CARBON TRUST

Making business sense of climate change

# Biomass sector review for the Carbon Trust

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This report has been prepared by Paul Arwas Associates for the Carbon Trust.

# Foreword

The biomass sector is very complex and varied with a multitude of different end-uses, technologies and potential fuel combinations. Recognising this complexity the Carbon Trust commissioned Paul Arwas Associates and Black & Veatch Ltd to carry out this study to better inform future Carbon Trust activity in relation to biomass.

The project's main objectives were to:

- Develop a robust fact base on the economics and impact of existing biomass technology
- Assess the realistic carbon saving potential of biomass in the UK
- Identify the main barriers (policy and market) to the further development of the biomass sector in the UK
- Identify where the Carbon Trust could help to deliver carbon savings by accelerating the development of the sector.

The Carbon Trust allocates resource to maximise carbon saving over time per pound invested. This approach was used in the early stages of this work to help select specific areas of biomass for further detailed analysis and ultimately to help focus future potential Carbon Trust activity. The study has taken a more "here and now" approach to the technologies and markets than some past studies, which have often looked at longer term potential and emerging technologies. Given the availability of biomass resource in the UK the Carbon Trust was particularly interested in identifying potential activity that could help to stimulate supply chains and associated infrastructure today using existing technology.

The Carbon Trust has placed the results of this study in the public domain to help inform the policy debate over how the carbon saving potential of biomass can be captured most cost effectively.

## Key findings

- Biomass has the potential to deliver material carbon savings today. Using UK resources alone carbon savings of up to 5.6 MtC per annum could be delivered
- Using biomass for heating via combustion and displacing fuel oil gives the most cost-effective carbon savings and is the closest use to being economic without subsidy at the present time
- Liquid biofuels can represent a commercially attractive application of biomass resources in certain situations given current government incentives (as evidenced by activity in this area). However, they are not the most resource-efficient use of biomass (both in terms of the "cost of carbon" and the total volume of carbon saved) using current technology
- When used for electricity conversion, biomass offers lower total carbon savings and higher cost of carbon delivered than for heat only or CHP (via combustion)
- Lack of confidence in a reliable fuel supply chain is one of the most significant barriers to the more widespread uptake of biomass generally, although there are a complex range of other barriers
- There are several policy options that have the potential to stimulate growth in the biomass sector, including capital grants, the EU-ETS, CCL and a renewable heat obligation. For any support mechanism to be effective, however, it must have longevity so as to encourage confidence in the market and to thus stimulate wider uptake
- The Carbon Trust is now beginning to scope out a project seeking to accelerate the development of biomass in the UK based on the experience it has gained in similar projects (e.g. the Marine Energy Challenge). The biomass project will focus on heating but will work to draw insights about linking supply and demand and managing risk that will be relevant for the whole sector.

# Executive summary

Biomass is an important part of the UK's renewable energy supply and, including landfill gas and waste combustion, it currently represents 85% of total UK renewable energy supply and 1.4% of total UK energy supply. Biomass has considerable untapped resource potential and so it could play an increasingly important role in helping the UK to meet its Kyoto Treaty targets and national carbon-emission reduction targets.

In order to focus its own efforts and to contribute to the policy debate on biomass the Carbon Trust commissioned a review of the biomass sector focusing on the present day costs, resources and carbon savings associated with biomass. The objectives of the review were to:

- Develop a robust fact base on the economics and impact of existing biomass technology
- Assess the realistic carbon saving potential of biomass in the UK
- Identify the main barriers (policy and market) to the further development of the biomass sector in the UK
- Identify where the Carbon Trust could help to deliver carbon savings by accelerating the development of the sector.

This review started from fundamentals. The first phase consisted of a high level screening of all the potential biomass chains[1] in the UK, identifying those key chains with the greatest potential for carbon saving at lowest cost. This first phase screening also took into consideration the Carbon Trust's ability to have a material effect on the rate of deployment of biomass in a particular area. The second phase involved a more detailed economic and carbon reduction assessment of the key biomass chains, evaluation of the barriers to development of biomass projects and drew a number of observations on future policy options for biomass.

The review covered all UK biomass resource with a number of exceptions such as peat, hospital waste and municipal solid waste.

[1]A Biomass "Chain" refers to a particular combination of resource, conversion technology and end-use, e.g. cereals via hydrolysis & fermentation into bioethanol (liquid transport fuel). A very large number of these combinations or "chains" were studied as part of this review.

The review drew on an extensive number of sources, including a detailed literature survey, in-house references, questionnaires and interviews with trade associations, industry participants and industry observers.

The policy observations that were drawn from the review, together with the results of the analysis itself, were subject to a detailed peer review with leading industry participants, observers and academics. The team that carried out the review worked closely with the Government's Biomass Taskforce to ensure our fact base and conclusions were considered as part of the Taskforce's work. This document is a synthesis of a large volume of detailed analysis. The purpose of this document is to place the results of this analysis in the public domain and to ensure that it is available to those interested in developing the biomass sector in the UK.

Biomass can be drawn from a very large number of sources. Our screening of the available biomass resource in the UK highlighted four key biomass fuels: forestry crops, dry agricultural residue, waste wood and woody energy crops. All of these have both significant carbon saving potential and relatively low cost of carbon if used in suitable chains. The four fuels could have a material impact on UK energy supply when used for heat and power. Currently they have the potential to supply up to an additional 41TWh/yr or about 1.5% of UK energy supply. In the future this could rise to c.80TWh/yr, mainly through expansion in the supply of woody energy crops and/or dry agricultural residue.

If available resources are used for biofuels the level of potential carbon saving decreases significantly compared with providing heat or electricity due to lower conversion efficiency. The cost of carbon for biofuels is much higher than for heat and electricity (without Government incentives). Consequently, biofuels are not covered in depth in this report although they were analysed in detail during Phase 1.

Although the UK has a considerable amount of biomass resource, gaining access to it is not always viable for developers and end-users as the UK currently has a relatively undeveloped biomass fuel supply infrastructure.

Just as biomass can be drawn from a number or sources, it can be converted to useful energy through a number of processes and delivered to a variety of markets. Our screening of biomass conversion processes demonstrated that currently combustion represents the best area of focus. Combustion is a proven, established conversion process and the lowest cost option available today. Except in niche applications, all the other conversion processes are either higher cost (e.g. anaerobic digestion and fermentation), not yet sufficiently commercially mature (e.g. gasification and pyrolysis), or generate limited carbon savings at this time (Fischer-Tropsch and trans-esterification).

Co-firing was not analysed in great depth as the potential for the Carbon Trust to be material in this area is limited. However, given current government incentives, it appeared that co-firing biomass in coal plants is economic and relatively attractive from a carbon-saving and cost of carbon saved point of view[2].

[2]Source: B&V.

Our review suggested a focus (from a cost-effective carbon reduction point of view) on very small scale (c.0.2MW) to industrial scale (c.30MW) units generating heat and power. The cost of carbon in domestic-scale applications was found to be very high.

Within combustion processes, heat applications, especially small heat (e.g. around 2MW), have the most attractive and robust plant economics, excluding government incentives. When replacing oil-fired boilers, small heat plant have the most favourable investment returns of all the applications examined (which included large and small CHP, large and small electricity only). The oil price is the main driver of heat plant economics. At our medium crude oil price scenario ($30/bbl), small heat is the only application with a positive IRR (c.5%) for all biomass fuels. At our high oil price scenario ($50/bbl), small heat plant returns are high enough to attract investment (c.20%). Large heat (around 30MW) and very small heat (around 0.2MW) generate positive returns for all fuels, but are probably too low for investment (i.e. c.10%). The most attractive of the other applications is large CHP, which at $50/bbl has positive returns for all of the key fuels.

With current Government incentives, large biomass CHP becomes attractive for investment, generating returns of between 15-20% at $30/bbl. Electricity-only plants have modest returns due to a poor ratio of capital cost to revenue.

Despite the potential economic viability of certain biomass plant, relatively little construction is underway. In part this is due to the significant barriers to development that biomass faces throughout all stages of development. Four main barriers affect all developers. These barriers increase the risk of investing in biomass (thereby increasing the cost of capital), and increase operating costs. Together these reduce the economic viability of biomass developments. The four main barriers are:

- *Market information (Project Initiation):* The lack of fuel market information makes identification and coordination of large scale supplies difficult to achieve. The need to contract without reference prices and terms increases negotiating and contracting costs
- *Fuel supply risks:* The absence of major counterparties results in credit risk. In addition, the lack of significant trading of the major fuels means that supply risks (quality, price or volume) cannot be hedged
- *Planning:* Public opposition to large biomass plant can be strong and, above a certain size, the Environment Agency is involved, adding complexity to the planning process
- *Policy costs:* For power generation plant the uncertainty inherent in the Renewables Obligation mechanism reduces the value of the Renewable Obligation Certificates (ROCs) received by non-integrated suppliers.

In addition, smaller developers are affected by a number of other barriers including lack of awareness and understanding of biomass by end-users/customers which leads to a perception of higher risk, poor availability of technical expertise (installation and maintenance) and lack of access to debt funding.

In a good fit with the economic analysis, heat applications face fewer barriers than CHP or electricity-only plant as they avoid issues related to the Renewables Obligation, debt financing and, in many cases, planning.

Replacement of oil-fired heat plant by biomass-fired systems is the most attractive from a carbon saving point of view, due to their high conversion efficiency and the high level of emissions from the displaced oil. Replacing all suitable oil-fired boilers with biomass-fired boilers would save c. 2.5MtC/yr and use almost 90% of the currently available biomass, or 45% of the currently and potentially available biomass (i.e. where energy crops are included). The remaining biomass could be used in large CHP plant or co-firing potentially saving up to a further 2.7MtC/yr.

Small and large heat are the only two applications with a low cost of carbon; c. £25/tC and c. £30/tC respectively at $30/bbl crude. Through deployment at scale and standardisation, small heat has the potential for significant cost reduction (c.25% of project costs). Large heat technology is mature and offers more limited opportunity for cost savings. None of the other biomass applications currently offers sufficient cost reduction opportunity to achieve these low costs of carbon; however, this situation should be reviewed periodically.

From a purely carbon perspective, therefore, the UK should exploit the largely untapped potential of heat applications, particularly small heat. To do so will require long-term financial support (possibly through the EU-ETS or a Renewable Heat Obligation and/or a capital grant scheme) and targeted action to address the key barriers to biomass development. This should include investment in large scale supply chain/technology demonstration programmes, education and information programmes, and ensuring the recent changes to the planning system are effective. However, in shaping the overall policy framework for biomass (including CHP, electricity and biofuels), the Government will need to take into account the other benefits of biomass (e.g. energy security, employment, despatchable electricity generation, etc).

The Carbon Trust is now beginning to scope out a project seeking to accelerate the development of biomass in the UK based on the experience it has gained in similar projects (e.g. the Marine Energy Challenge). The biomass project will focus on the use of biomass for heating at the small scale as a replacement for oil-fired boilers as this sub-sector offers the most cost-effective carbon savings at the present time and the Carbon Trust could have a material impact. While focusing on heat, the project will build a fact base that will facilitate the development of the biomass sector as a whole. A key objective will be to build a better understanding of the risks in development and how best to mitigate these across the entire biomass value chain, particularly the supply side.

# Introduction

## Background

Biomass involves using biologically derived products such as wood, straw or sewage sludge to generate heat, electricity or motive power. If the biomass source is sustainable, such as wood from a forest where new trees are planted to replace felled ones, then biomass is a source of low carbon renewable energy.

Biomass is unique among renewable energy sources. Firstly, it has a complex supply chain (from biomass resource to delivered service), whereas all other renewable sources, like wind or wave energy, have much simpler supply chains. There are many biomass sources including waste wood, specifically grown 'energy crops', and residues from forestry, agriculture and food manufacture. These biomass sources typically go through two stages of conversion: the first to generate a fuel by biological, thermal or chemical means; the second to generate useful energy through, say, a boiler which gives a delivered service (heat, electricity or biofuels for transport). This leads to a large number of possible combinations of sources, conversion processes and technologies and delivered services, and over 80 such combinations (or 'chains') were evaluated in this study.

Secondly, unlike wind or wave, biomass has a fuel cost. The prices of biomass fuels are set by market forces and are susceptible to sharp variations due to weather conditions and changes in demand from other industries that draw on biomass sources such as food, furniture and paper.

This poses difficult questions for both policy-makers and companies wishing to exploit biomass energy. For example, which of the large numbers of biomass chains are economic? Which generate material carbon savings and other non-financial benefits? Will future fuel price changes alter the relative economic attractiveness of the biomass chains, and will technological developments significantly alter the picture?

These are important questions, all the more so as biomass is one of only a limited number of renewable energy sources that the UK is relying upon to help meet its Kyoto targets and national targets for greenhouse gas and carbon emissions reduction. Biomass represented 85% of total UK renewable energy supply and 1.4% of total UK energy supply[3] in 2004. There is untapped biomass potential in the UK: other countries, including Austria and Finland, have shown that biomass can play an important role in reducing carbon emissions. Furthermore, biomass can generate other important benefits such as diversification of income for the rural economy and improvements in energy security.

## The Carbon Trust

The Carbon Trust is a business-focused, independent company, funded by Government, set up in 2001 with a remit to:

- Help UK business and the public sector meet ongoing targets for carbon dioxide emissions
- Increase business competitiveness through resource efficiency
- Support the development of a UK low carbon sector.

The Carbon Trust is already actively involved in the biomass sector, most notably through its funding of several innovative biomass research, development and demonstration projects.

In order to focus its own efforts and to contribute to the policy debate on biomass the Carbon Trust has commissioned a review of the biomass sector.

Biomass sector studies have been undertaken in the past, usually examining one element of biomass, either a specific part of the supply chain (e.g. resource availability) or a particular topic (e.g. future technology development).

By way of contrast this review covers the present day costs, resources and carbon savings associated with biomass. The objectives of the project were to:

- Develop a robust fact base on the economics and impact of existing biomass technology
- Assess the realistic carbon saving potential of biomass in the UK
- Identify the main barriers (policy and market) to the further development of the biomass sector in the UK
- Identify where the Carbon Trust could help to deliver carbon savings by accelerating the development of the sector.

[3]Source: DTI, percentages include landfill gas and waste combustion.

## Scope and approach

In line with the Carbon Trust's remit, the study focused on how to accelerate the development of those biomass chains which generate the greatest carbon saving at the lowest cost. The study also took into consideration the Carbon Trust's ability to have a material effect on the rate of deployment of biomass in a particular area. Although the other benefits of biomass were recognised (e.g. energy security, employment, despatchable electricity supply, etc.), they were not part of the formal analysis conducted as part of this study and would clearly need to be taken into account in developing the policy framework.

This study covered all major UK biomass resources apart from peat, hospital waste and municipal solid waste. Peat was not considered because of the potentially severe ecological damage caused by peat extraction. Hospital waste is governed by tight health and safety regulations and therefore was not considered. Municipal solid waste was not considered in detail as part of this study as waste falls outside of the remit of the Carbon Trust and a number of other organisations including WRAP (Waste & Resources Action Programme) are taking a lead in this area. It is estimated[4], however, that the potential energy supply in 2020 from the biodegradable portion of municipal solid waste is c.40TWh/yr.

In line with the Carbon Trust's objective to support the development of a UK low carbon sector, this study focused primarily on the UK's biomass resource.

The study started from fundamentals. In Phase 1, Black & Veatch Limited (B&V) conducted a high-level screening of all the potential biomass chains in the UK, identifying those key chains with the most potential for carbon saving at the lowest cost. A large number of interviews and questionnaires with the biomass industry were also undertaken in this phase and the barriers to biomass project development identified. In Phase 2, PAA (Paul Arwas Associates), together with B&V, conducted a detailed economic and carbon reduction assessment of the key biomass chains, evaluated the barriers to development of biomass projects, and drew a number of observations on the future of policy for biomass.

At the start of Phase 1, B&V identified all possible biomass resources and conversion technologies and quantified their potential. Those resources below a threshold of 3TWh/yr gross were eliminated from further investigation as not being material. B&V then reviewed all the possible combinations of the remaining resources, conversion technologies and delivered services (heat, electricity or biofuel for transport use) and identified those that were technically feasible.

Each of the resulting technically feasible chains was analysed over a range of applications from co-firing in a utility sized power station down to log-burning domestic stoves. Some of these permutations were eliminated as being impractical. For each of the remaining chains the potential carbon saving and the cost of that saving with and without Government incentives was calculated. The objective was to identify those technically feasible and practical chains which exhibit the highest potential carbon saving at the lowest cost of carbon.

To conduct Phase 1 of the study, B&V drew on an extensive array of literature sources and a large number of interviews and questionnaires.

In Phase 2, PAA built a detailed cash flow and emissions model of the key biomass chains identified in Phase 1. This calculated the Net Present Value (NPV), Internal Rate of Return (IRR), carbon saving and cost of carbon for typical projects in each of the key biomass chains, either with or without Government incentives. The input to the model was developed by further literature surveys, and interviews with trade associations, industry participants and industry observers, together with the outputs of Phase 1. This model was used to assess 28 biomass chains on the basis of economic attractiveness and carbon savings.

The interviews and questionnaires from Phases 1 and 2 were used to identify 35 barriers to the development of biomass. These were then grouped into three types: those affecting project initiation; project development; and the fuel supply chain. Finally all the barriers were ranked against each plant type, resource type and developer size.

The policy observations that were drawn from the Phase 2 analysis, together with the results of Phases 1 and 2, were subjected to a detailed peer review process with leading industry participants, observers and academics (see Appendix 1).

[4]B&V analysis of 'Quantification of the Potential Energy from Residuals (EfR) in the UK', by Oakdene and Hollins for the ICE and RPA, March 2005.

# Section 1. Fuel resource

## Summary

Biomass can be drawn from a very large number of sources. Our screening of the available biomass resource in the UK highlighted four key biomass fuels: forestry crops, dry agricultural residue, waste wood and woody energy crops. All of these have both significant carbon savings potential and relatively low cost of carbon if used in suitable chains. These four fuels could have a material impact on UK energy supply when used for heat and power. Currently they have the potential to supply a further 41TWh/yr or about 1.5% of UK energy supply. In the future this could rise to c.80TWh/yr, mainly through expansion in the supply of woody energy crops and/or dry agricultural residue. If used for biofuels the level of potential carbon savings drops significantly due to lower conversion efficiency. Although the UK has a considerable amount of biomass resource, gaining access to it is not always possible for developers and end-users as the UK currently has an undeveloped biomass fuel supply infrastructure.

## Key biomass fuels

Biomass is organic matter and there is a wide range of potential biomass fuels[5]. Many biomass fuels are wastes or residues, but some biomass fuels are grown especially for use in biomass plant. There are five main groups of biomass fuels: virgin wood, energy crops, agricultural residues, food waste and industrial waste.

- Virgin wood includes roundwood, cutting residues (brash), bark, sawdust, crowns, needles and residue of tree surgery
- Energy crops include woody energy crops like short rotation forestry, willow, eucalyptus, poplar, miscanthus, hemp, and also sugar crops (sugar beet), starch crops (wheat, barley, maize/corn), oil crops (rape, linseed, sunflower) and even hydroponics (lake weed, kelp, algae)
- Agricultural residue can be wet (pig and cattle slurry, sheep manure, grass silage) or dry (for example, poultry litter, wheat or barley straw, corn stover)
- Food waste can be wet or dry (from meat/fish, dairy and distillery wastes, etc.), or it can come from distribution or post-consumer waste (hotels and restaurants, cooking oils, surplus fruit and vegetables)
- Finally, industrial waste includes wet and dry textiles and paper wastes, wastes from sawmills, construction, furniture manufacturing, chipboard industries, pallets, and sewage sludge.

Many of these resources are not suitable for use in biomass plant at a large scale because their total energy yield is too small, or processing them would be too costly, or the potential carbon savings would be too small. In order to select the most suitable biomass resources for use at a large scale B&V quantified the current and potential energy yield for each individual resource. Those with a total energy yield of less than 3TWh/yr gross were eliminated from further investigation as not being material. The remaining fuel resources were combined with all conversion technologies and delivered services (heat, electricity or biofuel for transport) and the technically viable combinations were taken further for analysis. Such a combination of fuel, conversion technology and delivered service is known as a chain; for example, waste wood (fuel) being combusted (conversion technology), in a small CHP plant (application) to produce electricity and heat (delivered service).

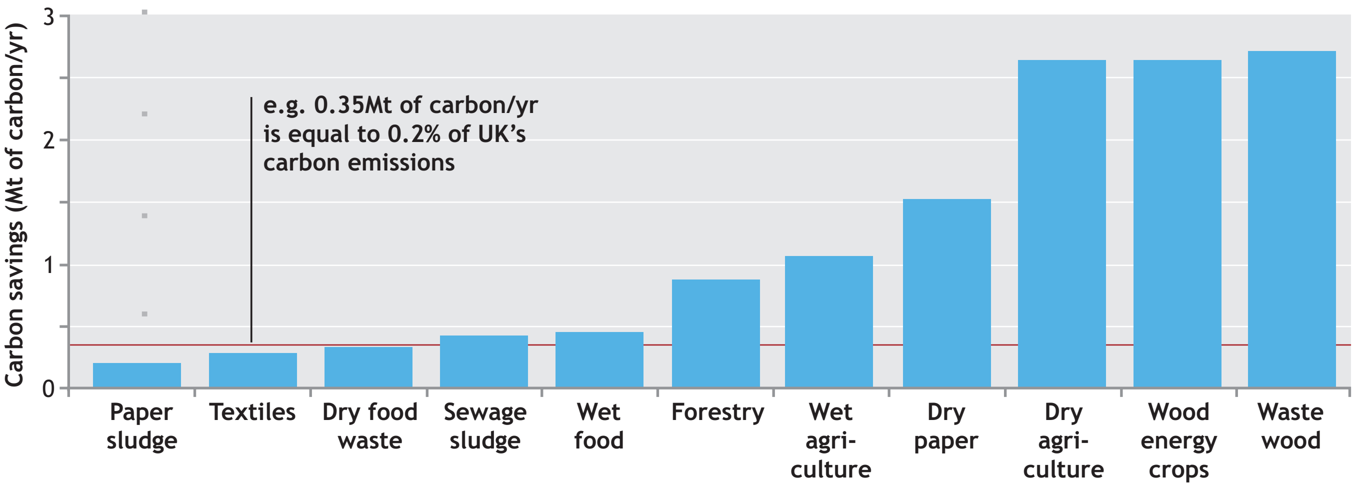
For each chain the total potential carbon saving was calculated (in Mt C/yr) for the various conversion technologies and delivered services, as well as the cost of saving a tonne of carbon (in £/t C). Figure 1 shows the potential carbon saving for the various biomass resources assuming, for illustrative purposes, they are used in heat applications to replace oil. Dry Paper, Dry and Wet Agricultural Residues, Wet Food Waste, Woody Energy Crops and Waste Wood, and are clearly the most significant resources. Forestry was carried through for further analysis as it can easily be used with other woody material. Sewage sludge, dry food waste and textiles were eliminated from further investigation due to low carbon savings (less than 0.2% of the UK's carbon emissions). The dry paper, wet food, and wet agricultural resources were not taken further due to their materially higher costs of subsidy (required for economic viability) compared with the other resources.

The review of biofuel end-use chains showed that, in the short term, they all have more limited carbon-saving potential than heat and electricity (see Biofuels box) and were, therefore, not taken further in this study.

Dry Agricultural Residue, Woody Energy Crops (assumed in this analysis to be grown on 680,000 hectares of set-aside land), Waste Wood and Forestry Crops used in heat and electricity chains are, therefore, the most attractive groups of biomass fuels in terms of carbon saving potential.

[5] Unless stated otherwise the term 'biomass fuels' refers to solid biomass fuel, as opposed to liquid biofuels, like bio-ethanol or bio-diesel.

***Figure 1*** *Carbon savings for UK biomass resources — replacing oil in heating*




Source: B&V

## Biofuels

As part of the high-level screening, B&V reviewed 24 different biofuel chains. The biomass sources included: wood (both farmed and waste), sugar beet, rapeseed, sunflower, wheat and straw. The fuels were: ethanol, Fatty Acid Methyl Ester (FAME), SynDiesel, methanol, Di-Methyl-Ether (DME) and hydrogen.

In line with the present day emphasis of the study, B&V focused on nine short-term biofuel chains (i.e. those producing ethanol and FAME with wood, sugar beet, wheat, rapeseed and straw as the biomass source as appropriate). Hydrogen chains are longer term as they rely on the development of a new fuel infrastructure and the successful commercialisation of fuel cells. SynDiesel, methanol and DME require further technical development, in particular linking the Fischer Tropsch process with biomass gasification. In addition, sunflower was not considered further as a source as it is not a major UK crop.

The carbon savings from using biomass resource as a biofuel were compared with alternative use in heat and power applications. The wood-based biofuels chain (wood to ethanol via acid hydrolysis and fermentation) shows carbon saving potential 2-3 times lower than that available from using wood in CHP plant. Similarly, all sugar beet, rapeseed and straw-based chains have carbon savings potential at or below 6500kg$CO_2$/ha/yr which are well below the worst case carbon savings for energy crops as fuel for CHP plant of 10,000kg$CO_2$/ha/yr. The more limited carbon-saving potential is mainly due to low overall conversion efficiency of the economically viable short-term chains, exacerbated, in some cases, by the low yields of the crop resources themselves.

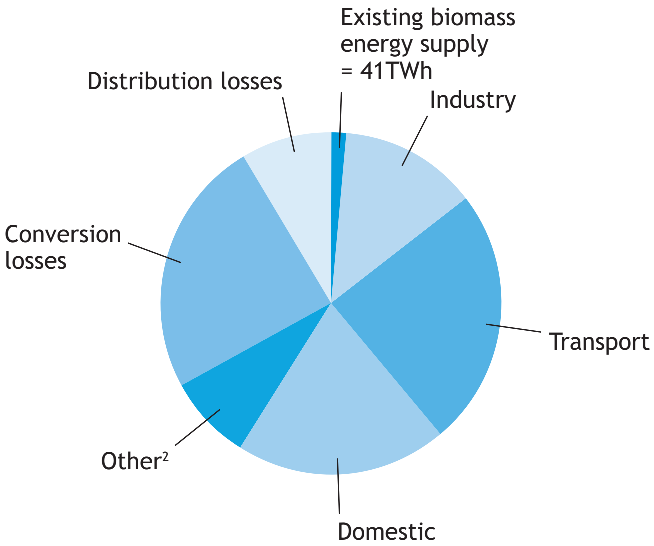
The cost of carbon was also assessed. This showed that the short-term biofuel chains have a cost of carbon of £800-5000/tC (without Government incentives). By way of comparison, the worst case cost of carbon for energy crops used as fuel for CHP plant is £350-550/tC.

As biofuel generates lower carbon saving at a higher cost (without Government incentives) than heat and electricity applications, it was not considered further in this study. However, we do recognise that biofuels meet a number of other policy objectives including security of supply and that a number of schemes are coming forward on a commercially viable basis with government incentives.

## Biomass resource availability

A combination of our key biomass chains can supply 41TWh/yr of energy based on existing availability, and there is scope to almost double the supply in the future. Existing biomass resources (41TWh/yr) can deliver a material amount of energy, representing c.1.5% of the total UK energy consumption (see Figure 2). If energy used in the transport sector is excluded, then the existing biomass resources could make up 2% of the current UK energy demand.

***Figure 2** UK energy consumption by final destination*[1]




**Total (2003): 2,700TWh**

Notes: [1]Excludes non-energy use of fuels
[2]Mainly agriculture, public sector and commercial property.
Source: DTI, B&V.

## Forestry crops

Forestry crops include poor quality stemwood, stem tips, branches and arboricultural arisings. There are limited competing markets for these low quality by-products, except the chip board industry. According to DTI data, current available yield is 1,060,000 odt/yr[6], or c.6TWh/yr, none of which is used for energy at the moment. We foresee no substantial increase in supply in the future. Although the Forestry Commission predicts that the overall available amount of stem wood will increase, most of this increased production will take place in the larger diameter high quality classes of wood, i.e. 14-18cm diameter, which are currently too expensive to be an economic biomass fuel.

## Waste wood

Waste wood is generated from a wide variety of sources including construction and demolition, wood packaging, furniture manufacture waste, and end-of-life furniture. The existing resource is used in several markets other than biomass, for example in animal bedding and the panel board industries. It is estimated that only 22TWh/yr is currently available for biomass and that in the future no additional waste wood will become available for biomass.

There was no detailed assessment of the availability of these waste wood products and therefore our estimate is from a number of different sources. WRAP has recently published a report entitled: 'Reference Document on the Status of Wood Waste Arisings and Management in the UK', which is broadly consistent with our estimates, allowing for differences in definitions.

## Dry agricultural residue

Dry agricultural residue includes wheat and barley straw, corn stover, oil crop[7] residue, poultry litter, sugar beet tops, oat crop residue and feathers. Hay is excluded as it is currently too expensive to be an economic biomass fuel. There is about 73TWh/yr of dry agricultural residue available, but most of it is already used, leaving 13TWh/yr for use in biomass plant. The existing demand for straw is very large with significant variation from year to year.

## Woody energy crops

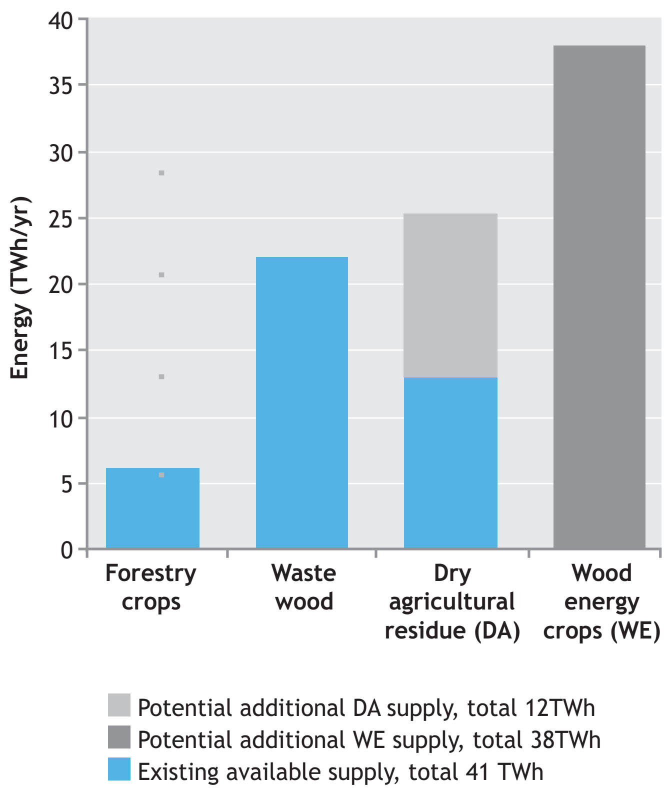
Woody energy crops are crops grown specifically for energy use and include short rotation forestry, willow, eucalyptus, poplar, miscanthus and hemp. At the moment very little is grown in the UK, c. 0.2TWh/yr. However, it is expected that considerably more energy crops will be grown in the future. The amount grown depends on the area and quality of land used, and the type of crops grown (each have different requirements and yields). Estimates of the land that could be used for energy crops vary greatly, but an area of 680,000ha (roughly equal to the former set-aside area) has been assumed for the purposes of this review. Depending on the balance of crops grown, the available biomass energy is 34-42TWh/yr (for the remainder of this report, an average of 38TWh/yr is used). In the long term biofuels production could also make demands on the available woody energy crop resource (for instance to manufacture bio-ethanol).

[6]odt = oven dried tonnes.
[7]Includes rapeseed and linseed. The oil product and residue are analysed separately. The quantity of oil crop residue is based on rapeseed yields.

The currently existing and potentially available amount of energy from biomass in the UK is summarised in Figure 3. It shows that the total amount of currently available energy from biomass in the UK is 41TWh/yr, with the potential to increase it to almost 80TWh/yr.

The 80TWh/yr figure for total biomass energy assumes that woody energy crops are grown on a land area of 680,000ha. If instead a mixture of food crops was grown on this land, and the residue used for biomass energy then we estimate that this would result in a reduction of the available biomass energy attributable to this land area from 38TWh/yr to 12TW/yr.

***Figure 3*** *Existing and potential energy supply from UK biomass resources*




Source B&V

## Fuel infrastructure

The UK currently has an undeveloped biomass fuel supply infrastructure.

There are few active fuel supply intermediaries in the UK, so biomass plant operators often need to contract directly with fuel suppliers:

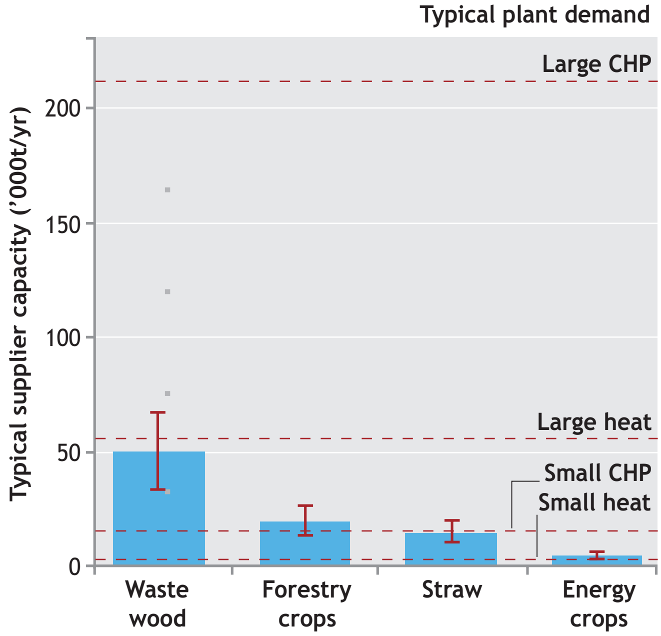
- Waste wood suppliers are the largest, typically they are able to supply c.50,000t/yr – based on their infrastructure to collect waste wood for the panel industry
- The supply of forestry crops is dominated by Forest Enterprise (of the Forestry Commission). The private supply market is relatively fragmented and a typical supplier of forestry crops could supply about 20,000t/yr
- Dry agricultural residues (such as straw) are produced as seasonal by-products. Some market intermediaries do exist, but large suppliers typically supply 15,000t/yr, although large intermediaries such as Anglian Straw have been created
- The estimated current supply capacity of woody energy crop producers is small, maybe 5,000t/yr. In the future, typical amounts of regional/local supply could reasonably be 50,000t/yr per supplier.

The current supplier base, therefore, could serve a small heat or small CHP plant (though there are other supply chain difficulties – see Section 3). For example, a small, 2MWe CHP plant would need about 18,000 wet t/yr fuel, which could readily be supplied by a few suppliers.

A large, 30MWth heat plant would require around 60,000 wet t/yr of fuel, which could be met either by one major supplier or, more likely, from a range of smaller suppliers.

However, a large CHP plant would stretch the supply base. For example, a 30MWe plant would require around 250,000 wet t/yr of fuel which would require the full output of about 15 typical suppliers.

***Figure 4*** *Typical supplier capacity and plant demand*




Source PAA

# Section 2. Project economics

## Summary

Just as biomass can be drawn from a number of sources, it can be converted to useful energy through a number of processes and delivered to a variety of markets. Our screening of biomass conversion processes demonstrated that currently combustion represents the best area of focus. Combustion is a proven, established conversion process and the lowest cost option available today. All the other conversion processes are either higher cost except in niches (e.g. anaerobic digestion and fermentation), do not yet have sufficient market maturity (e.g. gasification and pyrolysis), or generate limited carbon savings at this stage (Fischer-Tropsch and trans-esterification). Our review of markets, which excluded biofuels because of the focus on combustion, suggested a focus, for cost-effective emission reduction, on very small scale (c.0.2MW) to industrial scale (c.30MW) units generating heat and power. Co-firing was not considered in detail because of low Carbon Trust materiality in this area; also the cost of carbon in domestic-scale markets was found to be very high.

Within combustion processes, heat applications, especially small heat (e.g. around 2MW), have the most attractive and robust plant economics, excluding Government incentives. When replacing oil-fired boilers, small heat plant have the most favourable investment returns of all the applications examined (which included large and small CHP, large and small electricity only). The oil price is the main driver of heat plant economics. At $30/bbl crude, small heat is the only application with a positive IRR (c.5%) for all biomass fuels. At $50/bbl, small heat plant returns are high enough to attract investment (c.20%). Large heat (around 30MW) and very small heat (around 0.2MW) generate positive returns for all fuels, but are probably too low for investment (i.e. 10%). The most attractive of the other applications is large CHP, which at $50/bbl has low positive returns for two of the key fuels.

With current Government incentives large biomass CHP becomes attractive for investment, generating returns of between 15-20%. Electricity only plants have modest returns due to a poor ratio of capital cost to revenue.

## Conversion process

Biomass can be used to provide energy in many ways. The conversion is typically done in two stages. There are three main types of first-stage processes, which convert biomass into intermediate products:

- Biological processes, which include anaerobic digestion and fermentation and deliver biogas and ethanol
- Thermal processes, which include gasification, pyrolysis and combustion. Products can be char, oil and (hot) gas
- Chemical processes, which include Fischer-Tropsch and trans-esterification and deliver ethanol and bio-diesel.

The outputs of these processes are then fed into the second stage, which converts the intermediate products into energy. The seven conversion technologies considered in this project were boilers, steam turbines, steam engines, gas turbines, gas/liquid reciprocating engines, Stirling engines and fuel cells. Not all of these technologies can be combined with each conversion process. For example, you cannot use the hot gas produced by combustion to power a fuel cell.

Of the first stage processes, combustion currently represents the best area of focus for the Carbon Trust. Combustion is a proven, established conversion process and the lowest cost option available today (see Section 1). The products of combustion may be passed to steam or hot water boilers. Steam generated may be passed to steam turbine or steam engine driven generators for the production of electricity.

All the other first-stage processes have at least one major limitation.

Anaerobic digestion, which produces biogas, was not taken forward for further analysis. Although it has reasonable potential for carbon reduction, its costs are high at present, except in certain niches. This is due to high capital costs and low conversion rates. In the UK, the main feed for anaerobic digestion – wet agricultural waste – is mainly treated in open tanks until it can be spread on the land and therefore the current cost of disposal is very low.

Fermentation produces liquid biofuels (e.g. ethanol from sugar or starch). Fischer-Tropsch and trans-esterification processes also produce liquid biofuels (e.g. biodiesel from vegetable oil). Although these chains can be cost effective under current Government incentives, the cost of saving carbon through biofuels is relatively high compared to other potential routes (although this is strongly dependent on the fossil-oil price). These biofuels were not studied further because their potential total carbon savings are limited and the cost of carbon is high (see Section 1).

Gasification and pyrolysis produce a mixture of gaseous, liquid and solid products, depending on factors including pressure and temperature. The only end-use in which they are cost-effective, when compared to combustion, is electricity-only generation. However, as we will show later, electricity-only plant are not considered attractive compared to heat and CHP. Furthermore they are relatively early-stage technologies which are not yet sufficiently developed for full commercial use.

## Markets

There are four end-user markets for biomass emerging in the UK:

- **Co-firing** of biomass with coal in large-scale coal fired electricity generation plants. Power plant operators receive Renewable Obligation Certificates (ROCs) for the portion of their output that is biomass-fuelled. These generate a significant economic incentive for co-firing and many coal plants are currently co-firing
- **Industrial** scale units providing around 30MW electricity and/or heat to industrial sites. There are a number of sites being developed in the UK (e.g. Sembcorp, Peninsula Power, Lockerbie, Rothes)
- **Small-scale** (around 2MW) to **Very Small-scale** (around 0.2MW) units for commercial sites, schools, hospitals, nursing homes, etc, providing heat and/or electricity for off-grid and independent applications. Community heating is also possible at these scales, but has not been considered in detail during this study. Community heating, irrespective of the fuel source, has only limited penetration. In part this is due to the shortness of the domestic heating season in the UK (about 1,200 hours per year). In countries such as Austria or Finland where community heating has been developed much further, the heating season is much longer
- **Biofuel** derived from vegetable oil, sugar/starch or woody crops. This transport fuel (bio-diesel/bio-ethanol) supplants fossil-diesel and fossil-petrol supplies respectively. Markets are growing across the EU due to the EU Biofuels Directive and Government incentives.

Of these four, only the industrial and small-scale markets were studied further. Although co-firing is competitive in the current policy and business environment it was not considered further because of low Carbon Trust materiality in this area.

Biofuels were not considered further because the potential carbon saving is much lower, and their costs of saving carbon are higher, than for biomass heating and CHP.

Both domestic scale (10-50 kWth) biomass-fired heating boilers and stoves were investigated. The economics of such systems were found to be significantly worse than for the other biomass markets, primarily due to lower load factors. Therefore, as with co-firing and biofuels, these were not carried forward for further analysis.

## Plant economics

After selection of the most suitable biomass fuels, conversion processes and end-user markets, 28 chains remained. They consist of seven plant types, all using combustion, with four fuels. Definitions for the seven plant types are given in Table 1.

The four fuels were: forestry crops, dry agricultural residue (straw), energy crops and a 40% waste wood/60% forestry crop mixture. Instead of considering waste wood as a single fuel type, we have used a mixture of 40% waste wood and 60% forestry crops when assessing plant economics, as the Waste Incineration Directive (WID) allows such a plant to be treated as a co-incinerator. A plant running on 100% waste wood would be treated as an incinerator, and hence it would incur additional costs and face greater planning constraints.

In order to compare the economic competitiveness of the 28 chains we calculated the Internal Rate of Return (IRR) for each chain. The modelling was based on a 15-year cash flow forecast, with simplifying economic assumptions and suitable assumptions for the development of fuel prices (both biomass and fossil fuels), electricity prices and Government incentives (e.g. EU-ETS, ROC prices and capital grants).

***Table 1** Definition of plant types*

| | | | | Size | Displaced Fuel |
|---|---|---|---|---|---|
| LH | = | Large heat | = | 30MW th | Heavy fuel oil |
| LE | = | Large electric | = | 30MW e | Gas |
| LCHP | = | Large CHP | = | 30MW e | Gas |
| SH | = | Small heat | = | 2MW th | Light fuel oil |
| VSH | = | Very small heat | = | 0.2MW th | Light fuel oil |
| SE | = | Small electric | = | 2MW e | Gas |
| SCHP | = | Small CHP | = | 2MW e | Gas |

Fuel prices for forestry crops, dry agricultural residue (straw) and waste wood were based on current values established from our interviews. Energy crop prices reflected those that might be available if deployed at scale.

Revenues come from electricity sales (in the case of CHP and electric plant), and/or heat sales (in the case of heat and CHP plants). As there is no market for heat, the price of heat is based on the costs of the displaced fuels. Capital costs, O&M costs, operational efficiencies, load factors, interest rates, debt levels, construction time, electricity mark-ups/discounts over the wholesale price, embedded generation benefits, ROC and LEC pass-through factors, and oil and gas prices and mark-ups are based on in-house B&V benchmarks and industry interviews. Wholesale electricity, ROC prices, and EU-ETS carbon credit prices are based on Carbon Trust information.

The returns for all 28 chains are plotted in Figure 5, at an oil price of $30/bbl and including current public sector incentives. This shows that in the current policy environment only small heat and large CHP plant have positive rates of return for all four major fuel types. Small heat generates these returns when displacing oil-fired boilers. Against gas-fired boilers, heat applications generate negative returns. Note that small electric and large heat plant have very negative returns and payback times well over 15 years in this scenario.

The returns are quite sensitive to debt assumptions: increasing debt from 55% to 75% for large CHP plant increases the IRR significantly, for example from 19% to 28% using wood mixture as the fuel. Increasing debt for small heat from 0% to 20% has a very small effect (6.1% to 6.4% for small heat, wood mixture).

## We have used the following, simplifying economic assumptions

- 15-year lifetime and 15-year debt payback, with 15-year depreciation. Different schemes are possible, e.g. 20-year lifetime and 10-year debt payback, but as individual projects differ greatly, we have assumed the 15-year lifetime and debt payback as suitable average assumptions
- Interest on debt, 8%. Tax rate, 30%
- Construction period for large CHP, small CHP, large heat and large electric plant is assumed to be two years. Construction period for small heat and small electric plant is one year. Construction period for very small heat plant assumed to be less than one year
- Equity investment is spread over one year more than the construction period, starting in Year 0, and is counted as negative cash flow[8]
- Debt level (gearing):
  - All large plant 55%
  - Small electric and CHP 40%
  - Small and very small heat 0%

  These levels of debt are consistent with current economics and market and technology maturity. Individual projects will have individual circumstances that are different from the general analysis presented. As the market and technology matures, and if the underlying economics projects improve, then the levels of debt will rise, further improving equity returns. In the most favourable case, such as occurs in on-shore wind projects, debt levels may rise towards 80%
- We considered two scenarios for the oil price (in real terms): the base case is $30/bbl; the high oil price is $50/bbl. $30/bbl is the level financiers are commonly using for long-term investment decisions. Although the oil price as of 31st of August 2005 is well over $60/barrel, over a 15-year perspective $50/bbl remains a reasonable high oil price scenario when compared to historical trends.

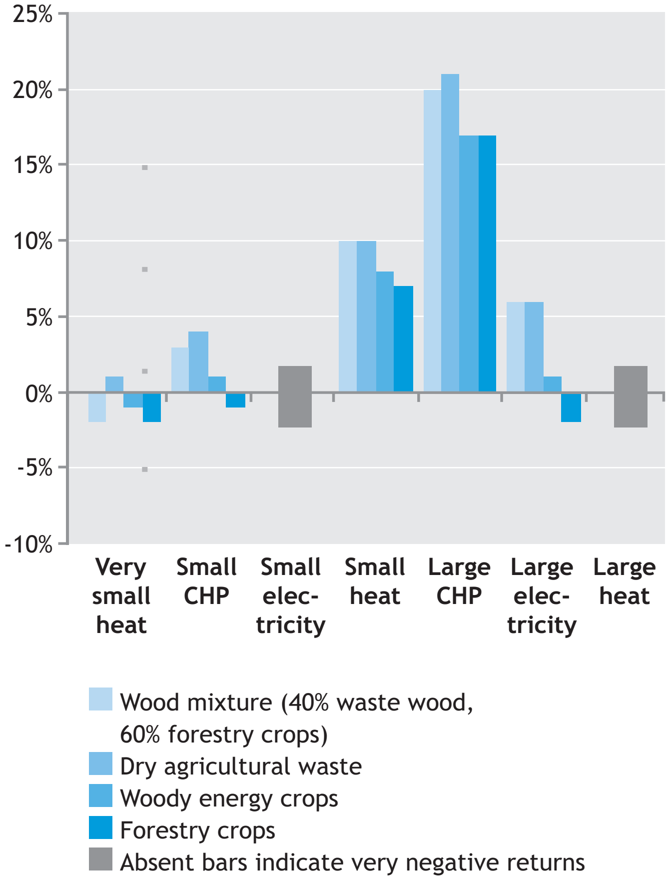
## Government incentives consist of

- Capital Grants: for which only small and very small heat plant can qualify. A capital grant is assumed to be 25% of capital costs
- Renewable Obligation Certificate (ROC): average of industry data is that 88% of the value is actually received by large generators and 75% by small generators
- EU Emission Trading Scheme (EU-ETS) credits: which are applicable to large and small electric plant, large CHP and large heat plant
- Climate Change Levy Exemption Certificates (LECs): average of industry data is that 80% of the value is actually received by large generators and 68% by small generators.

For further details on the assumptions, see Appendix 2.

[8] Hence it is possible to get negative IRRs in our model, corresponding to payback times over 15 years.

*__Figure 5__ Internal rate of return by plant type — current public sector incentives and oil at $30/bbl*

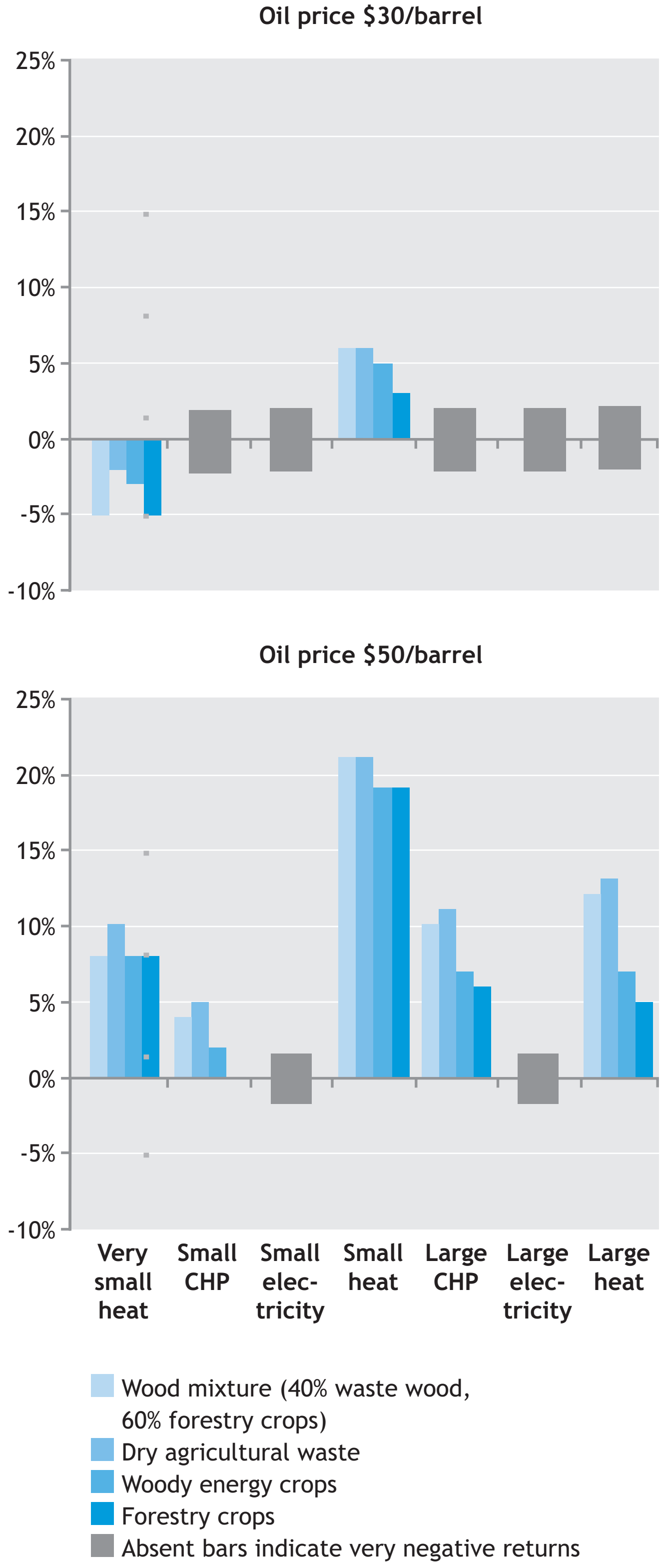



Source PAA

The returns are less sensitive to assumptions about conversion efficiencies. All types of heat plant are assumed to have heat conversion efficiencies of 85%. A 5% increase in heat conversion efficiency causes a 0.5% increase in the plant IRR and vice versa. However, increasing the electrical conversion efficiency for a large electric plant by 2% results in an increase in IRR of roughly 5% (although this does not account for the more expensive conversion equipment that would be required). For small electric plants it makes no calculable difference, as the payback times remain well over 15 years.

When the returns are modelled in an environment without Government incentives it becomes clear that the economics of electric and CHP plant are strongly dependent on the Renewables Obligation, since ROCs make up about half of the electricity revenue. As can be seen in Figure 6, only heat applications have positive rates of return without Government incentives in the $30/bbl scenario. Very small and large heat plant generate positive returns only in the high oil price scenario.

*__Figure 6__ IRR by plant type — no government incentives*

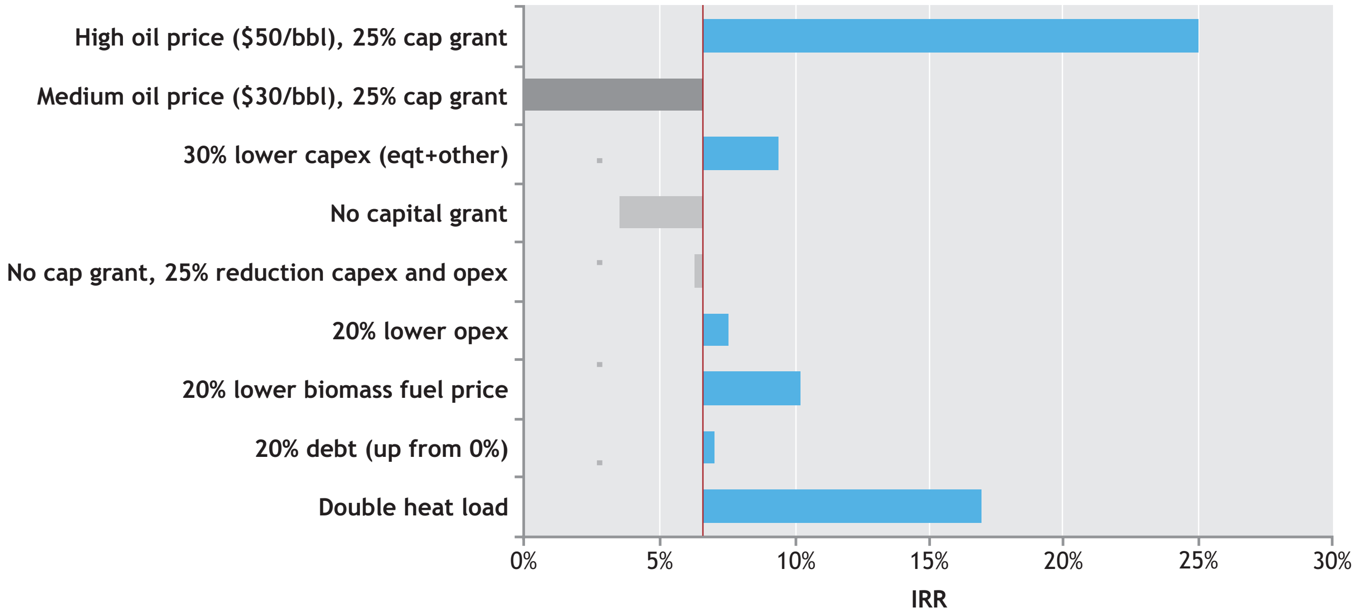



Source PAA

## Small heat plant

Oil price is the key economic driver for small heat (see Figure 7). In the current environment of high oil price and capital grants, small heat plant (~ 2MWth) are very competitive. Average sites of small heat boilers are expected to have low load factors, around 35%.

***Figure 7*** *Sensitivities for small heat boiler (2MW th)*

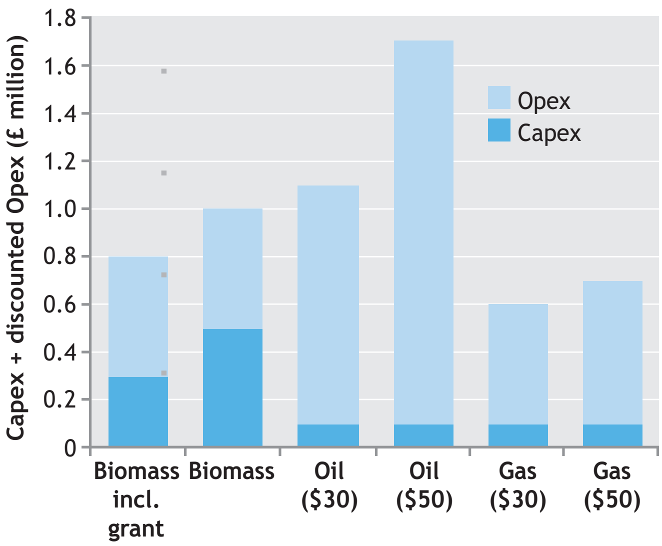



Note: Biomass boiler fuelled by forestry crops replacing boilers using light fuel oil. Source PAA

Choosing a site with a high heat load (e.g. nursing home) greatly improves the returns. Finally, a 25% reduction in capital cost (including equipment and installation) and operating costs increases the base case IRR by 2.8%, whereas removal of the capital grant reduces it by 3.1%. In other words, a 25% cost improvement would largely offset the current level of support.

Biomass small heat boilers have better lifetime economics than oil-fired boilers at both $30 and $50/bbl (see Figure 8). Above c$30/bbl fuel cost savings offset the higher investment costs of biomass boilers. Over 40% of the lifetime costs of biomass small heat boilers are capital costs, compared with 7-10% for fossil fuel boilers. Gas-fired boilers have lower lifetime costs than biomass small heat boilers, even at $50/bbl (we assume a link between oil and gas prices). Biomass boilers, therefore, will not displace on-gas grid boilers in any likely medium-term oil price scenarios, unless there are further substantial incentives. We have assumed that oil and gas boilers that are due for replacement have a lower conversion efficiency, around 75%, vs. 85% for modern boilers. Estimated clean-up costs for replacement of oil boilers (up to £50-75k in case of environmental damage) do not significantly change the results.

***Figure 8*** *Lifetime costs for biomass and fossil fuel boilers (2MW th) at $30/bbl*




Notes: Biomass boiler fuelled by forestry crops
Oil-fired boiler using light fuel oil
Lifetime 15 years

Source PAA

## Large heat plant

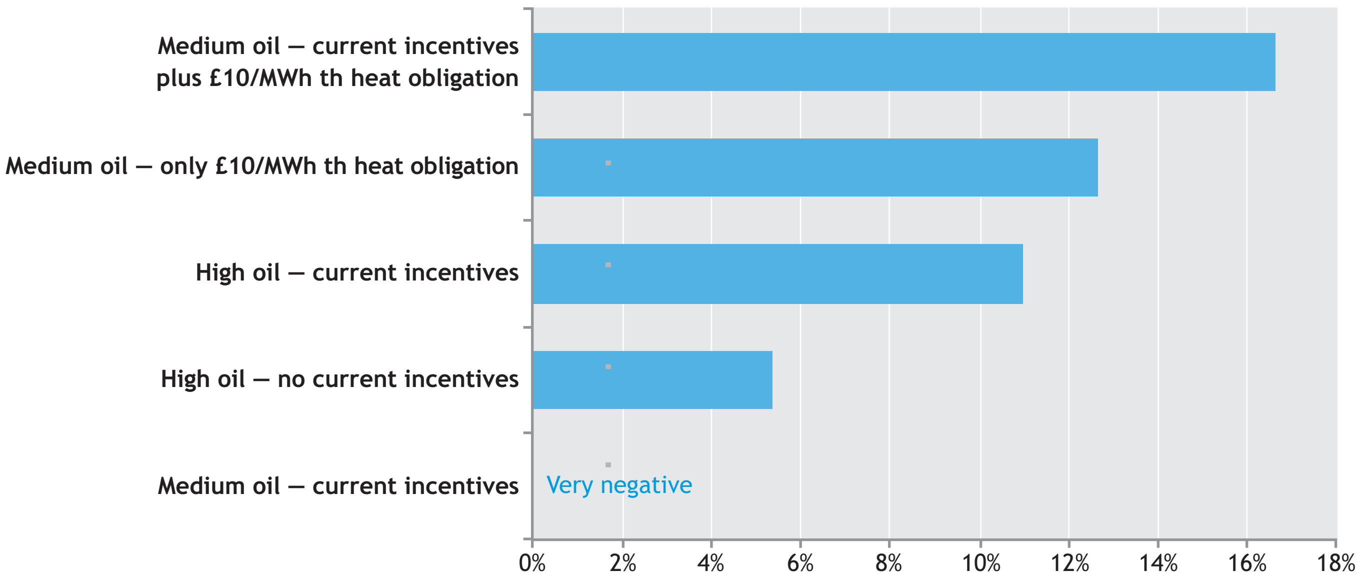
Large heat plant are almost economic in the current environment of high oil price and (modest) EU-ETS support, but they are very sensitive to revenue changes due to low unit capital costs. The revenues of heat plant are driven by the cost of the displaced fuel, which is almost twice as high for small plant than for large plant. In large plant biomass is assumed to displace heavy fuel oil, which is much cheaper than the gas oil displaced for small plant (due to both specification and economy of scale). Large heat has low unit capital cost around £360/kWth, compared to £1,630/kWe for large electric and £1,780/kWe for large CHP plant.

At a medium oil price, even with the current modest incentives via the EU ETS, large heat is very uneconomic. Support of £10/MWhth (equivalent to c.€50/t $CO_2$) would make large heat plant competitive even at medium oil price. This is illustrated in Figure 9, which shows the rates of return of large heat plant under various scenarios.

## CHP plant

The economic modelling shows that large CHP plant have a return of c.15% with Government incentives, but are highly uneconomic without it. Despite the fact they are economic in the current environment of Government incentives and a high oil price no biomass LCHP plant have been built over the past few years and only a few are in planning. Some sites that would warrant a LCHP plant have chosen to build electricity-only plant instead. The possible reasons for this are given at the end of this section. Small CHP is less economic than large CHP because of higher unit capital costs, O&M costs and generally lower load factors.

***Figure 9*** *IRR for large heat plant (30MW th) under various scenarios*




Source PAA

## Electricity generating plant

Large and small electricity plant have negative to moderate returns in all reasonable scenarios, including the one with current Government incentives. Revenues are driven by the electricity price which is expected to rise as oil prices rise. At $50/bbl and with Government incentives, large electric returns are positive, but below the level necessary for investment (see Figure 10).

Despite their modest economics under general circumstances, some large electric biomass plant have reached financial close (e.g. Sembcorp). There are several possible reasons for the apparent discrepancy between the analysis presented here, which indicates that such projects are non-viable, and those examples:

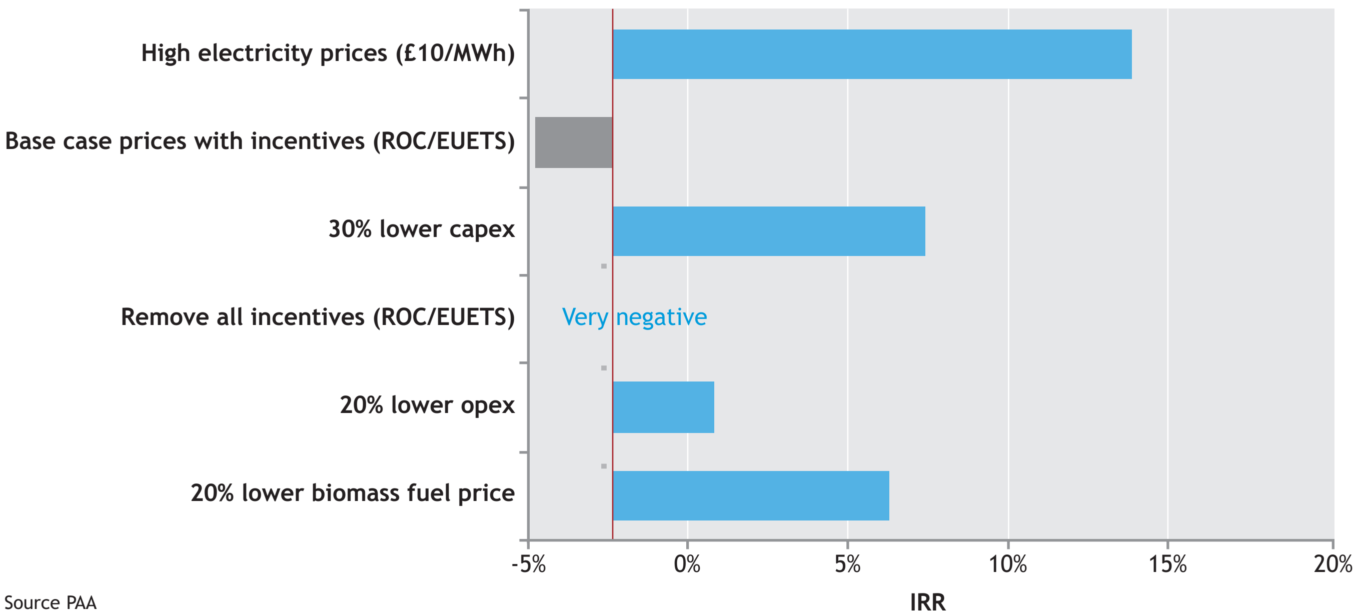
- Projects have received grants that have a significant impact on the economics through reducing the capital costs. Our model does not include capital grants for electricity projects, as these grants are not currently available
- Projects have been financed under a different structure, which effectively has a lower required return, e.g. through refinancing of existing businesses
- Projects have achieved higher power purchase agreements than assumed here, e.g. through internal power purchase agreements
- Fuel resource may be available in certain locations at lower costs than assumed in this analysis, which assumes fuel costs applicable to a large number of projects across the UK.

The returns of electric plant become worse with decreasing plant size. Small electric plant are not viable for any fuel under any scenarios. Conversion efficiency is lower and unit capital costs higher than for large electricity plant.

Finally, there are also specific reasons why some generators who might have been expected (from this analysis) to choose CHP generation have chosen to pursue electricity-only generation:

- Projects have only high temperature/grade heat demands. Using CHP to generate only high-grade heat is relatively inefficient and hence expensive
- Projects may have additional uncertainties related to the RO, e.g. adding a single biomass boiler within a large CHP generating station may cause the entire station to be treated as a co-firer, with attendant restrictions. However, adding an entirely separate biomass boiler unconnected to a heat system avoids this risk.

***Figure 10*** *Sensitivities for large electricity plant (30MW e)*




Source PAA

# Section 3. Barriers to development

## Summary

Despite the potential economic viability of certain biomass plant, relatively little construction is underway. In part this is due to the significant barriers to development that biomass faces throughout all stages of development. Four main barriers affect all developers; lack of market information on fuels, fuel supply risk, planning and policy costs. These barriers increase the risk of investing in biomass (thereby increasing the cost of capital), and increase operating costs. Together these reduce the economic viability of biomass developments. In addition, smaller developers are affected by a number of other barriers including lack of awareness and understanding of biomass by end-users/customers, poor availability of technical expertise (installation and maintenance) and lack of access to debt funding.

In a good fit with the economic analysis, heat applications face fewer barriers than CHP or electricity-only plant as they avoid issues related to the Renewables Obligation, debt financing and, in many cases, planning.

## Barriers within the stages of biomass development

Interviews, literature surveys and peer review have all confirmed the existence of a substantial number of barriers that impede the development of biomass at every stage. When a developer is involved (typically when a new plant is built on a greenfield site, often with high levels of debt finance) development comprises three stages, the last two occurring in parallel:

- *Project initiation:* Where the site and customers are identified, and planning and permitting are undertaken. In general the key problem at this stage is to convince customers and the local population of the merits of the project
- *Project development:* Where the project is financed and the permitted project is built. The key problems here are the high project costs due to lack of scale (in general each project is unique) and high complexity
- *Supply chain development:* Where fuel supply contracts are negotiated and then executed. The key problem is to secure supplies which are bankable from an investor's point of view.

The development process is simpler at small scale (i.e. very small heat) and when biomass is replacing existing heat plant (e.g. replacement of an oil boiler by a wood chip fuelled boiler), which often involves a package of equipment, installation, maintenance and fuel supply contract.

## Project initiation barriers

The barriers affecting the project initiation stage can be grouped into five areas; credit, financial market gap, market information, planning and end-user misalignment:

### Credit

Many, typically smaller, developers do not have a strong creditworthiness record. This is important for electricity plants, as lack of creditworthiness prevents a developer entering into discussions with an electricity supply company on a Power Purchase Agreement (PPA). In turn, a PPA is necessary to raise debt-based finance. The electricity supply company will only do business with a generator who can demonstrate a low level of counterparty risk. Lack of creditworthiness is much less of a barrier in heat applications as no PPA is required although if the developer is also supplying the fuel he will need to be able to demonstrate long-term reliability.

### Financial market gap

Typically it is advantageous to finance projects above small scale with a high level of debt, say above 50%, as this reduces tax charges and increases return on equity. However, small developers who seek to finance small-scale projects one at a time often find their debt needs are below the threshold required to gain the interest of most lenders (usually banks). Thus finance may not be available at all, or fees and interest rates may be substantially increased over usual levels, reducing the viability of the project.

### Market information

In order to get preliminary interest from the planning authorities and financial institutions, project developers need to demonstrate the availability of fuel supplies in considerable detail. This includes identifying the primary suppliers and secondary suppliers as back-up to cover contingencies such as poor weather and crop failure. In the case of CHP or heat projects, developers must also identify suitable heat demand from creditworthy customers. Both the biomass fuel and heat markets are opaque. Market information is often not collected and very rarely published. This means that projects are difficult to identify and/or place unnecessary market information costs on developers.

### Planning

Local opposition, inexperience and lack of resources in planning authorities, lack of coordination, and lengthy and unclear planning procedures can substantially increase project risk. For example, there is no standard planning template for biomass projects. Planning is an issue for all schemes at and above small scale and is particularly onerous for plant using waste (e.g. waste wood) as a fuel.

### End-user misalignment

A variety of barriers relating to end-users of biomass energy prevent users from taking what, on the face of it, is the rational decision to invest in biomass energy. This seems to affect small and very small-scale biomass schemes particularly.

Often energy is a non-core activity for the end-user (e.g. a supermarket, leisure centre or hotel) where, for non-energy intensive industries, the cost of energy is typically 1-2% of turnover. Investment in biomass may be seen as unattractive, despite a positive NPV, as:

- The initial capital cost is often higher than fossil fuel alternatives and companies often have constrained capital
- The payback period (10+ years) is far longer than the typical payback of 1-4 years for non-core investments.

Users are often poorly informed about the risks and benefits of biomass. For example, industrial heat loads are ideal for biomass as they have a high utilisation. However, unfamiliarity with both biomass technology and fuel supply chains can lead to a perception of high operating risk which is highly undesirable in an industrial situation where energy disruption would lead to severe impacts including loss of production, and loss of customers and market share. Furthermore, it appears the environmental benefits of biomass may not be widely appreciated by potential end-users.

Overall the barriers at the project initiation stage are typically of the 'go/no-go' variety, preventing potentially viable projects from starting. They impact very small heat projects the least, as these do not usually require either detailed planning permission, debt finance, or a developer with a strong track record of creditworthiness. Small heat and large CHP schemes are affected by most of the barriers, although small heat is not affected by the credit barrier and large CHP is not affected by the financial market gap barrier (undertaken by large developers). Small CHP is affected by all the project initiation barriers.

## Project development barriers

At the project development stage, there are three main barriers that increase the costs of a biomass scheme in ways that could be avoided in the future. These are:

### Policy costs

The current policy framework creates cost burdens for biomass schemes in two key areas. Firstly, there is a lack of availability of long-term PPAs, and inherent uncertainty in the Renewable Obligation mechanism for developers who are not part of an integrated electricity supply company. This barrier is common to almost all renewable power and has been well documented elsewhere[9]. This is translated into discounts on electricity and ROCs as high as 25% and increases the need for secure and inexpensive fuel suppliers. Secondly, where it is relevant, the Waste Incineration Directive (WID) imposes emission control costs that can make the difference between survival and closure for some biomass generators, whereas the risk of dioxin emissions from biomass generators is relatively low[10]. This is compounded by the broad definition of waste used in WID, covering all by-products. Clearly these policy costs affect those biomass projects which generate power and those which use waste as a fuel.

### Costs of finance

The financial market gap indicated earlier in this report leads, in the development stage, to high costs of finance because of higher equity requirements and higher interest rates and fees. This is compounded by the perception of a high degree of risk and the high individual project assessment costs, as biomass projects are not well understood by lenders.

### Project costs

All biomass developments have a variety of ancillary project costs such as legal costs and installation costs, including civil engineering costs and grid connections. In a biomass project the legal costs are particularly high because of the complex contractual obligations. The installation costs can be high, and access to the grid, as with many other renewable power technologies, is a lengthy process and financially risky. These costs affect all the biomass chains apart from very small heat, which has a simpler project structure and no need for grid connections.

All these costs have been included in our modelling used to generate the project economics presented in Section 2. The impact of addressing these barriers would, therefore, be to improve the economic viability of biomass developments.

In addition there is a specific market gap for very small heat, due to a lack of availability of expertise and training. This means there is a pressing shortage of installation skills, which substantially hampers the roll-out of (very) small heat boilers.

[9] DTI; Renewables Innovation Review.
[10] House of Lords Select Committee on Science and Technology; "Renewable Energy: Practicalities".

As in the project initiation stage, very small heat is affected by the fewest barriers overall (only the market gap in expertise and training). All other applications are affected by policy cost, costs of finance and project costs barriers, although small heat is less affected by policy costs (i.e. no issues around PPAs/ROCs).

Finally, there are a number of costs which are currently high but will reduce as the biomass sector grows. They are not barriers in the sense of market failures or inappropriate cost, but they will benefit from any incentives which accelerate the growth of biomass in general. These include:

- Maintenance costs
- The costs of performance guarantees, indemnities and insurance.

## Supply chain barriers

The principal barrier in the supply chain is fuel supply risk, which has two key elements: contracting risk and production variation.

A developer or end-user needs to be able to agree fuel supply contracts with creditworthy and reliable suppliers in order to run their operation and access debt finance (the supply contracts need to be 'bankable', i.e. be very low risk). There is a lack of such suppliers in the UK. Individual farmers or foresters are usually too small to be creditworthy and are sometimes regarded by creditors as unreliable debtors. Biomass fuels usually have alternative uses (e.g. in the paper or furniture industry) and, if prices in these markets exceed biomass fuel prices, the product could be sold to these alternative uses, leaving the biomass plant idle due to lack of feedstock. Furthermore there is little supply infrastructure, i.e. fuel intermediaries that are creditworthy and have a variety of contracts that enable them to mitigate climatic, price and other risks. This is not an absolute barrier as some creditworthy counterparties exist (e.g. in waste wood, and forestry contractors and organisations such as Forestry Enterprise), but at present these account for a small minority of the available biomass resource in the UK.

As biomass is a natural product there can be considerable variation both in quality (e.g. moisture content or level of contamination) and quantity (e.g. yield variations for energy crops). Again, due to a lack of a supply infrastructure (e.g. a liquid market where price or quantity risk can be hedged), this risk must be managed directly by the developer. In addition, the current policy framework compounds fuel supply risk by narrowly defining energy crops and placing restriction on the transportation of fuel for grant-funded plant.

Fuel supply risk affects all the key applications of biomass, although smaller-scale developments find the risk easier to manage as their demand is better suited to the supplier structure.

## Barriers from a developer's point of view

Examining the barriers from the developer's point of view, rather than from the application-type point of view, we see that large developers face four main barriers which increase risk, thereby increasing the cost of capital and increasing operating costs. Together these reduce the economic viability of biomass developments. The four barriers are:

- *Market information (Project Initiation):* The lack of fuel market information makes identification and coordination of large-scale supplies difficult to achieve. The need to contract without reference to standard prices and terms increases negotiating and contracting costs
- *Fuel supply risks:* The absence of major counterparties results in credit risk. In addition, the lack of significant trading of the major fuels means that supply risks (quality, price or volume) cannot be hedged
- *Planning:* Public opposition to large biomass plant can be strong, and the complexity of the planning process increases with plant size
- *Policy costs:* For power generation plant, the uncertainty inherent in the RO mechanism reduces the value of the ROCs received by non-integrated suppliers.

Small developers face all the above barriers although fuel supply risks are often more manageable at a smaller scale. They face, moreover, a number of additional barriers:

- *Credit:* Without credit, some small developers are unable to negotiate a PPA
- *Financial market gap:* Owing to the financial market gap, small developers may be unable to raise investment. Project finance is not viable for small projects, and small developers are not sufficiently capitalised
- *Cost of finance:* As a result of the higher equity requirement and higher interest rates/fees, the final cost of finance is generally higher than for large developers
- *End-user misalignment:* Lack of awareness of biomass boilers, and the non-core nature of energy, leads to lower than expected investment by end-users
- *Market gap:* Lack of expertise and training
- *Project costs:* Ancillary costs for smaller developers are higher.

In general, very small heat faces the fewest barriers. As the projects are far simpler, planning and financial barriers are low and RO issues are avoided.

For the latter reason, small and large heat applications face fewer barriers than CHP or electricity-only applications.

# Section 4. Carbon savings

## Summary

From a carbon saving point of view, conversion of oil-fired heat plant to biomass-fired systems is the most attractive approach, due to their high conversion efficiency and the high level of emissions from the displaced oil. Replacing all suitable oil-fired boilers with biomass-fired boilers would save c. 2.5 MtC/yr and use almost 90% of the currently available biomass, or 45% of the currently and potentially available biomass (i.e. where energy crops are included). The remaining biomass could be used in large CHP plant or co-firing potentially saving up to a further 2.7MtC/yr.

## Carbon savings based on available biomass resource

In calculating the carbon-saving potential of the various biomass fuel resources we have assumed that biomass usage has no net carbon emissions. Strictly speaking there will be some net carbon emissions due to harvesting, handling and transport which at least in the short term will be fuelled by fossil fuels and hence emit carbon. However, the standard emission factors for fossil fuels[11] (see below) do not include additional emissions due to extraction, processing and transport. Recent reports[12] have shown that the additional emissions for fossil fuels are significant and of the order of the net emissions for biomass. As these effects cancel each other out they have not been taken into account.

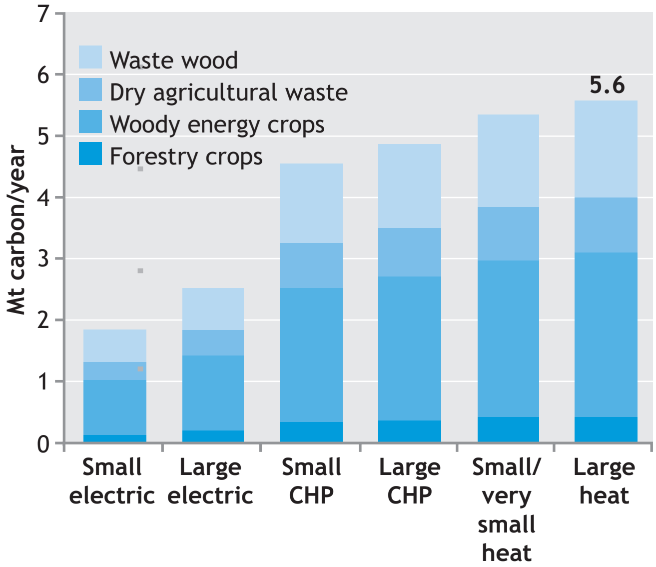
- Replacing electricity at 0.43t $CO_2$/MWh
- Electric and CHP plant displace gas at 0.22t $CO_2$/MWh
- Large heat plant displaces heavy fuel oil at 0.31t $CO_2$/MWh
- Small heat plant displaces light fuel oil at 0.29t $CO_2$/MWh.

Biomass could save a maximum of 5.6MtC/yr if all the existing and potentially available UK biomass resource was used in large heat, which has the highest conversion efficiency and displaces the higher carbon intensity heavy fuel oil (HFO), rather than light fuel oil (LFO) (see Figure 11). Using the same resource in small heat or very small heat only reduces the carbon savings slightly, and if used in large or small CHP the carbon saving falls to between 4 to 5MtC/yr. The low efficiency of electricity-only plant (less than 30% for combustion plant vs. 85% for heat plant) substantially reduces the carbon-saving potential to 1.8-2.5MtC/yr.

This assumes that woody energy crops are grown on c. 680,000ha. If it is assumed that 1Mha is available for woody energy crops then an additional 1.1Mt of carbon could be saved annually.

Note that the amount of carbon saving shown in Figure 11 cannot be added across plant types (across the columns), because the fuel can only be used once. In practice the total carbon saving will therefore be less than 5.6Mt carbon/yr, as resources will be used in different plant types.

***Figure 11** Potential total carbon saving by plant type*




Source PAA

[11]Source: Carbon Trust. [12]"Balance of Energy and Greenhouse Gas Emissions Throughout the Life Cycle of Natural Gas and Heating Oil as Fuel for Domestic Heating", RDC, Feb. 2005 and "Carbon Energy Balances for a Range of Biofuel Options", DTI Report B/B6/00784, 2003. The order of magnitude of these effects are c. 10% for heat and c. 20% for electricity.

## Impact on imports

In calculating these carbon savings we have assumed that only UK sources of biomass are used, i.e. no additional import of biomass. However, the biomass supply chain is currently a major barrier, and some projects (mostly co-firers) are using imported biomass, partly to overcome this barrier.

Transported biomass material needs to be of a reasonable bulk density, in order to keep transport costs and its associated carbon emissions low. Several studies have shown that although the carbon emissions associated with long-distance sea transport of biomass are higher than those associated with the use of domestic biomass, they remain relatively low compared with the savings generated by displacing fossil fuels. Liquid biofuels have a high energy density (GJ/$m^3$) and are easily transported; therefore biofuels (ethanol, biodiesel, vegetable oils) are likely to be manufactured at the location where the resource arises and transported to end-users.

Given the high availability of biomass outside the UK, carbon savings using imported biomass could be substantial, even once the associated transport emissions are accounted for.

Imported wood currently has similar delivered costs to domestic supplies. Imports are therefore expected to have little impact on the viability of biomass developments. Ultimately the cost of imported resources will rise as demand increases, and can be expected to normalise across Europe driven by widespread imports by countries such as the Netherlands.

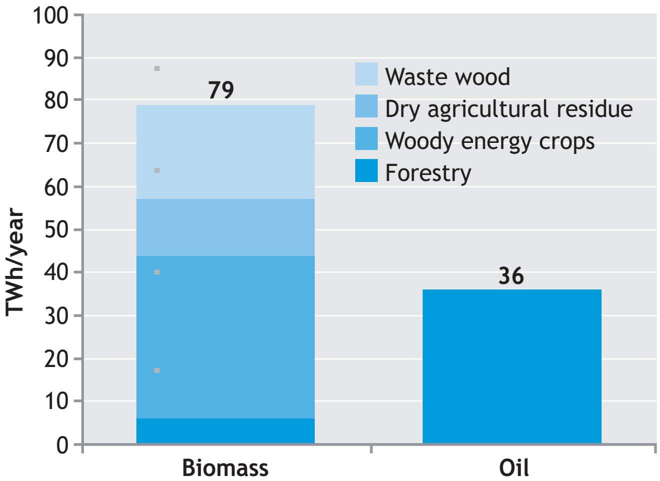
Therefore, although the use of indigenous biomass is preferable from an economic development and carbon reduction viewpoint, relying on imports may continue to be useful in the short term, as well as necessary in the long term.

# Carbon savings based on substitution potential

We have estimated the potential carbon saving, taking into account the demand for the fuels that biomass would displace (notably fuel oil) and the size of the applications that biomass could penetrate. Note these estimates illustrate what could occur if UK biomass resources were allocated to maximise carbon saving. In reality, actual carbon savings from UK biomass resources will, almost certainly, be lower.

The most viable applications for biomass (excluding Government incentives) and those with the highest carbon savings are heat applications where biomass displaces oil. According to DTI data, non-domestic users (industrial non-iron/steel and non-transport) consumed 2.9Mt/yr of fuel oil in 2004, or c. 36TWh/yr. Most of this oil is used for heating, in applications varying from very small to large heat. In Section 1 we showed that all current domestic biomass from the three current resource groups together could deliver 41TWh/yr (6TWh from forestry crops, 13TWh from dry agricultural residue and 22TWh from waste wood). Therefore about 88% (i.e. 36TWh of the 41TWh total) of the current carbon savings potential of biomass, or c. 2.5MTC/yr, could be achieved by replacing all non-domestic oil usage with biomass plant. If the potential amount of woody energy crops is added, about 45% of the total carbon savings potential could be achieved (see Figure 12). Much of the dry agricultural waste (straw) resource is likely to be used in large applications due to handling issues (straw is mostly available in large and heavy bales).

***Figure 12*** *Total potential biomass energy and non-domestic oil energy*




Source PAA

The remaining biomass resource totalling 43TWh/yr (5TWh/yr of currently available biomass, and 38TWh/yr potentially available biomass) is likely to be used in two further markets:

- Large CHP plant substituting gas. In the current policy environment large CHP is competitive and the next most economically attractive use after heat if Government incentives are ignored. A study for the Carbon Trust[13] estimated that the unexploited technical potential in industrial applications for gas-fired large CHP plant is roughly 6.7GWe. Exploiting less than half of that potential would use all the remaining 43TWh/yr of potential biomass energy in CHP plant and would save c. 2.7Mt/yr of carbon per year
- Co-firing. This was not analysed in great depth as the potential for the Carbon Trust to be material in this area is limited. However, it was concluded that co-firing biomass in coal plants is economic and relatively attractive from a carbon-saving and cost of carbon-saved point of view[14]. If it is assumed that on average coal stations use 3% biomass then in total in the UK co-firing would use c. 10TWh/yr of biomass fuel and could save c. 0.7MTC/yr. Note that this would only be valid for the short to medium-term future, as the Government is planning to phase out co-firing support on the longer term.

Finally, there may also be two other markets into which biomass could (eventually) be used. Firstly, in the domestic heating sector, which used about 2.4 Mt fuel oil in 2004[15]. Due to the low load factor (around 15% in the UK) and relatively high unit capital costs this sector is currently not competitive. However, some wood boiler suppliers are reporting a growing interest from the domestic sector, especially as the oil price continues to rise. Secondly, there is the use of petroleum gases[16] in the industrial non-iron/steel, non-transport, and domestic sectors, which could be replaced by biomass.

Overall, we estimate that about 5MTC/yr could be saved in the UK by using all current and potentially available biomass. Half could be saved by replacing the oil used for heating in the industrial non-iron/steel and non-transport sector and the remainder in large CHP or co-firing applications.

[13] AEAT: "Study of the Carbon Savings and Economics of CHP Schemes".
[14] Source B&V.
[15] Source DTI.
[16] Includes ethane, propane, butane and other petroleum gases.

# Section 5. Implications for Policy and the Carbon Trust

## Summary

Small and large heat are the only two applications modelled that presently have a low cost of carbon[17]; c.£25/tC and c.£30/tC respectively at $30/bbl crude. Through standardisation and deployment at scale, small heat has the potential for significant cost reduction (c.25% of project costs). Large heat technology is mature and offers more limited opportunity for cost savings. None of the other biomass applications currently offer sufficient cost reduction opportunity to achieve these low costs of carbon; however, this situation should be regularly reviewed.

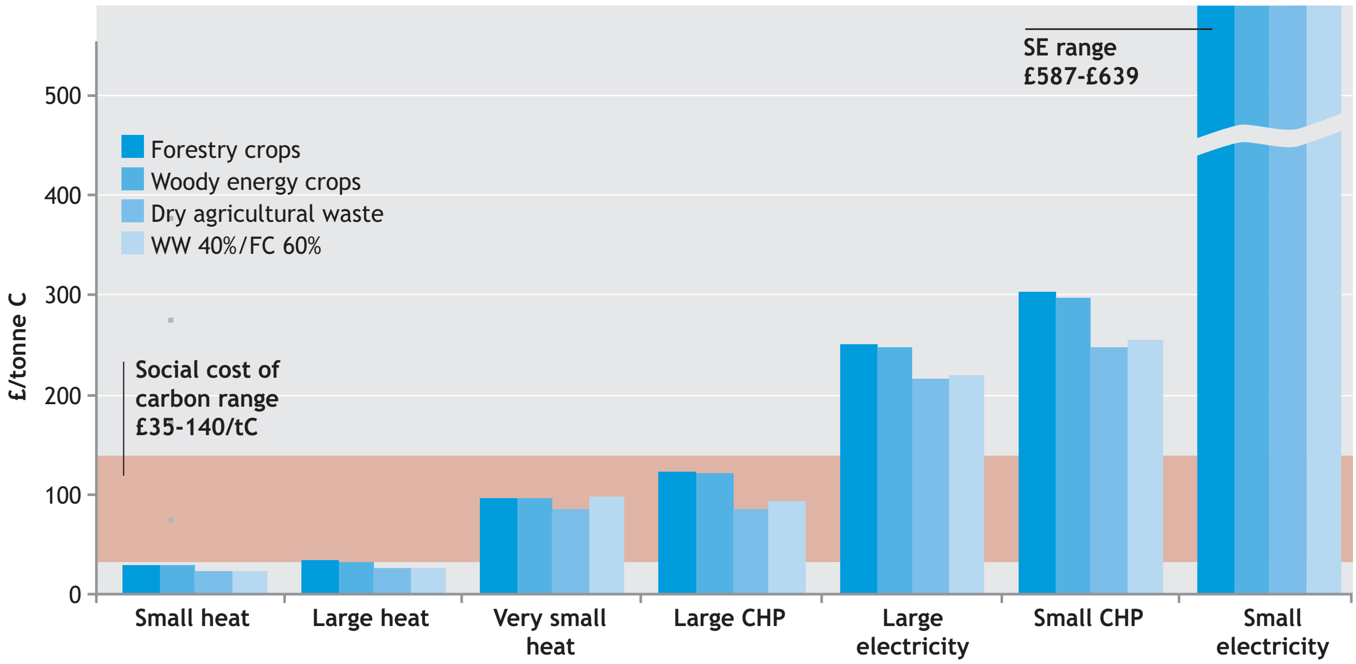
On a cost-of-carbon basis, therefore, the UK should consider exploiting the largely untapped potential of heat applications, particularly small heat. To do so will require long-term support (e.g. through the EU-ETS or a Renewable Heat Obligation and/or a capital grant programme) and targeted action to address the key barriers to biomass development. This should include investment in large scale supply chain/technology demonstration programmes, education and information programmes, and ensuring the recent changes to the planning system are effective. However, in shaping the overall policy framework for biomass (including CHP, electricity and biofuels), its non-carbon benefits will need to be considered (e.g. energy security, employment opportunities, non-intermittent electricity supply, etc).

## Costs of carbon

Whereas all the biomass applications which we have studied in detail have considerable scope to save carbon, only heat applications can do so cost effectively at present.

We have estimated the current cost of carbon for each of the major biomass applications (defined as cost per tonne of carbon saved to bring the NPV of an investment to zero at a discount rate of 15% without any government incentives). This shows that two heat applications, small heat and large heat, have the potential to deliver cost-effective carbon savings. Using our base case of $30/bbl, both have a cost of carbon below £35/tC, the bottom of the current range of the Social Cost of Carbon. The range of costs of carbon is £23-29/tC for small heat and £27-34/tC for large heat (see Figure 13) depending on the type of fuel. At $50/bbl, the costs of carbon for small heat become negative, and those for large heat are very low at £5-15/tC.

***Figure 13*** *Cost of carbon per type of biomass plant*




Notes: 1 Assuming $30/barrel oil, excluding any existing Government incentives
Sources: UK Government Economic Service/PAA

[17] Cost of carbon has been defined as the cost of bringing the NPV of a biomass project up to zero at a discount rate of 15% without any current policy support, per tonne of carbon saved.

Two further applications, very small heat and large CHP, deliver carbon savings within the range of social costs of carbon, £35-140/tC. At $30/bbl, very small heat has a cost of carbon of between £86-97/tC dropping to £40-52/tC at $50/bbl. Large CHP has a cost of carbon between £94-131/tC at $30/bbl, dropping to £62-121/tC at $50/bbl.

All the other applications, large and small electricity and small CHP, have costs of carbon well above £140/tC (the upper limit of the social cost of carbon) at $30/bbl and $50/bbl, and so can not deliver cost-effective carbon savings at present.

In general for heat, CHP and power applications, the lowest cost of carbon is generated by dry agricultural waste and the highest by forestry crops, although the difference is marginal in terms of policy conclusions, noting that in general dry agricultural waste is more suitable for large-scale applications.

## The case for Government support — small heat

The case for Government support for small heat is strong. In addition to the lowest current costs of carbon, small heat has the potential to further reduce its cost of carbon.

At present, small boilers are sized for specific applications and sold in low volumes, with high marketing and distribution costs. Equipment costs are not greatly affected by the low scale in the UK as most small boilers are manufactured outside the UK and at high volume. Increasing penetration could lead to a reduction of 20-30% in final project costs through economies of scale and a higher level of standardisation.

A cost reduction of 25% in small heat projects reduces the cost of carbon from c. £25/tC to £18/tC. In high load factor applications, such as residential care homes and buildings where both heating and cooling are required, it is likely that small heat would be fully competitive at $30/bbl.

Despite its favourable cost of carbon and the potential for further cost reductions, small heat currently receives limited long-term Government assistance. For example, small heat plant is too small for Phase 1 of the EU-ETS and the Climate Change Levy (CCL) provides no incentive for applications that would otherwise use fuel oil as this is exempt from the CCL.

There are a great many potential applications for biomass at an intermediate size between small and very small heat. Many of these intermediate-sized applications are likely to have similar characteristics to small heat and therefore will have the same case for Government support.

As part of this review we have not quantitatively evaluated the alternative ways in which the Government might intervene. However, our analysis would suggest that to reduce carbon emissions using biomass, intervention should seek to encourage investment in small heat. This should drive down costs and establish robust fuel supply chains which will in turn have wider benefits for other biomass applications. Achieving this will probably require some form of financial support to underpin future oil price uncertainty, and action to address the key barriers to the development of biomass.

We have not conducted a detailed appraisal of biomass policy mechanisms, as that is part of the wider remit of the Government Biomass Taskforce. However, based on our interviews and analysis, we have briefly examined five different potential financial support measures: capital grants, EU-ETS, CCL, Renewable Heat Obligation (RHO) and other fiscal measures. Although no scheme is ideal, the most promising measures appear to be the EU-ETS and the RHO and, potentially, capital grants if the current scheme is re-thought.

Inclusion of small heat into the EU-ETS has a number of advantages. It is a long-term scheme which taxes carbon emissions directly, and the current price of carbon provides sufficient support. On the other hand, the administrative costs of the EU-ETS may be too high for small developments, the new entrant reserve is limited and, as the EU-ETS is a market-based scheme, the future price of carbon is uncertain.

Creation of an RHO has been subject to considerable debate in policy circles and we will not seek to replicate existing argument here. However, from the biomass point of view, an RHO could provide a long-term framework within which support levels could vary according to, among other factors, the variation in oil prices. However an RHO maybe very difficult to set up in practice.

As currently established, capital grants have been ineffective. Our interviews have highlighted three main problems: the temporary nature of grants (and therefore the lack of certainty needed to stimulate infrastructure investment), the distortions in the boiler market caused by grants and the high level of bureaucracy involved in applying for a grant. It may be possible to re-structure the capital grant scheme to overcome these problems, but no concrete suggestions were made as part of our interviews.

The other potential support measures seem unlikely to be effective. Industry believe that the CCL will not continue, and this undermines its impact on investment decisions. Other fiscal measures (e.g. ECAs and reduced VAT) are likely to have limited impact, either because the subsidy level is low or because coverage is poor (i.e. VAT which only effects non-business applications). However, in the latter case there is some indication that VAT on biomass boilers is a significant hurdle for very small users.

In addition to providing financial support, Government may well have a role in addressing 5 out of the 10 key barriers to the development of biomass identified in this report:

- *Market information:* The provision of information on resource, in this case biomass fuel, is a public good that Government could ensure is readily available, as it does in other areas.
- *Fuel supply risks:* Fuel supply will not be fully available until biomass projects are in place to create a demand. On the other hand, biomass projects will not be developed until fuel supply is available. Government can have a role to play in addressing this systemic market failure by encouraging the development of a fuel supply infrastructure e.g. by setting up supply chain demonstration programmes
- *End-user misalignment:* This barrier covers a variety of market failures including lack of awareness, split incentives (e.g. the landlord/tenant split) and systemic failure (e.g. externally imposed budget constraints). It is clearly legitimate for Government to address market failures e.g. by enhancing support activities such as information provision
- *Market gap:* As the key provider of skills in the UK, the Government has a role in addressing the lack of expertise in certain heat applications
- *Planning:* Government clearly has a role in aligning the planning process to its objectives.

The above include all the major barriers to heat schemes in the project initiation stage which prevent the start-up of biomass developments, as well as the key supply-chain barrier and the non-cost project development barriers. We expect that successfully addressing these barriers would have a material impact on the development of biomass as a whole.

We have not assessed in detail the ways in which to address these barriers. However, solutions could include:

- Large-scale demonstration projects to establish regional supply chains and drive down costs. As part of this demonstration project, fuel and heat demand availability could be mapped and published
- Support programmes (e.g. education, information and training) to help deal with end-user misalignment and the expertise/market gap
- Monitoring of the impact of PPS22 to establish if it provides a suitable planning framework for biomass.

## The case for Government support — large heat

The case for Government support of large heat is much less strong.

At high oil prices ($50/bbl), large heat is almost economic, and with a modest level of support (e.g. £3/MWth) would be economically viable. However, large heat returns are very sensitive to changes in oil prices, more so than small heat. Large heat plant IRR drops from 11% to very negative on reducing oil prices to $30/bbl (see Figure 9). In contrast small heat IRR drops from 25% to 7% on reducing oil prices from $50/bbl to $30/bbl. Therefore, investors will have to expect that oil prices will remain consistently high for the long term (say 10-15 years) before being convinced of the viability of large heat. Even at current high oil prices, this long-term expectation has not been established.

Furthermore, large heat plant technology is very mature and expected cost improvements are small. Unlike small heat, therefore, there is little prospect of being able to phase out Government incentives, unless oil prices stay high long term.

## The case for Government support — other applications/technologies

At present the other biomass applications we reviewed have relatively high costs of carbon starting at over £80/tC. At present they do not offer the scope for improvement required to be economic without Government support. Consequently, from a carbon perspective, the case for Government support is much less clear than for small heat. However, in shaping the overall policy framework for all biomass (including CHP, electricity and biofuels), the Government will need to take into account the other benefits of biomass (e.g. energy security, employment, despatchable electricity generation, etc).

Large CHP and large electric are mature technologies with, therefore, limited scope for improvement and cost reduction. However, through the advent of new technology, small electric has the potential for cost reduction. In order to be economically viable, however, it would require very considerable cost reductions, of the order of 80% in both capital and operating costs, which is well beyond the scope currently envisaged. Small and very small CHP are the applications where technology is likely to have the biggest impact in terms of cost reduction. Successful development of technologies such as combustion/gasification feeding Stirling engines or turbines/fuel cells could reduce costs by up to 50%. However, at $30/bbl, a reduction of c. 70% is required to be economic without Government support. Clearly, this situation should be monitored in future, as technology may open up greater scope for cost reduction, or long-term oil price expectations may increase markedly.

## Next steps for the Carbon Trust

The Carbon Trust is now beginning to scope out a project, seeking to accelerate the development of biomass in the UK based on the experience it has gained in similar projects (e.g. the Marine Energy Challenge). The biomass project will focus on the use of biomass for heating at the small scale as a replacement for oil-fired boilers as this sub-sector offers the most cost-effective carbon savings at the present time and the Carbon Trust could have a material impact. While focusing on heat, the project will build a fact base that will facilitate the development of the biomass sector as a whole. A key objective will be to build a better understanding of the risks of development and how best to mitigate these across the entire biomass value chain, particularly the supply side.

# Appendices

## 1. Peer review participants

***Table 2*** *Peer review participants*

| Name | Title/Organisation |
|---|---|
| David Clayton | Secretary to the Biomass Task Force |
| Anna Briggs | Group Commercial Manager, Bronzeoak |
| Andrew Wood | Director, Bronzeoak |
| David Williams | Managing Director, Eco2 Limited |
| Dr. Robert Rippengal | Commercial Director, Econergy Limited |
| Peter Webster | Director, The Energy Crops Company Limited |
| Melville Haggard | Executive Chairman, Impax Capital |
| Gaynor Hartnell | Director of Policy, Renewable Power Association |
| Peter Billins | Advisor, Renewable Power Association |
| Steve Lavery | Timber Operations Director, Tilhill Forestry Limited |
| Dr. Patricia Thornley | Research Fellow, University of Manchester |

## 2: Modelling assumptions and references

***Table 3*** *Sources of forecasts for renewable energy Government support*

| Renewable support type | Source of forecast |
|---|---|
| Renewables Obligation Certificate (ROC) prices | Oxera, 'Economic analysis of the design, cost and performance of the UK Renewables Obligation and capital grants scheme', Report prepared for the National Audit Office, January 2005 |
| European Emissions Trading Scheme (EU-ETS) support | The Carbon Trust |
| Biomass emission credits | Taken as portion of EU-ETS, according to B&V benchmarking data |

***Table 4*** *Large heat plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW th | 30 | Assumption for large plant |
| Capacity factor | % | 80% | B&V industry benchmark |
| Electrical conversion efficiency | % | - | |
| Heat conversion efficiency | % | 85% | B&V industry benchmark |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW th | 360 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh th | 2.00 | Derived from B&V CHP industry benchmark |
| **Revenue** | | | |
| Replacement heat price | £/MWh th | | Forecast based on use of heavy fuel oil, with boiler efficiency of 85%[2] |
| EU Emission Trading Scheme for large heat plant | £/MWh th | | The only heat plant that are eligible for part of ETS |

[1]Mechanical, Electrical, Instrumental, Control and Automation. [2]Source: B&V.

***Table 5*** *Small heat plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW th | 2 | Assumption for small plant |
| Capacity factor | % | 35% | B&V industry benchmark |
| Electrical conversion efficiency | % | - | |
| Heat conversion efficiency | % | 85% | B&V industry benchmark |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW th | 225 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh th | 2.50 | PAA interviews |
| **Revenue** | | | |
| Replacement heat price | £/MWh th | | Forecast based on use of gas oil, with boiler efficiency of 85%[2] |

[1]Mechanical, Electrical, Instrumental, Control and Automation. [2]Source: B&V

Small heat plant will typically heat nursing homes, swimming pools, etc, where a higher heat load could be assumed. However, applications like schools may have lower heat loads. Hence the capacity factor is assumed to be 35%, as a reasonable average. Note that the economics of a plant are very sensitive to the heat load assumption: a 10% increase (decrease) in heat load will lead to roughly a 5% increase (decrease) in IRR.

Very small heat plant (Table 6) typically heat stately homes, small office clusters, etc, where an assumed capacity factor of 30% is a reasonable average.

*Table 6 Very small heat plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW th | 0.2 | Assumption for small plant |
| Capacity factor | % | 30% | B&V industry benchmark |
| Electrical conversion efficiency | % | - | |
| Heat conversion efficiency | % | 85% | B&V industry benchmark |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW th | 410 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh th | 4.50 | PAA interviews |
| **Revenue** | | | |
| Replacement heat price | £/MWh th | | Forecast based on use of gas oil, with boiler efficiency of 85%[2] |

[1]Mechanical, Electrical, Instrumental, Control and Automation. [2]Source: B&V

*Table 7 Large electric plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW e | 30 | Assumption for large plant |
| Capacity factor | % | 85% | B&V industry benchmark |
| Electrical conversion efficiency | % | 28% | B&V industry benchmark |
| Heat conversion efficiency | % | - | |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW | 1,630 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh e | 10.70 | B&V industry benchmark |
| **Revenue** | | | |
| Wholesale electricity price | £/MWh | | CT earlier project data, forecast to 2020 |
| Embedded benefit | £/MWh | 2.57 | CT earlier project data, averaged over three regions |
| Emission Trading Scheme for large electric plant | £/MWh | | Based on €7/t $CO_2$ up to 2008, then linear increase to €25/t $CO_2$ by 2020. Assumed 50% pass through to customers[2] |
| 88% of Renewables Obligation Certificate | £/MWh e | | Average of industry data is that 88% of the value is actually received[3] |
| 80% of Levy Exemption Certificate | £/MWh e | 3.36 | Average of industry data is that 80% of the value is actually received[3] |

[1]Mechanical, Electrical, Instrumental, Control and Automation. [2]Source: CT [3]Source: B&V

***Table 8** Small electric plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW e | 2 | Assumption for small plant |
| Capacity factor | % | 60% | B&V industry benchmark |
| Electrical conversion efficiency | % | 20% | B&V industry benchmark |
| Heat conversion efficiency | % | - | |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW | 2,431 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh e | 17.90 | B&V industry benchmark |
| **Revenue** | | | |
| 85% of wholesale electricity price | £/MWh | | CT earlier project data, forecast to 2020. 15% reduction compared to large electricity due to low negotiating power |
| 80% of embedded benefit | £/MWh | 2.06 | CT earlier project data, averaged over three regions |
| 85% of Emission Trading Scheme for large electric plant | £/MWh | | Based on €7/t $CO_2$ up to 2008, then linear increase to €25/t $CO_2$ by 2020. Assumed 50% pass through to customers[2] |
| 85% of LE ROC value | £/MWh e | 2.86 | 15% reduction compared to large electricity due to lower negotiating power |

[1]Mechanical, Electrical, Instrumental, Control and Automation.
[2]Source: CT.

***Table 9** Large CHP plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW e | 30 | Assumption for large plant |
| Capacity factor | % | 85% | B&V industry benchmark |
| Electricity conversion efficiency | % | 24% | B&V industry benchmark |
| Heat conversion efficiency | % | 56% | B&V industry benchmark |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW | 1,780 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh e | 10.70 | B&V industry benchmark |
| **Revenue** | | | |
| 75% electricity import price + 25% electricity export price | £/MWh | | CT earlier project data |
| Emission Trading Scheme for large electric plant | £/MWh | | Based on €7/t $CO_2$ up to 2008, then linear increase to €25/t $CO_2$ by 2020 |
| 88% of Renewables Obligation Certificate | £/MWh e | | Average of industry data is that 88% of the value is actually received[2] |
| Replacement heat price | £/MWh th | | Forecast based on use of gas, with boiler efficiency of 85% and ratio of "large industrial user price to wholesale price"[2] |

[1]Mechanical, Electrical, Instrumental, Control and Automation.
[2]Source: B&V.

***Table 10*** *Small CHP plant*

| Plant | | | Rationale or source |
|---|---|---|---|
| Size | MW e | 2 | Assumption for small plant |
| Capacity factor | % | 60% | B&V industry benchmark |
| Elec conversion efficiency | % | 16% | B&V industry benchmark |
| Heat conversion efficiency | % | 64% | B&V industry benchmark |
| **New-build capital costs** | | | |
| TOTAL, includes equipment, installation (civils, MEICA[1]), and other (legal, financial, EIA, planning) | £/kW | 2,643 | B&V industry benchmark |
| **Operation costs** | | | |
| Total operating and maintenance cost | £/MWh e | 17.90 | B&V industry benchmark |
| **Revenue** | | | |
| 15% higher electric revenue than LCHP, due to higher uplift to onsite hosts over the wholesale price | £/MWh | | B&V for uplift factors; CT earlier project data |
| 85% of LCHP ROC value | £/MWh e | | Average of industry data is that 88% of the value is actually received[2] |
| Replacement heat price | £/MWh th | | Forecast based on use of gas, with boiler efficiency of 85% and ratio of "large industrial user price to wholesale price"[2] |

[1]Mechanical, Electrical, Instrumental, Control and Automation.
[2]Source: B&V.

***Table 11*** *Fuel costs*

| Resource | Fuel costs (delivered) £/GJ |
|---|---|
| Forestry | 2.7 |
| Woody Energy Crops | 2.66 |
| Dry Agriculture | 2.18 |
| Waste Wood | 1.50 |

Source: B&V, PAA
Note: Woody Energy Crops figure is weighted average figure over 15 years, current value is 3.0 £/GJ

# Notes

## Notes

**www.thecarbontrust.co.uk**
**0800 085 2005**

The Carbon Trust works with business and the public sector to cut carbon emissions and capture the commercial potential of low carbon technologies.

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