise fuel related difficulties, and to gain experience and expertise in this area.

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1. INTRODUCTION

Westonbirt Arboretum is the National Arboretum of the Forestry Commission, providing a very popular visitor centre attracting over 350,000 visitors per year. Usage of the site is shared between the Forestry Commission itself, Maples Restaurant and the Friends of Westonbirt.

As a high profile Forestry Commission site with high annual visitor footfall, it is appropriate to consider whether it could act as an exemplar of the usage of woodfuel. This situation is further enhanced by the fact that, while the site is connected to the main UK electricity Grid, mains natural gas is not available on site and consequently heating is currently achieved through a combination of LPG, oil and electricity. In addition, routine forestry management of the site can be expected to provide a certain proportion of the fuel, though it is anticipated that this would require some supplementary supplies.

The Forestry Commission is keen to encourage the use of wood as fuel for a number of reasons, and the most effective way to do this is to demonstrate successful installations at sites where they can be seen by large numbers of visitors. Possibly the context in which most members of the general public will be aware of the use of woodfuel and other biomass as an energy source is that of greenhouse gas emission reduction, and this is a vital role it can perform. However other benefits, equally valid in different ways, include establishing a local market and supply chain for small round wood (SRW) and low quality forestry co-products of the timber industry. This can provide a much required additional income stream to farmers and woodland owners, helping to promote rural development, and, by providing a market for the products of thinning and maintenance operations, has been shown in other countries to promote better management of woodland.

The Gloucestershire Renewable Energy Action Plan endorses the renewable energy target for Gloucestershire of 40-50 MW of electricity by 2010 proposed in REvision 2010, of which it is envisaged that 5 MW would be derived from woodfuel and energy crops. In addition, although renewable heat targets were not included in REvision 2010 a target of 5 MW of biomass heating by 2010 has been agreed for Gloucestershire. In order to meet these targets the Action Plan proposes a number of priorities, including:

- Awareness raising and provision of information (which should include promotion of practical examples).
- Establishing new renewables projects (including local woodfuel supply and examples of wood fuel projects).

Heating from woodfuel is well established on the continent, in particular in Austria and Scandinavia, where it is a widely accepted and popular energy solution. It is supported in many countries by government initiatives and incentives in recognition of the advantages of biomass fuel over the fossil alternatives, including reduced carbon emissions. This strategy has the ability to keep fuel supply and the associated employment both within the country and within the local rural community at a time when there is widespread difficulty and uncertainty within agricultural and rural communities in many countries across Europe.

The use of woodfuel for heating is also gradually increasing within the UK, mainly on the back of equipment imported from Europe. However, although many installations have been very successful, as is often the case with a fledgling industry, there has been something of a learning curve and mistakes have been made in some cases. It is generally acknowledged that the majority of problems can be traced back to some aspect of the fuel. This is not surprising as, although equipment may readily be imported from one country to another, and operating regimes are not greatly dissimilar, biomass fuels must generally be sourced locally. Consequently a user is dependent upon the local supply chain which may or may not have any experience or understanding of the characteristics required by woodfuel users as distinct from other potential users of wood chips. Where such expertise exists however, woodfuel heating has been shown to work effectively and economically in many installations around the UK.

Wood fuelled CHP, too, is widely and successfully used in mainland Europe. Until recently however, these tended to be combined with relatively large scale district heating installations with a thermal load of a few MW and above. At this scale conventional steam turbine generating technology is a reasonable option allowing the use of well established technologies. At smaller scales, however, electricity generation using conventional steam turbine technologies is much less efficient and economic and, in the absence of a single optimum alternative technology, a number of options have been developed over the last few years. Many of these are now emerging into the market place as commercial offerings.

These new technologies offer the potential for efficient electricity and CHP generation at much smaller scales than previously possible, and commercial systems are being offered by a number of manufacturers. However it must be recognised that they are still at a relatively early stage of deployment with, in most cases, a very small number of installed systems. Consequently, unforeseen difficulties may be encountered and most systems will be to a greater or lesser extent developmental.

2. SPECIFYING THE REQUIREMENT

As has been observed above, the scale of the system required is critical to the technology options available, and these will be discussed fully below. This means that it is vital to undertake an analysis of the current and future requirements of the site and all potential users of the installation before any short-list of potential suppliers can be assembled. While there is no need for this to be precise, it is important to identify correctly the approximate loads for which the system will be expected to provide.

For a site that is connected to an electricity Grid, it is the anticipated heat load that should be at the heart of the analysis as, although a deficit or excess of electricity generation can be readily rectified by the Grid, incorrect heat production is not so readily modified. Although almost all biomass boilers feature some facility allowing modulation of the output to some fraction of maximum capacity, they do not typically operate at such high efficiency, meaning that money is wasted and environmental performance is degraded. For this reason, best practice in Austria is that, instead of specifying the power of a biomass heating system for the maximum performance required, wherever possible it is specified to meet the demand of the majority of winter days and a back up facility included to help meet the peak requirements. This is because the maximum output may then only be required on a very few of the coldest days in the year, meaning that it will be running below optimum for the vast majority of its life. Owing to the ease with which gas, LPG or oil fired boilers may be modulated to provide low output, combined with the relatively low cost of the hardware compared to the costs of many of these fuels, this can be a cost effective solution. This can also be designed to provide some level of back up facility to provide heat for the most important applications in the event of failure of the primary system.

Wood and other biomass burns at its most efficient in a high temperature environment, tending to make equipment relatively large and comparatively expensive for small scale units. It is therefore highly to be preferred that where a number of potential users are grouped in relative proximity, a single boiler is used and hot water distributed to each user. The benefits of this are widely exploited in European district heating schemes which are frequently highly sophisticated, often incorporating detailed heat metering of each user independently. On a site like Westonbirt therefore, as much of the potential heating load should be amalgamated into a single central biomass system as possible. In considering the total load, though, it is intuitively obvious that there is a limit to how far this can be pursued and that while a large additional heat load close to the plant should be included, a small one a significant distance away may not be suitable for inclusion. In Austria, a rule of thumb sometimes employed is that there should be a minimum heat load of 1 kW per metre of additional distance required.

Analysis of the total load of the Westonbirt site is complicated by the fact that there are three distinct users (the Forestry Commission, Friends of Westonbirt and Maples Restaurant) and multiple buildings used for a range of purposes (see Figure 1). In order to assess the total load on-site a combination of approaches has been employed. This has primarily centred around existing energy use as measured by invoices from utilities and fuel suppliers over the past year or so. This approach is complicated by a number of factors. Firstly, while some fuels, such as oil, are exclusively used for heating purposes, others, like LPG and electricity, may be used for a number of purposes such as lighting, cooking, powering equipment, etc. Secondly, such invoices will cover a period of time that may include both cooler and warmer days. While this will prevent the disproportionate inclusion of short periods of unusually cold weather, and hence high power requirement, in the UK a billing period of more than a week or two may be expected to include some relatively warm weather. For quarterly bills the calculated value may be expected to be a significant underestimate of the true power requirement for even quite common low temperatures. Thirdly conversion of kWh used to kW of power requirement depends upon the usage regime. If heating is turned on at the start of the day and off again at the end a ballpark figure of 10 hours per day may be assumed, however if heating is maintained throughout the night, the figure would be 24 hours. Finally, not all invoices were available for analysis. Despite these difficulties, an attempt was made to assess the average demand during the winter months assuming a 10 hour operational day.

Figure 1 A map of the buildings on the Westonbirt site

As an alternative approach, a heating engineer's rule of thumb of heat demand for a typical building is, for top and bottom floors, a requirement of 65 W/m^2. The majority of the buildings at Westonbirt cannot be regarded as typical, in particular the Great Oak Hall, Maples and the shop, all of which have very high ceilings, for which allowance must be made and a figure of 130 W/m^2 has been used. As a result of this, these calculations also cannot be regarded as highly accurate, however, in combination with the approach above, should help to ensure that the numbers calculated represent a reasonable assessment for the purposes of identifying suitable technologies.

In addition to the current accommodation there are also plans for possible future development, and the potential demand from this should be included in the analysis, albeit at a provisional level.

Separate bills were available for the Plant Centre, which is on Economy 7 dual rate electricity. Assuming that the majority of the night time electricity is used for powering storage heaters, and this represents the majority of the heating, a heat demand of around 9 kW could be calculated. From a floor area of 115 m^2, a calculated value of 7.5 kW can be obtained. As the Plant Centre is approximately 500 m from the main accommodation it is therefore clear that it would not be viable to include this in a site heating system, consequently separate provision of some kind will be required.

Independent bills for Sleights are not available, however based on a floor area a heat load of 15 kW can be calculated. Again, as it is around 750 m from the main accommodation, this does not warrant inclusion in the main system.

Calculation of the demand of the Forest Shop based on electricity invoices received give a figure of 12.5 kW. As this is billed quarterly, and the quarter with the highest demand ends in April, this is expected to be a significant underestimate. Based on floor area, and allowing for its ceiling height, a figure of 36 kW is arrived at. A realistic figure for the sake of calculation is therefore likely to be around 25-30 kW.

Maples Restaurant is independently billed monthly and has a wet under floor heating using LPG. Peak electricity usage appears to be around 6,000 kWh per month, with a similar figure for LPG usage. These would correspond to 20 kW for each, however a proportion of the LPG is used for cooking purposes. Based on the floor area, and assuming 130 W/m^2 as a result of the high ceiling, a figure of 31 kW is calculated.

The Great Oak Hall also has wet under floor heating, using LPG. However it is invoiced internally to the Friends of Westonbirt. Based on a floor area calculation, a heating requirement of 25 kW is calculated.

The offices, also, are not independently billed, though from the floor area, a figure of 18 kW can be calculated.

Other current accommodation includes the Education Centre, café, toilets, visitor services, etc., and the total demand of all of these is estimated to be around 20 kW.

Invoices to cover the offices, Great Oak Hall and the Education Centre, etc., give peak LPG usage of approximately 64 kW, oil usage of very approximately 42 kW, plus electricity which would total around 12 kW if it were heating, though the usage is unclear.

Finally, Keepers' Cottage, is estimated to add a further 12 kW to the total.

In addition there is a proposed further 830 m^2 of planned development, including 160 m^2 sawmill, 300 m^2 Tractor shed and Tree Team building and a further 370 m^2 of offices. The Tractor Shed will not be heated, but it is to be expected that the rest will. The new development, if fully realised as anticipated, may be expected to add an additional heat load of around 40 kW, depending on design and operational details.

Based on invoices for LPG gas and heating oil, a current heat requirement of around 130 kW can be estimated. If some of the electricity is used for heating purposes this might increase the total by up to 30 kW out of a peak total electricity load of around 54 kW. There is also a potential additional future requirement of around a further 40 kW of heat. A total requirement, including the future building programme, may therefore be expected to be around 170-200 kW.

The breakdown based on floor area is given in Table 1.

Table 1 Heat loads calculated from floor areas

Building	Area (m^2)	Projected heating (kW @65 W/m^2)	Projected heating (kW @130 W/m^2)	Estimated requirement (kW)
Offices	280	18.2		20
Shop	275	17.9	35.8	30
Maples Restaurant	235	15.3	30.6	30
Great Oak Hall	190	12.4	24.8	25
Sub total				105
Keepers Cottage	185	12.0		12
Education	65	4.2		
Café	50	3.3		
Visitor Services	35	2.3		
Toilets	70	4.6		
Skilling Toilets	40	2.6		
Admissions	5	0.3		
Potting shed	40	2.6		
Sub total		19.9		20
Sleights	230	15.0		excluded
Plant Centre	115	7.5 (11)		excluded
Proposed sawmill development	*160*	*10*		
Proposed Tractor shed and Tree Team building	*300*	*6 Partially heated*		
Additional development	*373*	*24*		
Sub total		40		40
Total				**177**

3. CURRENT BIOMASS CHP TECHNOLOGIES

At electrical outputs above about 1 MW_e (corresponding to around 3 MW_{th} of heat output) conventional superheated steam turbine technology can be used. Alternatively biomass gasification used with a gas turbine in a number of configurations may also be appropriate at high output levels. However, at the much lower heat output required for this application neither of these options is appropriate.

3.1 Organic Rankine Cycle (ORC)

Both reciprocating steam engines and steam turbine make use of the thermodynamic Rankine Cycle. At small scales this becomes very inefficient and expensive owing to the high temperatures and pressures required, however it is possible to replace water as the working medium with an organic compound with a lower boiling point, such as a silicone oil, freon or organic solvent. This allows the system to work more efficiently at much lower temperatures, pressures and at smaller scale. In addition, as the working medium may be much less corrosive to components such as turbine blades, superheating is no longer necessary to prevent droplet formation as a result of pressure drop in the turbine. The turbine can also operate at a lower speed and consequently the whole system can potentially be made more reliable.

CHP systems, including wood fired ones, based on ORC technology are now commercially available from a number of manufacturers, including the Italian company Turboden, however electrical outputs are typically in the range 300 kW_e–1.5 MW_e with thermal to electrical output typically around 5:1, giving minimum thermal output of about 1.5 MW_{th}. This technology is therefore still currently above the scale required for this application.

3.2 Internal combustion engine

Small scale biomass gasifiers exist that can convert biomass into a product gas consisting of a mixture of carbon monoxide (CO), hydrogen (H_2), plus carbon dioxide (CO_2) and a range of small hydrocarbon molecules, such as methane (CH_4). In addition, there will also be a high proportion of nitrogen (N_2) from the air (unless the gasifier is oxygen fed) and, depending on the gasifier design, there may also be tars and particles that may need to be removed. This product gas is a flammable fuel, and can be used for a number of purposes. One of these, following suitable clean up and cooling, is to run an internal combustion engine such as a gas engine or modified diesel or petrol engine.

Many commercial biomass CHP systems operate in this way, at a range of scales from around 10 kW_e to 1 MW_e, and typically give heat to electrical output ratio of 2:1, even down to 1:1, potentially ideally suited to the scale of this application. Gasifiers are, however, inherently more complex than a simple combustion based system and there are a number of areas that can potentially give rise to difficulties.

There are a number of different designs of gasifier and the majority of those intended for use with an internal combustion engine are of down draft (fixed bed) design. These are well suited to this kind of application as tars tend to be cracked to smaller molecules within the gasifier, requiring far less subsequent gas clean up. Good gas clean up is critical to reliable operation of the engine, and this may include a particle filter and/or a cyclone as well as tar removal to protect the engine. Good gasifier design is essential to ensure that maintenance of the filter components is kept to a reasonable level.

Down draft gasifiers, however, tend to require a high degree of consistency in the fuel supply, and cannot readily be scaled up above about 1 MW_{th}. A steady flow of homogeneous fuel is necessary to ensure consistent gas production and fuel that contains a significant proportion of twigs and leaves may not flow sufficiently smoothly. One way to ensure consistency of fuel is to incorporate a briquetter unit into the installation, which can allow the use of a wide range of feedstock, including dried sewage sludge.

This tends to be the most widely available technology to meet biomass electricity generation needs at around 100 kW_e output levels.

3.3 Stirling engine

The Stirling engine is an external combustion engine, in which differential expansion of the working gas (such as air, helium or hydrogen) in hot and cold regions of the engine drive the piston(s). As combustion is external and the system is sealed, contamination can be less of a problem than with an internal combustion engine, and maintenance accordingly eased.

Heat can be provided by direct combustion of biomass, or by combustion of product gas from a biomass gasifier. Owing to the somewhat lower purity requirements for the gas in the latter option, an up-draft gasifier can be utilised, potentially easing the fuel supply constraints.

Stirling engines tend to be available in sizes offering electrical output up to about 75 kW_e.

Stirling engines are less well proven, more experimental technology than conventional internal combustion engines, and they tend to be less efficient, giving rise to a higher heat to electricity output ratio of 4:1 or greater.

A number of manufacturers are offering commercial systems based on this technology, though the number of manufacturers of the engine itself is more limited.

3.4 Steam engine (reciprocating)

Although possibly viewed as rather old fashioned technology, a conventional reciprocating steam engine can be used for electricity generation at a range of scales. It offers the attraction of robust, tried and tested, relatively simple technology, and commercial systems designed for woodfuel CHP applications are available.

Efficiencies tend to be relatively low, however, with a thermal to electrical output ratio of perhaps 15:1, depending on the system and scale.

3.5 Gas micro-turbine

Another, more experimental technology in this application is the use of a gas micro-turbine driven either directly by flue gas, or by air indirectly heated via a heat exchanger. A compressor is required to raise the gas pressure to a suitable value, which requires significant power input.

There are very few micro-turbine based biomass CHP systems in operation at present, and should be regarded as technology still very much under development, however a relatively low heat to electrical output ratio of around 2:1 has been quoted by a manufacturer, suggesting good efficiency.

4. COMMERCIALLY AVAILABLE SYSTEMS

In the light of the calculated heat demand for the Westonbirt site, and the technologies commercially available at this scale, a short-list of woodfuel CHP systems has been drawn up and is presented in Table 2, together with some of the key characteristics of each.

Table 2 Key characteristics of commercially available systems

Manufacturer	Technology	Thermal Output (kW_{th})	Electrical output (kW_e)	Fuel required (kg/hr @ %MC)	Calculated overall efficiency (%)	Max MC (%)	Fuel @ 35% MC (kg/hr)	Fuel for 500 MWh heat (tonnes)	Electricity O/P for 500 MWh heat (MWh)	Annual fuel cost @ £38.60/t £)	Energy costs deferred* (£)	Approx cost quoted (£)
Biomass CHP Ltd.	Down draft gasifier + gas engine	200	130	110 @ 0%	45-57	50	170	425	325	16 400	56 150	260 000
Biomass Engineering Ltd.	Down draft gasifier + gas engine	200	100	100 @ 15-20%	73	20	123	310	250	12 000	50 150	300 000
Innovation Technology Ltd.	Down draft Fluidyne gasifier + IC engine	200	100	100 @ 6%	60	35	145	360	250	14 000	50 150	230 000
Mawera UK Ltd.	Combustion fired Stirling engine	250-300	35	160 @ 50%	77-90	50	123	250	70	9700	32 470	250 000
Stirling Denmark ApS	Up draft gasifier + Stirling engine	145	35	50 @ 25%	90	50	58	200	125	7700	39 125	140 000
Talbott's	Indirect, combustion fired gas micro-turbine	200	90	100 @ 20-25%	76	40	123	310	225	12 000	48 150	350 000
Waste to Energy Ltd.	Down draft gasifier + modified diesel engine	100	100	100 @ 20%	49	20	123	615	500	23 700	70 150	

* Calculation based on calculated heating energy spend of £24 000 p.a. (see text, below) plus electricity produced costed at 12.1 p/kWh (including ROCs at 4 p/kWh) for on-site electricity usage up to 150 MWh and 8 p/kWh for exported electricity above this.

5. OPERATIONAL ISSUES

As outlined above, all the woodfuel CHP systems operating at this output level may be regarded, to a greater or lesser extent, as pre-commercial, development systems. It would be unrealistic to assume that any can be installed with as much confidence as a commodity commercial appliance. However many manufacturers offer guarantees on major components. There is, however, considerable difference in the number of installed examples between different systems, and most manufacturers will invite prospective purchasers to see systems in operation. Talking to the engineer responsible for the system, particularly site staff rather than representatives of the manufacturer, can help to give a realistic assessment of system reliability, performance and maintenance requirements and is strongly recommended.

5.1 Solid fuel usage

Solid fuel tends to be of relatively low bulk volume energy density compared to oil or LPG, and biomass is significantly lower in this respect than coal. This means that large volume storage is required, and high volume feed rates. Storage of woodfuel and other biomass fuels is a critical component of the system and must meet a number of requirements if efficient, long term, low maintenance operation is to be ensured with the minimum of difficulties. The storage receptacle must be sufficiently large to accommodate a sufficient store of fuel. What is deemed ‘sufficient’ will depend upon a number of factors, including the nature of the fuel supply arrangements, the user, staff availability, backup provision, etc. A domestic user, for instance, may wish for deliveries no more frequently than once every two or three months, while a large site with full time support staff may be happy to receive deliveries every few days and will simply require sufficient reserve for one or two weeks. If fuel supply is handled in-house, a significant reserve may be maintained as small round wood (SRW) logs drying under cover, and chipped as required.

5.2 Fuel supply

Problems associated with fuel and fuel supply are at the root of the majority of problems with biomass heating systems in the UK. Fuel, and in particular fuel consistency, can be even more critical for electricity generation, in particular for many gasifier designs. Most systems quote a maximum moisture content (MC) for the fuel, and these are listed for each system in Table 2. Figures of about 35% and above can usually be achieved by air drying, however lower figures are likely to require some form of active drying. Most manufacturers requiring a low MC should be able to incorporate a chip dryer, making use of a small amount of low grade heat from the CHP heat circuit.

If this project is to be managed as an exemplar on behalf of the Forestry Commission it is expected that fuel will be supplied by the Forestry Commission, both from within the Westonbirt site itself, and from other local FC sites. It is envisaged that this will be supplied in the form of SRW that will be stacked, stored and air dried on site before use. When required for use it will need to be chipped to a specification agreed with the equipment manufacturer. There are many wood chippers currently on the market with a wide range of sizes and capacities, however not all are designed for woodfuel applications, and many are not capable of reliably producing suitable chips from all material to be used. Appropriate choice of chipper is vital to achieving good, fuel quality wood chips.

There are therefore various options available. A suitable chipper, or chipping service, can be hired in as required from an organisation such as Gloucestershire Wood Fuels, who have indicated that they would be prepared to do this. Alternatively a suitable chipper could be purchased for the project. As the demand would be very low, this would represent inefficient usage unless some scheme were conceived whereby other local woodfuel users were also able to make use of it on a co-operative basis. It might be possible to obtain funding for this kind of operation from the Bio-energy Infrastructure Scheme when the second application round is opened.

5.2.1 Fuelwood specification

The requirements for SRW for woodfuel are not as tight as those for pulpwood. Significant handling, output and yield improvements can be achieved by imposing a very loose specification of:

- 3-5 m length (mean 4 m)
- 20 cm butt
- 2 cm tip.

Linear storage requirements for the SRW are also reduced compared with a 2.3 m length.

5.2.2 Quantities

Based on an estimated heating requirement of 100% operation for 10 hours per day for the five winter months (November to March) and an average usage factor of 50% for the two months at each end of this period, a total effective annual operating period of 2200 hours can be calculated. Assuming a 200 kW heat load a total annual heat requirement of 440 MWh is assumed. To allow for overnight slumber operation at 10% fuel input, a total equivalent figure of 500 MWh will be used. A detailed energy audit would be required to obtain a more definitive figure, and if winter 24/7 operation was adopted this figure would be significantly higher. In Table 2 we have used the manufacturers' fuel feed requirement figures to calculate the fuel required at 35% MC to generate 500 MWh of heat, and the co-generated electricity output. The annual fuel requirements vary from 200 tonnes to over 600 tonnes, however this last figure may be regarded as somewhat approximate as we have been unable to obtain accurate performance figures.

To give an idea of storage requirements, an estimated annual fuel wood requirement of 500 tonnes at 35% MC is used which is the figure that can be routinely achieved in the UK under an air drying protocol. Some of the systems listed above can take wood at this moisture content (or above) while there are a few which require a lower figure (e.g. 15-20%) which will require that a chip drier unit, making use of some low grade heat from the systems, is included in the system design.

Fuel wood requirement of 500 tonnes at 35% MC corresponds to around 625 tonnes of fresh SRW, or 688 m^3 of softwood (at 1.1 m^3/tonne) or 594 m^3 of hardwood (at 0.95 m^3/tonne). When chipped this will correspond to 1,600 – 1,860 m^3 of wood chips. For a 100 m^2 fuel store filled to 2 m depth, this will represent 8-9.5 fills p.a. If two thirds of this fuel is burned over the six winter months, then over this period refilling will have to be scheduled roughly every month (every 4-5 weeks).

If the fuel store is assumed to be full (200 m^3) at the start of the winter, then there will need to be an additional amount of dry (35% MC) roundwood stored under cover at road side to cover the winter months. If this fuel store were used for wood chips its capacity would be 74 m^3 of solid timber equivalent. If used for a buffer stock of assuredly dry SRW chipper feedstock, its capacity would be 140 m^3 of solid timber. In order to maximise harvesting, transport and chipping efficiencies it is suggested that a mean roundwood length of 4 m, rather than the more usual 2.3 m, is employed. In this case, assuming softwood fuel, for a maximum stack height of 2 m, 70 m of linear, road side stacking space will be required for the winter if the fuel store were used to store chips, or 60 m if it stored additional, dried SRW. If standard pulpwood length of 2.3 m is used, these would correspond to 120 m and 105 m.

N.B. These figures only cover the fuel requirement for the winter months. If a full year's supply were to be delivered in April for summer drying, the total (softwood) linear stacking requirement would be about 125 m for 4 m lengths, or 220 m for 2.3 m lengths, for which roadside hard standing would be required.

5.3 Fuel storage

A potentially significant issue if large stocks of wood chips are to be stored is the risk of fire, particularly from spontaneous combustion. Unless they are very dry, piles of wood chips will start to compost, giving rise to loss of calorific value (energy). In very large piles the heat thus generated can potentially cause spontaneous combustion. Guidelines in different countries vary, but advice is that no pile should be allowed to grow to over 8-10 m in height. In addition, storage of damp chips can give rise to mould formation, and fungal spores can present a significant health hazard if inhaled, so use of a particle mask is recommended.

There is a wide range of different designs of biomass and wood fuel store, however there are a number of characteristics it must exhibit. It must maintain the fuel in good condition, in particular protecting it from moisture. It should be well ventilated to allow the dissipation of any water vapour evaporated off to assist further drying, and to minimise composting and mould formation. It is also important that the design and siting of the store ensures ease of both delivery of fuel into it, and transfer of fuel from it to the boiler or CHP system. If the predominant delivery mechanism is expected to be in a tipper truck, then it is highly preferable that the fuel can be tipped directly into the store if at all possible. This may imply a ramp up to the top level of the store up which the truck can drive, or even an underground store, especially if the CHP system is to be accommodated in a basement, though this can give rise to ventilation and damp issues. Both these options can be relatively expensive, however. Various other options exist, including conveyors, chip blowers, etc., either on-site, or incorporated into specialist delivery trucks.

Other delivery methods will place different requirements on the fuel store. If wood is to be chipped on site it may, for instance, be most convenient to store SRW for drying near to the chip store and chip it directly into the store. There should also be storage for a stock of dry SRW ready for chipping. A proposed woodfuel store design is presented in section 6.4.1.

It must also be possible to extract the fuel into the feed system conveniently. In particular there must be no 'dead' areas from which chips cannot be extracted.

5.4 Operation and maintenance

Solid fuel heating systems inevitably require a higher level of operational and maintenance input than liquid or gaseous fuels for a number of reasons. This is not unique to biomass but in general is even more marked with coal. Even as high quality, even sized, dry wood chips, more mechanical effort is required to transfer a solid than a liquid or gaseous fuel from the storage area to the boiler, and even, potentially, within the combustor itself. If the fuel (either biomass or coal) has surface moisture that tends to cause it to clump together, irregular shapes and sizes of particle, or a significant inclusion of dust, this becomes harder still. Oversize particles, especially of irregular shape not only cause difficulties for flow, they can also bridge across constrictions or angles in the fuel feed line, rapidly giving rise to complete blockage. This must be remedied immediately and sensors in the system can give notice of such problems. Even if a complete blockage does not occur, the change of input energy flow rate associated with different fuel density as a feed of relatively large chunks is replaced with one consisting predominantly of dust, for instance, can change the output power sufficiently to trigger a warning, or even trip the system.

Many biomass heating and CHP systems incorporate a modem to allow remote monitoring of the system by the manufacturer or maintenance engineers or to notify an on site engineer of difficulties or a fuel blockage via a pager.

Mechanical wear and tear of some fuel feed systems, like auger designs, can also require maintenance, however this tends to be less of an issue with wood chips, compared with coal which is a far more aggressive material.

Solid fuel produces ash, which must be periodically removed and disposed of. Wood produces far less ash than coal, however a figure of between 0.5 and 1% can typically be expected, giving rise to a few kilogrammes of ash per tonne of fuel consumed. The majority of this will be 'bottom ash', falling out of the bottom of the grate or gasifier body, depending on the design, with a small proportion of fine 'fly ash', carried out in the flue gas and caught in a filter or cyclone. The ash contains most of the minerals (though not the nitrogen) from the wood, and can often be used as a soil treatment. If there is the potential for heavy metal or other toxin contamination of the woodfuel, however, this will be highly concentrated in the ash and care must be taken with disposal. If 24-hour operation is intended then the system design must incorporate some kind of automated de-ashing to remove ash to a sealed hopper that can be periodically emptied on, perhaps, a weekly basis. Most biomass combustion systems will incorporate some degree of auto de-ashing, to ensure that ash does not begin to obstruct pipe ways, however the system will still need to be periodically shut down to allow removal.

Cyclone, bag house and other flue filters will need periodic emptying, cleaning or replacement. Internal combustion engines running on biomass product gas will usually have a tar filter or scrubber which will also require periodic maintenance or replacement.

Any moving mechanical system will also require routine maintenance to ensure that lubrication, cooling, bearings and wearing surfaces remain in good condition and are cleaned, inspected and replaced as necessary. For an internal combustion engine this may be a reasonably conventional process, however for a Stirling engine or a micro-turbine more specialist attention may be required.

Most system manufacturers offer some kind of maintenance contract, usually in combination with training of site staff for routine operation and maintenance. Other operating models, such as heat supply contracts or a full Energy Service Company (ESCo) exist, whereby not only maintenance is contracted out, but different components of operation, equipment ownership and fuel supply. Given the potential of the Forestry Commission to obtain valuable experience from this project, as well as maintain fuel quality control, it would seem to be preferable for this particular project not to contract out fuel supply.

Whether operation and maintenance is performed by existing site personnel, a specialist, a maintenance contract or some form of heat contract or ESCo, the time and expense required for this must be included in calculations. Based on experience with other relatively experimental biomass systems, however, it is felt to be important that there is a technically competent member of Westonbirt staff who 'has ownership' of the project and is personally committed to doing their best to ensure its smooth operation, and also to evaluate day by day performance. As discussed in the Introduction, it would seem to be very appropriate that a high profile Forestry Commission visitor site with high visitor throughput undertakes to evaluate small scale biomass CHP at this, relatively early stage in its development as a commercial product. This would suggest that the person with responsibility for operation of the system is likely to be the best placed to undertake the routine documentation of system operation.

6. COSTS AND SAVINGS

6.1 Fuel costs and savings estimates

If a commercial wood chip provider was used, they might be expected to be able to deliver suitably chipped fuel at £45 per tonne at 35% MC. Although net calorific value (CV) per oven dried tonne varies between hardwood and softwood, between different tree species, and even (quite significantly) between different parts of the same tree, an average value for softwoods (as are likely to form the bulk of the fuel for this installation) may be taken as 18 MJ/kg (at 0% MC). Net CV at other values of moisture content can be calculated by including the latent heat of vaporisation of water (2.26 MJ/kg). £45 per tonne at 35% MC corresponds, therefore, to around £4.10 /GJ, or 1.5 p/kWh of delivered energy.

If woodfuel is sourced from within the Forestry Commission at £22 per green tonne (fresh, delivered roundwood at 50% MC), this would correspond to £28.60 per tonne at 35% MC. If a contract chipping service were employed at a rate of £10 per tonne, this would increase it to £38.60 per tonne, and be equivalent to £3.54 /GJ, or 1.3 p/kWh. If FC harvesting costs were not charged, but contract delivery and chipping were, then this figure would be reduced to 1.1 p/kWh.

In comparison, based on recent prices, oil is costing 4.4 p/kWh, LPG 5.7 p/kWh and electricity 8.1 p/kWh (all excluding VAT).

Calculations of fuel cost savings must be based on actual current usage plus expected additional usage from proposed new building projects. With a woodfuel CHP system, however, the operation regime may well be different, with the possibility of 24 hour operation, compared to a current daytime only heating regime, or overnight slumber mode. It is therefore not appropriate simply to perform calculations based on predicted units of heat produced. Excess electricity production is expected to be exported to the Grid and sold, and consequently all electricity produced can be given a value.

Actual fuel cost savings will vary from one CHP system to another, depending on the efficiency (compared to that of the previous system(s)) and the ratio of electricity to heat output. They will also depend on operational details such as whether the system is operated 24 hours per day, or simply during the occupied hours. Relative running costs (including maintenance, disposal of ash, consumables, etc.) compared to the previous system should also be taken into account for a full detailed analysis.

In Table 2 the total annual fuel costs to generate 500 MWh of heat are calculated (bearing in mind the caveats above concerning the fact that this figure is almost certainly an overestimate), based on the figure of £38.60 per tonne, for FC supply and contract chipping at £10 per tonne. It can be seen that the annual costs vary from £7700 to £23 700.

Although 500 MWh of heat generation have been used in calculations of fuel usage, in calculating deferred heating costs only actual heating of current buildings has been assumed, with similar operation in proposed new buildings.

Invoices obtained for the relevant buildings yield a current total annual energy spend of around £27 000, which includes around £11 000 for electricity, a proportion of which is currently used for heat, with probably the majority used for non-heat applications. This corresponds to around 420 MWh, of which 115 MWh are electricity. Not included in these totals are Keepers' Cottage and a planned future development programme, leading to an estimated additional 52 kW of heating load and perhaps an additional 100-150 MWh of energy. At the lower heating cost of oil this would add a further £4400-£6600. A total predicted energy spend on heat of very approximately £24 000 can be calculated, which will be deferred by the CHP system.

In Table 2 the total deferred energy costs range from £32 470 to over £70 000. Electricity used on-site is costed at 8.1 p/kWh, plus 4 p/kWh from Renewable Obligation Certificates (ROC); electricity exported through the Grid via an organisation such as Smartest Energy would only be worth around 8 p/kWh, including ROCs (see Section 6.2). Current plus predicted future on-site usage is assumed to be 150 MWh.

6.2 Electricity savings and Grid connection

Westonbirt is already connected to the main UK electricity Grid. This offers two advantages. Firstly, any deficit or excess in electricity production can be buffered by the Grid. Secondly, there is the possibility that any excess production can be sold for financial return. However, since there is currently no feed-in premium tariff for renewable electricity in the UK, as is found in many other European countries, it is always preferable to consume as much generated electricity on-site as possible before exporting any to the Grid.

All renewable electricity is, however, eligible for ROCs, whether it is consumed on-site or exported. These do not have a fixed value, but are currently worth around £40 /MWh. Some utilities formalise this into a scheme whereby they offer a fixed rate for the electricity, again, whether it is consumed or exported, in exchange for the ROCs. The Good Energy Home Generation Scheme operates on this basis and currently offers 4.5 p/kWh. This removes the onus on the user to submit monthly generation data to Ofgem to claim the ROCs.

In addition to ROCs, LECs (Levy Exemption Certificates) may also be credited for ‘good quality CHP’ and Renewable Source Electricity (RSE), and these may also be traded, separately from the electricity itself. The current price is about £4.30 /MWh.

Finally, any electricity excess to site requirements may also be sold at a rate depending upon the purchaser. This requires a settlement export meter that will measure the number of kWh exported to the local distribution network. This will be subject to a lease fee payable to the local meter operator. In addition there is liable to be a one-off connection charge from the local distribution company. In the case of Westonbirt, the local distribution company is SSE Power Distribution, who have been approached to evaluate the likely approximate cost entailed by exporting electricity to the Grid. They have estimated the cost for conversion of the current 11,000 V overhead line to three phase, establish a transformer station and make a suitable connection to the generator as in the range £35 000-£40 000, however there could be additional costs associated with obtaining permission from land owners.

Smartest Energy currently pay around 3.5 p/kWh for electricity exported to the Grid, plus 0.43 p/kWh for the LECs, as well as around 4 p/kWh for the ROCs for all the electricity generated. This means that electricity used on site, in addition to defraying the full cost of purchasing electricity at around 8.1 p/kWh, will also bring in 4 p/kWh, while electricity exported will raise a total of around 8 p/kWh.

While this is not nearly as much as is offered for renewable electricity under some EU feed-in tariffs, it can still amount to a significant sum over the lifetime of a CHP system. Several manufacturers quote expected annual operation of 8,000 hours. If 8,000 hours of 100 kW_e electricity generation were all used on site it would defray around £65 000 of purchased electricity, as well as raising £32,000 from the sale of ROCs, giving a total of £97 000. This would require 24 hour operation for 333 days a year, or a 90% overall availability, year round.

The 800,000 kWh of electricity would, however, exceed the total requirement of the Westonbirt site, and also a significant proportion would be at night when the demand is very low. In addition, it would imply year round generation of electricity. This is necessarily accompanied by heat generation and summer heat requirement is minimal. If this were to be done then any heat generated at this time would need to be simply dissipated, requiring some form of heat dump equipment.

Although wood is a low carbon fuel it is not carbon neutral, owing to the energy input required for planting, maintenance, harvesting, transport and comminution. It also does release carbon dioxide (CO_2) into the atmosphere during combustion and although this does not constitute a net addition compared to that recently absorbed during growth, in contrast to fossil CO_2, it does constitute conversion from sequestered carbon. Electricity generation should therefore only be undertaken when there is also a demand for heat, and reduced when heat demand reduces by modulation the output.

Consequently the deferred energy costs in Table 2 have been calculated based on 500 MWh annual heat requirement, and the electricity co-generated with this heat is listed. For the 35 kW_e Stirling engine based systems the total annual electricity output is less than the predicted annual electricity requirement of 150 MWh, and it will be necessary for the Grid to supply the difference. For the other systems there will be a net annual surplus. It must be remembered, however, that for any system there will be instantaneous surpluses and deficits depending on how it is being operated at the time.

For the smallest Stirling engine based system, the electricity is predicted to yield a value of £8470 p.a. Larger systems will displace the predicted output of 150 MWh p.a., up to a value of £18 150. Additional output will need to be exported to the Grid, and would yield, through Smartest Energy, a value of around 8 p/kWh, with a greatest additional value of £28 000, giving a total value from electricity of £46 150 p.a.

6.3 Carbon savings estimates

In a similar way to calculations of fuel cost savings, carbon savings must be calculated on actual current usage, plus planned new buildings, and compared with expected usage pattern of the new CHP system. Current energy usage has been estimated as 205 MWh p.a. LPG, 100 MWh oil and 120 MWh electricity (assume 20 MWh, for heat). A new building programme may be expected to add a further 100-150 MWh of heat to this (assume oil, as above), and perhaps 50 MWh of electricity.

Carbon dioxide emission from the use of a given fuel consist of both the direct emissions from combustion and those associated with the total production and life cycle. In the case of fossil fuels these latter contributions add to the total, however in the case of woodfuel and other biomass, although energy is required for cultivation, woodland management, harvesting, transport etc., the CO_2 absorbed during growth of the biomass means that total life cycle CO_2 emissions, although not truly carbon neutral, are still significantly lower than those associated with combustion.

Various studies have tried to assess these life cycle emissions for various energy forms, including a study from Sheffield Hallam University, performed under the DTI Sustainable Energy Programme. It includes figures for both oil and UK Grid electricity, as well as natural gas, though not for LPG. As the total life cycle emissions of both oil and natural gas are of the order of 20% higher than the simple combustion emissions, this correction has been applied to the simple combustion figure for LPG.

Table 3 Carbon dioxide emissions from different fuel options

Fuel	Life cycle CO_2 emissions (kg/MWh)	Predicted annual fuel consumption (MWh)	Annual CO_2 emissions (tonnes)	Annual cost (£)
Oil	313	280	87.6	12 300
LPG	250	205	51.3	11 700
Electricity (UK Grid)	540	150	81	12 200
Total		**625**	**219.9**	**36 200**
Wood	5	1000–3100	5.0–15.5	7700–23 700

Based on these figures, and the energy consumption figures (Table 3) (including allowance for new buildings, assuming oil heating) a total CO_2 annual emission figure of 220 tonnes CO_2 can be calculated. The amount of wood required depends on the specific system selected. Using the range of figures from Table 2, of 200-615 tonnes @ 35% MC, this corresponds to a range of emissions of 5.0-15.5 tonnes of CO_2. It is also appropriate however to include the contribution of any excess electricity exported to the Grid. Although this will not reduce the CO_2 emissions of the Westonbirt site, it will contribute to a reduction in UK emissions. Depending on which CHP system is chosen, and hence how much electricity is generated, this could be up to 350 MWh (189 tonnes CO_2).

6.4 On site infrastructure requirements

6.4.1 Woodfuel storage

It is suggested that woodfuel storage would be in a four bay, standard agricultural steel frame Dutch Barn type building of the following specifications:

- 5 m to eaves (to allow for specific vehicular access and unloading operations)
- Each bay to be *c*. 5 m wide.
- Depth of building *c*. 5 m.
- A concrete floor throughout i.e. *c*. 100 m^2.
- Building to be sited with longitudinal axis close to east/west as possible.
- Northern, western and eastern facing sides to be walled up to 2 m height between steel uprights. Wooden railway sleepers with intermediate steel supports are best; but pre-formed concrete silage clamp sides are an acceptable alternative.
- Standard agricultural, York boarding type vertical cladding above 2 m to eaves height on northern, western and eastern sides (or similar that allows for good airflow).
- Roof to overhang (at least on the southern facing side) by 1.5 m to allow for driven rain penetration protection.
- If also used for roundwood storage, the two gable ends should each be provided with 2 x 2 m height RSJs (*c*. 5") to support the thrust weight of timber stacks.

Prices for this tend to vary widely throughout the UK. Such a building might cost *c*. £10 000–£15 000 erected.

Total capacity of such a building would be *c.* 200 m^3 of chipped wood (max.), equal to *c*. 74 m^3 of equivalent roundwood volumetric measure. At 35% MC this would be *c*. 788 GJ of input energy, or *c.* 219 000 kWh.

The best use for such a building would be for the storage of a buffer stock of dried roundwood, for chipping during the wetter winter period (November to April) as this would then contain a greater energy store. If used exclusively for this purpose, the side walls and cladding could be omitted, but the roof overhang should be on the northern side as well.

Immediately adjacent to the boiler plant area, a silo of wood chips will be required, from which fuel is fed directly to the boiler. This in turn is fed from the fuel storage barn.

The boiler plant area may be planned into one enclosed bay area; in which case the fuel storage area will be reduced by 25%. If this is chosen, a walking floor type of chip feeding system employing a scraper, such as that used at the West Dean site at Chichester, is better suited to operations than a rotating agitator with sprung arms. As some of the possible CHP systems have a footprint larger than the 5 x 5 m allowed by this layout, either a separate, adjacent boiler room could be employed, or the overall size of the Dutch Barn could be increased accordingly. If bays were significantly larger than the size suggested, or there was a requirement to make them rectangular then again a walking floor arrangement would be required.

If a walking floor feeding system is not possible, then the building and chip replenishment provisions become more complicated. For example, the chip store will need to be totally enclosed on all sides, to a height of 2.5 m, and also be of a construction to prevent leakage of chips. There will also need to be a suitable ramp and reception system created for the tipper unloading of chip deliveries, such as from HGV or agricultural truck/trailer. NB Any chip storage must be rain-proof.

Storage of SRW prior to chipping must be on bearers (to permit air circulation beneath) on hard standing, with stacks on an east-west alignment. Stacks should be covered with a well secured tarpaulin or strong plastic waterproof sheet, and will require regular checking for signs of damage or vandalism. The whole area will need to be securable to allow unloading, handling and chipping operations to be carried out without public access.

If local roundwood storage and chipping is to be used, deliveries are best handled by means of standard agricultural silage trailers, which can readily be contracted in. A good chipper and efficient loading set-up can fill a two wheel silage trailer in around half an hour, so a sufficient number must be available to keep a contract chipper busy and minimise idle time.

6.4.2 On-site operator

It has been proposed that a technically competent member of staff at Westonbirt be allocated responsibility for day to day operation, maintenance and monitoring of the installation. Although this is unlikely to require full time attention once the system has fully bedded in and has been operating for a while it is realistic to expect that, following initial commissioning of the system, there will be a period of learning and optimisation of the *modus operandi* required for reliable routine operation, and this is likely to take up a larger proportion of the operator's time than will be required after the first few months of operation.

If the Forestry Commission commits to installing such a system that could perform an extremely valuable role as an exemplar of what is currently still very much pre-commercial technology, it also important that it commits to making the lessons learned from the project available to both other potential woodfuel users, and the UK biomass industry and that operation is therefore thoroughly documented and published. This should include providing visitor access and quality interpretation of the system and the associated issues such as the use of biomass and woodfuel for low carbon heat and power, the woodfuel supply chain and the technologies involved.

It is therefore expected that an operator will be expected to be required full time during the initial stages of the project, but that time commitment could be reduced as is felt appropriate after a time.

6.4.3 Other potential expenses

- Contract local chip haulage by agricultural silage trailer system. It is estimated that one day per month, in winter, would suffice for silo refilling. Estimated requirement would be for two tractors with drivers and two wheeled silage trailers running a shuttle service for one working day. A total of 8 hours each (including placement) at *c*. £15 per hour = £240 per winter month period (November to March). There would be some similar work outside this period, but with the CHP plant estimated at approximately 50% downturn for a further two months at each end of the season, plus some out of season operations, we can estimate approximately half the above work load, around £120 per month, giving a £2160 p.a. total.
- Provision and installation of underground heat distribution mains to cover the site, from a combustor placement in the woods to the north west. Some previous Forest Research work has given a mean figure of £100 per linear metre installed, but this would depend upon variable factors such as existing underground and trafficking considerations. For just the main block of buildings at this complex, i.e. excluding the plant centre, an estimate of 400 m could be reasonable, giving a total cost installed of *c*. £40 000.
- An FC owned chipping and timber handling facility may be a desirable alternative option rather than depending on contract chipping for essential supply frequency and chip quality. In which case, it may be considered that this would be a key function of the specific operative's duty, as it would take only a relatively small part of monthly hours. Consequent machinery investment could be:

– A suitable agricultural tractor arrangement e.g. 100–120 hp Valmet agricultural tractor with a reverse driving position capability *c.* £40 000.

– A linkage mounted hydraulic crane/loader of *c.* 4.5 m reach, that would leave the hitch free = c. £8000.

– A towable chipper, proven to give the desired chipping quality, from small roundwood up to 20 cm butt diameter = *c.* £ 25 000.

– The cost of operative training should also be included (two weeks plus travel and accommodation) *c.* £4000.

- Practical and objective input into the fuel supply system organisation, installation, start-up and consolidation. This is essential to ensure the system operates at maximum efficiency from the outset. The alternative would be to attempt to try and develop a protocol after the system is already in operation. Technical Development expertise can provide help with this; 10 days at £410 = £4100.

6.5 Project management

The complexity of this project is considered beyond that which would normally be within the remit of Forestry Commission Land Agents, and consequently it should be placed with a professional project management body. This need not be a specific woodfuel company as only those project issues directly associated with the woodfuel combustion equipment requires the services of a specific woodfuel energy company.

Woodfuel supply chain decisions can be assisted by Forest Research Technical Development, and it is important that these matters are considered from a very early stage. There are four basic models to be considered.

1. An Energy Service Company (ESCo) owns, operates and maintains the equipment as well as sources and handles all fuel supply. This would require least input from Forestry Commission staff, however it gives the least benefit, both financial and in terms of undertaking a working case study under FC management, with FC fuel supply chain. It is also a model that is not yet as well established and proven in the UK as in other European countries.
2. A local woodfuel supplier would supply suitable quality wood chips as required at a commercial rate. Maintenance and management of the CHP system to be the responsibility of the manufacturer/installer, with a suitable member of the on-site staff trained for day to day maintenance. It has also been proposed that (s)he should undertake monitoring and documentation of system operation and performance and the regular publication of public reports.
3. Forestry Commission to supply suitable SRW supplies; Contract chipping and contract local haulage. Again maintenance and management of the CHP system would remain with the manufacturer/installer, with a suitably trained member of staff providing day to day monitoring, maintenance, support and documentation.
4. Forestry Commission to handle all fuel supply operations in house, including haulage and chipping. Once again maintenance and management of the CHP system would remain with the manufacturer/installer, with a suitably trained member of staff providing day to day monitoring, maintenance, support and documentation. This option would require the purchase or lease of a suitable wood chipper. As this installation alone would not be expected to provide a high usage load factor for such a chipper, it would suggest that it either be made available to other local woodfuel projects on a commercial basis, or actually used to establish additional local woodfuel supply chain infrastructure.

In view of the position of the Forestry Commission, and the potential value of being able to keep control of fuel quality, as well as demonstrating best practice, it is proposed that options 3 or 4 would be the most appropriate and valuable.

6.6 Grants and support

There are national grant or support programmes that might be of relevance to this project.

DTI Low Carbon Building Programme (LCBP): Launched in April 2006 as successor to the Clear Skies and Solar PV grant schemes. Phase 1 of the LCBP has funding streams for household, community organisations, housing associations, schools, not for profit and for private businesses, for which there is £28.5 million. The Energy Saving Trust is Programme Coordinator for Phase 1 and bio-energy is specifically mentioned. It includes two streams: Stream 1 for smaller schemes (grants up to £30 000); Stream 2 is for medium and large scale micro-generation projects. Phase 2 has £50 million and is managed by the Building Research Establishment (BRE). Information is expected to be available from November 2006.

Community Renewables Initiative (CRI): A scheme from the Countryside Agency, now co-ordinated by the Severn-Wye Energy Agency, to provide advice and support for community groups planning renewable energy schemes, including schools, offices, farms, community halls, etc.

DTI Technology Programme: Intended to stimulate research and development between UK firms and research establishments, 25% grants available for near market or exploitation projects. Grants are accessed through Knowledge Transfer Networks (KTNs).

Bio-energy Infrastructure Scheme: A grant scheme to farmers, foresters and businesses to help develop the supply chain for woodfuel, and energy crops. Provides grants to assist the purchase of capital equipment and also for the purchase of storage and hard standing facilities. Currently closed to new applications but a second application round is intended.

7. RISKS

As has been explained above, in order to be able to achieve relatively efficient biomass fired CHP systems operating in the sub 1 MW_e output range, some aspect of the technology is relatively novel and must therefore be viewed, to some extent at least, as under development. There is likely, therefore, to be some element of technical risk associated with any of the systems included in this report.

The potential impact of this risk will depend upon which component of the system is least well established. Some of the systems listed above make use of conventional combustion technology, combined with novel generating equipment, such as a Stirling engine or a micro-turbine. Other systems use more conventional generating technology, such as an internal combustion engine, but drive it with the output from a gasifier. While there is always the potential for operational difficulties to be encountered with any such equipment, it is reasonable to expect that the greatest likelihood of problems may be found with the more novel technology.

If fairly standard combustion technology is employed, with more novel generating equipment, then should difficulties or a failure be encountered, the most likely outcome would be loss or reduction of electricity generating capacity, but, depending on the design of the system, it is possible that a proportion of heat output might be maintained. Although reduction or loss of electrical output would reduce the economic benefit from this component, for a Grid connected site this would simply entail the temporary purchase of Grid electricity until the system has returned to operation. Depending on the design of the system, not all may be capable of delivering heat in the event of failure of the generating equipment and if this is to be included as a criterion for selection of a specific system it should be established clearly with the manufacturer before a final decision is made.

If novel gasifier technology is employed then any difficulties experienced with this component of the system, this could result in loss of both electrical output and heating to the site, or reduced output in both. It has been proposed that some or all of the existing fossil fuel powered heating be retained to provide peak output for the few winter days of maximum heating demand. This would allow the main system to be specified to operate at close to maximum output (and hence maximum efficiency) for a much larger proportion of the year.

This capability could also then act as a backup heating system in the event of failure or under performance of the biomass system, for whatever reason.

In addition to consideration of the likely result of difficulties or failure of a system component, thought must be given to the likely ease with which it may be rectified. If a conventional internal combustion engine is used, for example, replacement components such as seals, bearings etc. may be more readily obtainable than those for a more exotic design, such as a Stirling engine. It is also more likely that they can be fitted by an on-site or local engineer rather than having to call in an engineer from the manufacturer.

Against this, however, must be set the fact that a Stirling engine has been designed to provide a robust, lower maintenance system, in some cases hermetically sealed, potentially even to the extent of having the generator built into the crankcase, optimised for low maintenance use in this environment. By contrast an internal combustion engine may be operating with a fuel for which it was not designed and may have been modified from its original design. Equally, though gasifier technology may be regarded as currently more experimental in this application and at this scale, gasification of biomass and coal has been undertaken successfully for many decades. Even conventional biomass combustion systems can encounter problems if the fuel does not meet the specification for which it was designed.

It must be stressed that the best way to assess the reliability of a given system is to see one or more systems in operation and discuss with those responsible for day to day operation, if at all possible personnel with no connection with the manufacturer. While difficulties and the occasional breakdown may be expected in the early days following the installation of a system, a great deal can be learned about the robustness of the system, and the attitude of the manufacturer in this way. The manufacturer should be able to provide information on the design maintenance schedule, but it is important to gauge how close this is to the requirements in practice. Particularly, a representative sample of the fuel that is to be used with the system should be shown to the manufacturer to ensure that both parties are entirely clear on what is to be used.

It must also be understood that with the market for such devices, and even for biomass heat in the UK, in a very immature state, the potential for manufacturers and suppliers to encounter financial difficulties and go out of business is relatively high. If this were to happen it might make obtaining support or spare parts for an installed system difficult. It might happen that parts and assets are transferred to another company and engineers continue to provide support under a different organisation, however they might not, so an assessment of what consumables, parts and maintenance tasks could cause difficulties if this were to happen should be undertaken as part of the process of choosing a system.

In addition to the potential for failure of such a system to leave the Westonbirt site without heat, unable to achieve the anticipated income from electricity savings/sales, or to incur unexpected additional financial outlay, there is the, ultimately potentially more far reaching risk of a high profile biomass CHP project failure. While a high quality, successful exemplar of biomass technology will certainly prove valuable to the biomass energy market and industry, a high profile failure, for whatever reason, would be disproportionately damaging, and far more widely known! All reasonable steps must be taken to avoid this if at all possible and it must be accepted that this may mean additional expense to err on the side of caution and ensure corners are not cut for the sake of (potentially false) economy.

As has already been mentioned, the most common cause of difficulties and failure of biomass heat systems is poor quality or inappropriate fuel and it will be even more important if a gasifier design is chosen. It is therefore vital to ensure that there is good mutual understanding between the appropriate member(s) of Westonbirt/FC staff and the manufacturer of the selected system which fuel is to be employed and acceptable range of specifications. Once agreed, whatever system is used for fuel supply, it is vital that all fuel accepted for use meets that specification. This is likely to require a high level of monitoring, at least in the early stages, and in-house supply may be the easiest way of ensuring consistent quality.

To summarise, the major risks are:

- At the scale required all biomass CHP systems employ at least some technology that is at a relatively early stage of development.
- This may therefore fail to perform as expected or fail entirely, potentially leading to:
  - loss of electricity production (impacting the economics)
  - loss of heat (requiring use of a backup heating system)
  - significant damage to the UK biomass energy market development.
- With an immature market there is a risk of manufacturers or suppliers going out of business. With highly specialised, novel equipment, if this were to happen it might be difficult or impossible to obtain consumables, spares or maintenance support.
- If fuel supply is outsourced there is the possibility that it fails to meet the required specification, or suitable supply is interrupted.

8. CONCLUSIONS AND RECOMMENDATIONS

Systems

There are a number of commercially available woodfuel CHP systems of the capacity required. It must be recognised at the outset that all available systems at this scale incorporate technology that is relatively unproven. If this project is undertaken it must be understood to be more in the nature of a study than purely the installation of a capital equipment upgrade. There are risks associated with this project and they have been outlined above.

Project

It could potentially be very valuable for the Forestry Commission to set an example in this pre-commercial phase of development of biomass CHP by taking on the risks associated with experimental technology with a commitment to making it work. There must, however, be full commitment to the success of the project as failure could have an extremely negative impact on market development.

It is recommended that a technically competent member of Westonbirt staff be allocated to the project, initially full time though this could subsequently be reduced, to monitor, evaluate and document the whole process of installation, commissioning and day to day operation to allow other potential users to benefit from the experience obtained, and also to learn from any mistakes made. This could be done in a number of ways, such as via periodic reports or postings on the Westonbirt web site, or even in the form of a blog. If this were to be done, it would require full consultation with the manufacturer of the system to be installed and all relevant personnel at the outset, to ensure that everyone involved is fully aware of, and supportive of the initiative.

It is suggested that the complexity of this project is beyond that which would normally be within the remit of Forestry Commission Land Agents and that project management should be placed with a professional body with suitable expertise.

Fuel

A consistent supply of fuel that meets a specification agreed with the CHP system manufacturer is critical. In order to ensure this, and also to allow the Forestry Commission to build up experience and expertise in the supply of quality woodfuel, it is recommended that the FC is closely involved with the fuel supply. This could either be by undertaking the whole process in-house, including supply of suitable SRW, drying, chipping and haulage, or by outsourcing some aspects to trusted local contractors with suitable expertise, such as chipping or haulage. Monitoring of chip quality will still be important.

Annual fuel requirements are expected to be around 400–1000 tonnes at 35% MC, depending on system chosen.

Suitable hard standing to allow for on site drying of SRW, and weatherproof buildings for storage of dried fuel as well as for the CHP system itself, will be required. They must be sited and designed for ease of access, delivery and handling.

A loose SRW specification is proposed, of average 4 m lengths, with a 2 cm tip to give improvements in yield and handling efficiency. At this length, 500 tonnes would require 125 m of linear road-side stacking space. At a standard pulpwood length of 2.3 m, 220 m would be required.

Heat

Biomass combustion/gasification equipment tends to be relatively large and expensive at small scale and requires significant fuel handling equipment. It is therefore significantly more efficient to install a single system to service as large a heat load as possible within an economic distance of a central plant. The Plant Centre and Sleights are not near enough, but all other current and planned buildings on site could be included and the estimated approximate total heating requirement is 170–200 kW. An accurate energy audit will be required to ascertain the exact requirement.

The construction of a heat distribution main will entail additional expense and significant disruption.

Electricity

Equipment specification should be dictated by the heat demand, not electrical output. The Westonbirt site is connected to the UK electricity Grid and costs of electricity export are being investigated. Any deficit can be made up from the Grid and it is expected that any excess production could be exported, which should provide income.

Technologies

At the heat scale required, potentially suitable available biomass CHP technologies are:

- Biomass gasifier providing fuel gas to run an internal combustion engine (gas engine or converted diesel engine); four potential commercial systems.
- Stirling external combustion engine using heat from direct biomass combustion or fuel gas from a biomass gasifier; one system of each available, using the same engine.
- Gas micro-turbine driven by air indirectly heated by biomass combustion; one potentially suitable system is available.

9. Acknowledgements

Carbon Plan Ltd.

The Carbon Trust

The Centre for Sustainable Energy Bristol

Combined Heat and Power Association

Danish centre for Biomass Technology

DEFRA

Econergy

Gloucestershire Wood fuels

Good-Energy

NFU

Regen SW

Renewable Heat and Power

Royal Agricultural College, Cirencester

Rural Enterprise Gateway Knowledge Network

Scottish and Southern Power

Severn Wye Energy Agency

Smartest Energy

S.W. Woodland Renaissance.

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NB Any of these can be supplied on request in pdf format.

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Manufacturer information

Biomass CHP Ltd., Londonderry, NI

Contact details

Unit 27, Templemore Business Centre, Northland Road, Derry City, Co. Londonderry BT48 0LD

www.exusenergy.com

brianw_at_b9energy@hotmail.com Brian Williams, Technical Director

Systems

Downdraft gasifier + gas engine (currently; have looked at modified diesel) based CHP systems. Modularised: 130kW$_e$ 130-200kW$_{th}$ (depending on fuel moisture content: 50%-30%) – 1.56MW$_e$ 1.56-2.3MW$_{th}$ 130kW$_e$ requires (equivalent of) 110 od kg/hr

415V 3Ph

Footprint: 6m x 5m x 7.3m (high)

Formerly **Exus Energy Ltd.**, formerly **B9 Energy Biomass Ltd.** Currently unable to offer commercial guarantees, but expect to be able to do so in about 12-18 months.

UK presence

UK company

Case studies

Blackwater Valley I	100kW$_e$	
Blackwater Valley II	200kW$_e$	£400 000
Beddington ZED	130kW$_e$	
SMP R&D facility, Sweden		

Biomass Engineering Ltd., St Helens

Contact details

Junction Lane, Sankey Valley Industrial Estate, Newton-le-Willows WA12 8DN

www.biomass-uk.com

Tel: 01925 220338 Fax: 01925 220135

a.connor@biomass.uk.com (Andrew Connor – Project Manager)

Systems

Down-draft gasifier coupled with gas engine. Standard range: 250-275kW$_e$/450-600kW$_{th}$ Could build small system to special order.

Need 10-20% MC, but often incorporate a drier system using some low grade heat. Not too fussy on fuel spec. provided the majority (~90%) is basically SRW can manage some leaves and bark.

Offer turn key systems, and can also offer maintenance contract with modem link, or can have modem notification of on site staff.

Can modulate down to ~50% with some loss of efficiency (say 20-30%).

Footprint: 10m x 15m x 4m (high)

Formerly **Shawton Engineering**

UK presence

UK company

Case studies

ECOS Millenium Centre, Ballymena, N Ireland 250-275kW$_e$ (net – 300kW$_e$ gross) 450-600kW$_{th}$ £30/MWh 250kg/hr wood chips @ 15-20% MC pdf

Mossborough Hall 270kW$_e$

Innovation Technologies (Ireland) Ltd., N. Ireland

Contact details

47, Manse Road, Ballycarry, Carrickfergus, Northern Ireland BT38 9HP

www.innovation-tech.co.uk

Tel: 028 9337 3379 Fax: 028 9337 8039

info@innovation-tech.co.uk Ian Millikan

www.fluidynenz.250x.com Doug.Williams@orcon.net.nz

Systems

Uses **Fluidyne** downdraft gasifier (from New Zealand) and Hino gas engine/IC engine: 35kW$_e$/70kW$_{th}$ – 550kW$_e$/1.1MW$_{th}$ ITI-Fluidyne range

Atlantic class system AC100: 100kW$_e$ 200kW$_{th}$ 100kg/hr fuel. ~6% MC

Atlantic class AC50: 50kW$_e$ 100kW$_{th}$

Mega class systems: up to 2MW$_e$ experimental at present. US$1.5m-1.8m excluding the engine.

415V 3Ph

Footprint: 8m x 8m x 3.5m excluding fuel silo

UK presence

UK company

Case studies

Winnipeg, Canada 500kW$_e$ Mirrlees dual fuel engine 2.5 t/hr wood chips experimental

Mawera UK Ltd., Lichfield

Contact details

31, Enterprise Industrial Park, Britannia Way, Lichfield, Staffordshire WS14 9UY

www.mawera.co.uk www.moldow.com www.mawera.com

Tel: 01543 258844 Fax: 01543 416311

jac@mawera.co.uk (John Clissett)

Systems

Biomass boilers (110kW – 13 MW) with choice of Stirling (35 or 70kW$_e$), ORC (300kW$_e$ – 1.5MW$_e$) via 300ºC thermal oil, or steam turbine (100kW$_e$ – 2.5MW$_e$).

Use Turboden ORC unit.

Stirling engine systems using Danish engine (same unit as Stirling Denmark) but direct combustion: 35kW$_e$ 300kW$_{th}$ ~160kg/hr @50%

415V 3Ph

Footprint: Suggest building 16 m x 15 m x 6 m high

UK presence

UK representation of Austrian company

Case studies

8 cylinder Sterling engine pilot plant 75kW$_e$ 475kW$_{th}$ 1,000 hr operation

Stirling Denmark ApS, Denmark

Contact details

www.stirling.dk

Diplomvej, build. 373 - DTU - 2800 Lyngby, Denmark

Tel: +45 45 25 93 70 Fax: +45 45 25 93 71

hc@stirling.dk Prof Henrik Carlsen

Systems

Updraft gasifier + Stirling engines 35kW$_e$, 75kW$_e$ 35kW$_e$ delivers 145kW$_{th}$ heat from 200kW in. Up to 40-50% MC fuel with few constraints on fuel quality. Can take some bark and leaves.

8,000 hr/yr operation expected. Takes ~ half an hour to start up gasifier if operating the previous day; about half a day from totally cold. Operates 1,500 hours between cleaning of hot region of engine, which is a simple process, takes about one day and can be undertaken by site staff. They expect to extend this to 4,000 hours.

Designed for main service interval of 8,000 hours, but recommend 4,000 hrs for the first few years. This takes 2 people three days and requires specialist engineers. Incorporates modem link for remote diagnostics.

No modulation in output possible on current systems, but down to 30-40% planned for the future, and not expected to be complicated.

Footprint: 2m x 2m x 4m high (alternative configurations available)

UK presence

None at present, but hope to find a UK partner for servicing and perhaps marketing.

Case studies

Some 35kWe plants in Germany and Austria, but they are confidential. Plant in Denmark to be installed by end of 2006 which should be well documented.

Talbott's, Stafford

Contact details

Drummond Road, Astonfields Industrial Estate, Stafford ST16 3HJ

www.talbotts.co.uk

Tel: 01785 213366 Fax: 01785 256418

enquiries@talbotts.co.uk

Systems

Step grate combustor plus indirect fired micro turbine BG100: $100kW_e/200kW_{th}$
Wood chips, SRC, miscanthus up to 40% MC

Quote about $90kW_e$ net output ($100kW_e$ gross)

Electrical: 415V 3 Ph 50Hz

LTHW: Up to 90ºC

Footprint: Two stacked 20' x 8' x 8'6" (6.1m x 2.4m x 2.6m) shipping containers with fuel store to one side. Total 6.1m x 10m x 5.2m

UK presence

UK company

Case studies

Harper Adams Agricultural College, Shropshire $100kW_e$ (gross) $150kW_{th}$

Waste to Energy Ltd., Suffolk

Contact details

Eyston, Borley Green, Sudbury, Suffolk CO10 7AH

www.wastetoenergy.co.uk

Tel: 01787 373007 Fax: 01787 373535

info@waste-to-energy.co.uk

Systems

Downdraft gasifier technology with units from 10kW – 1MW, or larger with multiple units. Gas used to drive gas or modified diesel engine.

Wide range of fuels briquetted before use for consistency. 15-20% MC fuel required, but system can incorporate drier. Regard wood waste as an easy fuel. They have “2 or 3” small scale systems (50kW$_e$) in operation as well as larger systems. Roughly 1:1 electrical to thermal output. 50kW$_e$ from ~100 kg/hr fuel supply. Would use modified diesel engine.

Formerly **Vitec**

The recent death of the managing director has made obtaining detailed information about the system difficult.

UK presence

UK company

Case studies

Anglian Water BRER Project 250-330kW$_e$ 0.5 t/hr 1,100 t/yr dried sewage sludge £1.5m

In addition to the equipment manufacturers above, there are a large number of project and engineering consultants who can specify and design a system.