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Minimising greenhouse gas emissions from biomass energy generation

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This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Rio House, Waterside Drive,
Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

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Dissemination Status:
Released to all regions

Keywords:
Biomass; climate; change; energy; emissions; greenhouse; renewable; power; heat

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Steve Killeen

Head of Science

Executive summary

This report sets out the results of analysis carried out by AEA for the Environment Agency as part of its work to support the development of a sustainable bioenergy industry in England and Wales.

It assesses the greenhouse gas (GHG) savings that biomass feedstocks which could be used in heat and power schemes in the UK offer compared to fossil fuels. The savings are calculated using the Biomass Environmental Assessment Tool Version 2 ($BEAT_2$), which was developed for the Environment Agency and Defra (Department for Environment, Food and Rural Affairs) by AEA and North Energy Associates. $BEAT_2$ calculates the emissions of carbon dioxide, methane and nitrous oxide over the whole lifecycle of a biomass energy scheme (including biofuels), from cultivation of the energy crop, through processing and transport of the fuel, to combustion of the crop at a power station or boiler and disposal of ashes.

This analysis has resulted in the following conclusions, with a separate policy summary report also available that sets out the Environment Agency's recommendations based on this report:

Greenhouse gas emissions from energy generated using biomass are generally, but not always, lower than those from fossil fuels.

For example, using short rotation coppice chips to generate electricity can produce 35 to 85 per cent less emissions than a combined cycle gas turbine power station per unit of energy delivered, whereas using straw can, in some cases, produce over 35 per cent more.

How a fuel is produced has a major impact on emissions.

Transporting fuels over long distances and excessive use of nitrogen fertilisers can reduce the emissions savings made by the same fuel by between 15 and 50 per cent compared to best practice.

The treatment of avoided emissions from the disposal of wastes is critical and needs to be further developed.

We consider that in cases where it is clear that a single route accounts for most of current disposal and is likely to do so into the future, then an allowance could be given for the emissions avoided from disposal. This would be the case, for example, with animal manures where the final point of disposal is almost always spreading to land. For waste feedstocks such as waste wood, where there are a number of potential alternative uses for the wood, as well as disposal, it will be more appropriate to take an average of emissions savings over these routes, or the disposal route with the lowest GHG saving to ensure that savings are not overestimated.

Land use change can negate any emission savings.

Using formerly fallow land to grow bioenergy crops can reduce emission savings from a fuel by up to 10 per cent. Planting on permanent grassland is worse, with emissions savings significantly reduced and in some cases reversed.

Setting minimum standards for GHG savings could help maximise emissions savings from bioenergy production.

We consider that appropriate minimum standards for GHG savings for biomass feedstocks would be as set out below:

Table 1.1 Recommended minimum standards

Fuel form	Minimum GHG saving compared to gas	Maximum GHG emission for biomass feedstock ($kgCO_2e$ per MWh)
Pellets	65%	79
Other solid and liquid forms	70%	68
Biogas (except for that derived from poultry waste)	90%	23
Biogas (derived from poultry waste)	50%	113

An alternative to setting standards as a percentage saving, which requires identification of the fossil fuel being used for comparison, would be to simply set a maximum value for the GHG emissions associated with production of the feedstock, avoiding the need to specify the fossil fuel to be used as the comparator. These values are also shown in the table above.

The standards recommended are achievable by most feedstocks and energy crops, but are stringent enough to ensure that large reductions in savings do not occur due to poor operating practice or land use change.

Energy conversion efficiency is an important factor in reducing emissions.

We consider that if minimum standards are to be set for GHG savings that biomass feedstocks deliver, rather than for the heat and power they produce, then they should be complemented with minimum standards for conversion efficiencies in boilers, power plants and combined heat and power (CHP) plants. A review of existing legislation and voluntary schemes in the UK and other EU countries, together with AEA's knowledge of the efficiencies being achieved by some new boilers, suggests that:

- Minimum standards for domestic boilers could be raised above those in current legislation to at least 75 per cent and possibly 80 per cent. Minimum standards for medium sized boilers should be set, and a value of around 90 per cent would be an achievable standard.
- The introduction of a minimum standard for power plants could help to ensure that reasonable efficiency standards are always met, particularly in smaller plants.
- The Energy Using Products Directive could be a suitable EU-wide vehicle for setting standards for boilers as it covers all boilers up to 500kW.

Emission reductions of several million tonnes of greenhouse gases per year could be achieved by following good practice.

Based on current market projections, we estimate that by 2020 the emission of greenhouse gases equivalent to several million tonnes of carbon dioxide per year could be avoided if good practice in fuel production, processing and transport and energy conversion efficiency were to be followed.

Contents

1 Introduction

This report sets out the results of analysis carried out by AEA for the Environment Agency as part of its work to support the development of a sustainable bioenergy industry in England and Wales. It assesses the greenhouse gas (GHG) savings that biomass feedstocks which could be used in heat and power schemes in the UK offer compared to fossil fuels. The savings are calculated using the Biomass Environmental Assessment Tool Version 2 ($BEAT_2$), which was developed for the Environment Agency and Defra (Department for Environment, Food and Rural Affairs) by AEA and North Energy Associates. $BEAT_2$ calculates the emissions of carbon dioxide, methane and nitrous oxide over the whole lifecycle of a biomass energy scheme (including biofuels), from cultivation of the energy crop, through processing and transport of the fuel, to combustion of the crop at a power station or boiler and disposal of ashes.

2 Methodology

For more information on the methodology used within $BEAT_2$ please visit the Biomass Energy Centre's website at www.biomassenergycentre.org.uk/BEAT. Information on the parameters entered into $BEAT_2$ as part of this work can be found in Section 10.

It is important to note that for the majority of this analysis we have used $BEAT_2$ to estimate emissions up to the point the biomass fuel enters the boiler, engine or power plant. This results in a measure of emissions in units of kilograms of carbon dioxide equivalent per million watt hours (kgCO_2e per MWh) of energy contained in the fuel before it is converted into useful delivered energy. This is different from carbon dioxide equivalent per million watt hours of delivered energy, such as heat or electricity, which includes energy conversion efficiency. This is the efficiency with which a system, such as a boiler, converts energy in a fuel into usable energy, such as heat.

After calculating emissions from biomass produced using good practice, we used $BEAT_2$ to examine the variation in greenhouse gas savings that could occur from changes to factors such as longer transport distances, poor yields and land use change, and the extent to which following 'best practice' might increase GHG savings. Again, the parameters used can be found in Section 10. The results show that emissions could be substantially increased in some cases, suggesting that a policy instrument such as setting minimum standards for GHG savings might be necessary to safeguard the emission reductions that biomass could potentially deliver. Based on the analysis, we suggest the level of reductions at which such values might be set.

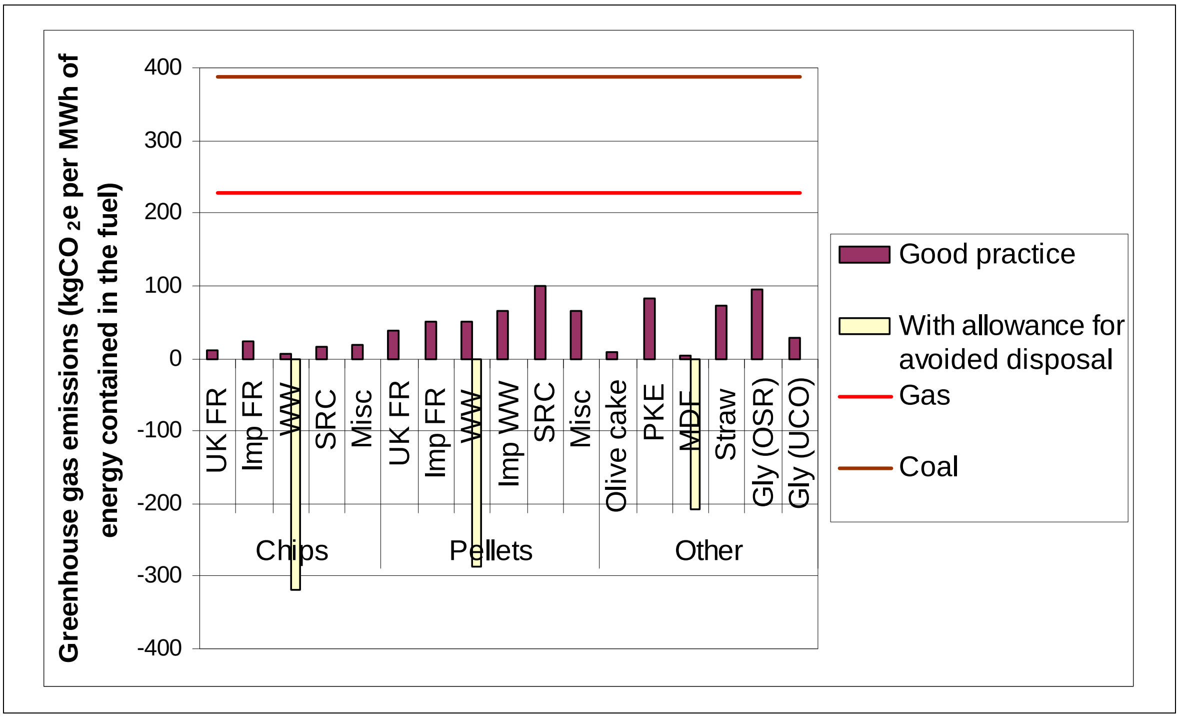
Maximising GHG savings from biomass also demands that it is converted as efficiently as possible into heat and/or power. We therefore included conversion efficiency as an extra factor that could contribute to the variation in emissions savings from different biomass fuels. We have also reviewed current legislation and voluntary schemes (see Sections 7 and 11) which specify minimum conversion efficiencies for boilers, combined heat and power and generating plants and made recommendations as to where these could be strengthened.

Finally we discuss how $BEAT_2$ could be used as a tool to assess whether feedstocks meet a minimum GHG saving standard.

3 Greenhouse gas savings from biomass schemes

3.1 Solid and liquid feedstocks

Figure 3.1shows GHG emissions associated with the production, processing and delivery of a range of biomass feedstocks, in terms of kgCO_2e per MWh of energy contained in the fuel.



Key:

UK FR	UK forestry residues	Imp FR	Imported forestry residues (from the Baltic)
SRC	Short rotation coppice	Misc	Miscanthus
WW	Waste wood	Imp WW	Imported waste wood (from the Baltic)
PKE	Palm kernel expeller	MDF (shr)	Medium density fibreboard (shredded)
Gly (OSR)	Glycerine from biodiesel production using oil seed rape	Gly (UCO)	Glycerine from biodiesel production using used cooking oil

Figure 3.1 GHG savings from feedstocks assuming good practice

Again, it is important to note that this is not the same as a MWh of heat or electricity produced by burning a fuel. The energy in these feedstocks could be used in a range of applications, for example to produce:

- Electricity, either by cofiring in existing coal-fired power stations, or in biomass power stations.

- Heat in industrial and domestic heating systems.
- Electricity and heat in CHP plants.

They might therefore replace a range of fossil fuels – coal, gas and light and heavy fuel oils – which themselves have differing GHG emissions associated with their production and combustion. The two fuels with the highest and lowest GHG emissions per MWh of energy contained in the fuel – coal and gas respectively – are shown for comparison on the graph.

The biomass feedstocks shown were chosen to demonstrate the range of GHG savings which can be expected from feedstocks that could be used in the UK now or in the near future. The savings estimates are typical of what could be achieved under 'good practice' conditions, that is, where the schemes are well operated with efficient processing of the feedstock and energy crops are planted on good soils so achieve reasonable yields. The exact parameters used are shown in Section 10.

3.1.1 Explanation of results

GHG emissions from feedstock production and delivery vary significantly – from about 10kgCO_2e per MWh for waste products such as waste wood and MDF, up to 100kgCO_2e per MWh for pellets formed from short rotation coppice (SRC) chips. GHG savings compared to gas thus range from over 95 per cent to 56 per cent (see Table 3.1).

Key reasons for higher emissions for some feedstocks are:

- Transport distance: Shipping wood fuels in from, for example, the Baltic states, adds about 10kgCO_2e, and, in the case of PKE, shipping from Indonesia accounts for 96 per cent of emissions.
- Drying prior to pelletisation: Energy used for drying fuel chips prior to grinding and pelletisation leads to higher emissions for pelleted fuels[1]. This is particularly so for SRC which has a higher moisture content than the other fuels considered. The GHG emissions associated with drying can be minimised by using biomass sources to provide the necessary heat.
- Use of nitrogenous fertilisers: In the case of straw and glycerine, a byproduct of biodiesel produced from oil seed rape, emissions are relatively high due to emissions from the production and application of nitrogenous fertilisers to the wheat and rape crop respectively. Specifically in the case of straw, the GHG emissions from growing wheat are divided between the wheat grain and straw according to the value of each, so that 14 per cent of cultivation emissions are allocated to the straw.

If percentage GHG savings were estimated on the basis of delivered energy, that is, per MWh of heat or electricity produced rather than per MWh of energy in the fuel as above, then savings would be lower for electricity generation in a dedicated plant. This is because gas can be used in CCGT (combined cycle gas turbine) plants, which have a much higher efficiency (typically over 45 per cent) than biomass plants based on open cycle steam turbines (typically about 35 per cent at a large size, and under 35 per cent for smaller sizes). Biomass boilers for heating can have efficiencies which are comparable to fossil fuel boilers. The importance of setting standards for energy

[1] Pellets have several advantages. They are easier to handle and store, and boiler feeding can be automated, which is why they are preferred for small domestic systems.

conversion efficiency to help ensure that GHG savings from biomass are maximised is considered later.

Table 3.1 Percentage GHG savings from biomass feedstocks assuming good practice

	Feedstock	Emissions ($kgCO_2e$ per MWh)	Percentage saving compared to coal	Percentage saving compared to gas
Chips	UK forestry residues	10	97%	95%
	Imported forestry residues	22	94%	90%
	Waste wood	7	98%	97%
	Short rotation coppice	17	96%	93%
	Miscanthus	18	95%	92%
Pellets	UK forestry residues	38	90%	83%
	Imported forestry residues	50	87%	78%
	Waste wood	51	87%	77%
	Imported waste wood	66	83%	71%
	Short rotation coppice	100	74%	56%
	Miscanthus	65	83%	71%
Other	Olive cake	9	98%	96%
	Palm kernel expeller	82	79%	64%
	Medium density fibreboard	5	99%	98%
	Straw	73	81%	68%
	Glycerine from oil seed rape	94	76%	58%
	Glycerine from used cooking oil	28	93%	87%

3.1.2 Accounting for the use of wastes

Several of the schemes examined utilise a 'waste' as a feedstock, such as waste wood from sawmills, or waste MDF from furniture manufacture. In these cases, use of the waste for bioenergy can result in additional GHG savings, as the GHG emissions associated with the disposal of the waste are avoided. To explore this, we estimated the additional GHG savings resulting from avoiding disposal of waste wood and MDF to landfill, assuming that a proportion of landfill gas is collected and used to generate electricity. The GHG emissions associated with disposal to landfill are substantial and, as Figure 3.2 shows, when an allowance is made for avoiding them, utilisation of feedstock for bioenergy generates GHG savings even before any displacement of fossil fuels is considered.

Disposal to landfill is the 'end use' for these wastes with the highest GHG emissions due to the methane contained in landfill gas which is not recovered and leaks from the landfill site. Assuming that waste is disposed of to landfill thus results in the greatest GHG 'credit' for using the waste as a bioenergy feedstock. For some wastes there are other potential end uses which may have lower GHG emissions, or even offer GHG savings, and these should also be considered, particularly if significant amounts of the waste could be 'disposed of' by that route. For example, clean wood waste can be recycled into particleboard, which avoids the use of virgin timber and therefore avoids GHG emissions. Assuming that this was the route for disposal would reduce the overall GHG savings of the bioenergy scheme (from 240 per cent if the alternative 'use' for waste wood is assumed to be landfill to 88 per cent if the alternative use is assumed to be recycling). Clean waste wood can also be composted to produce a mulch, but GHG emissions associated with this route are very low so, unlike landfill, add only very small amounts to the savings made by the bioenergy scheme. Such differences in GHG emissions mean that alternative markets for biomass wastes must be considered when the assumed disposal route is determined.

3.2 Biogas from anaerobic digestion of waste

Figure 3.2 shows the GHG emissions from the production of biogas. In most of the anaerobic digestion (AD) bioenergy schemes evaluated, there are significant GHG emissions from the scheme. This is because the boundary of the analysis was initially set to include emissions associated with the disposal of waste products from the process. In the case of AD of animal manures, emissions from storage and spreading to land of the digestate from the AD plant are high and thus lead to overall emissions for the production of biogas which are in some cases higher than those from coal and in all cases higher than those from natural gas. However, if the animal manures were not utilised in the AD plant, then they would need to be stored before spreading to land. This would result in emissions of methane and nitrous oxide from storage, which is assumed to be in lagoons, and from spreading (see Figure 3.3). Allowing for the avoidance of these emissions is important, as is consideration of all other indirect emissions, if the overall impact of the AD plant on GHG emissions is to be assessed accurately. Once an allowance is made for these avoided emissions, the AD scheme delivers significant GHG emission reductions.

The inclusion of an allowance for avoided disposal of wastes, and the assumed method of disposal, are critically important in determining the level of emissions savings. In some cases, such as manures, it will be clear that a single route accounts for most of current disposal, and should be chosen as the 'reference' system. In other cases, such as clean waste wood, there may be recycling or reuse options which also need to be considered. In order to avoid an over optimistic picture of emissions savings it would be best to use the route with the lowest GHG emissions associated with it as this would give the smallest credit to the biomass system when it is avoided.

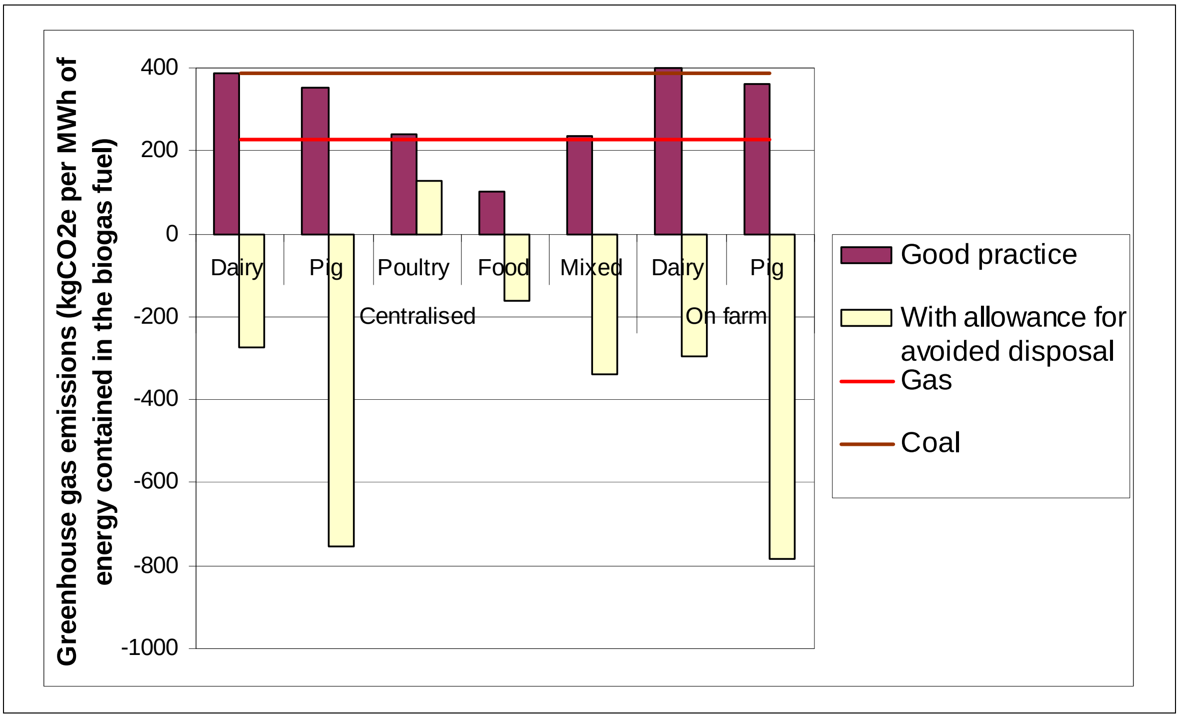


Figure 3.2 GHG emissions from biogas assuming good practice

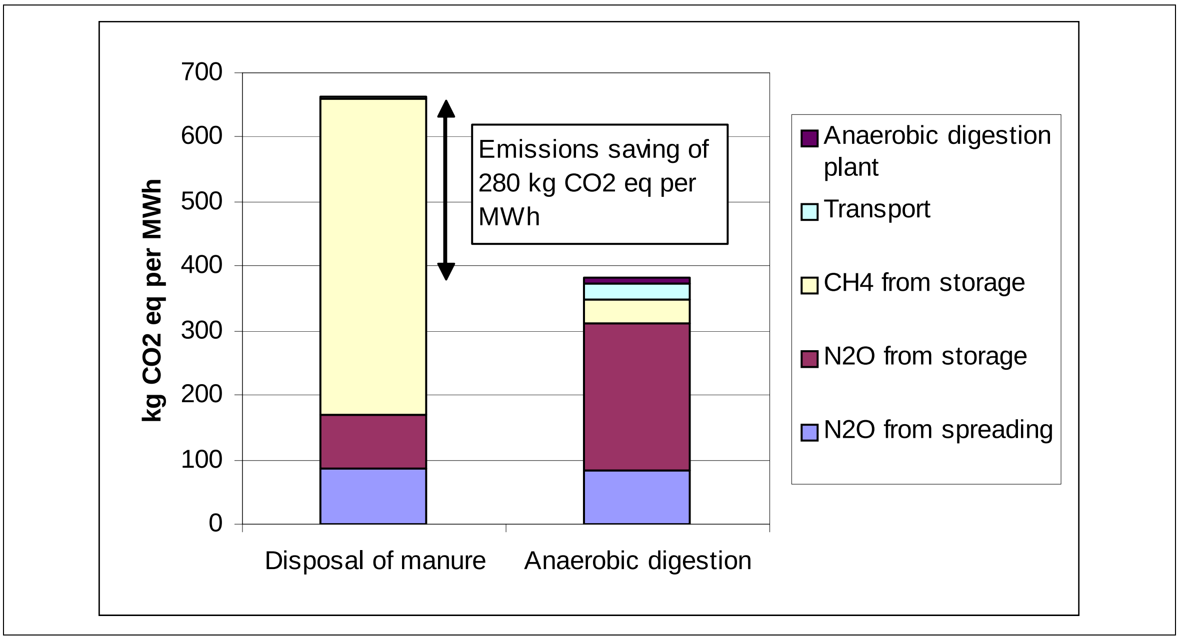


Figure 3.3 Comparison of GHG emissions from disposal of dairy manure and production of biogas from dairy manure to produce electricity

4 The impact of best and worst practice on GHG savings

Many parameters can affect the GHG emissions from a biomass scheme. Figure 3.1 shows typical values that can be achieved with good practice (good yields and low losses during processing). For a selection of schemes, we examined the variation in savings which might result if a scheme achieved the ‘best’ or ‘worst’ values for characteristics which significantly influence GHG emissions. Figure 4.1 shows how widely emissions savings may vary for a selection of feedstocks.

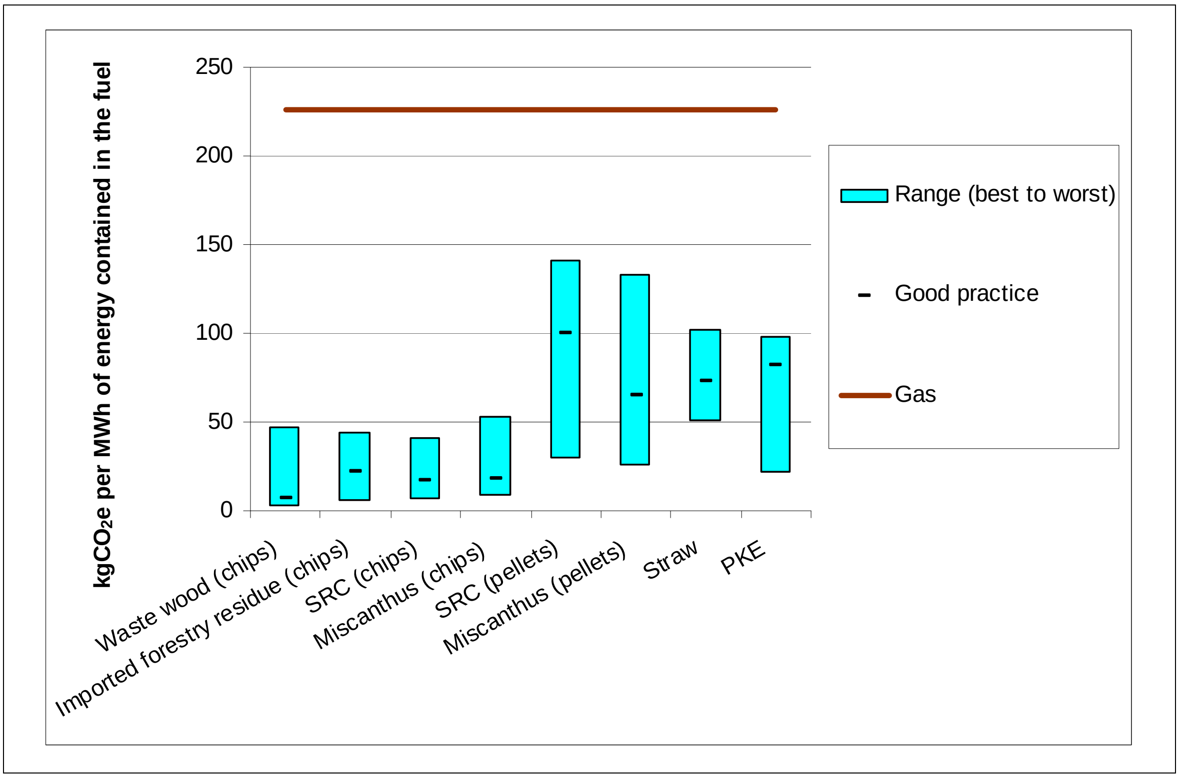


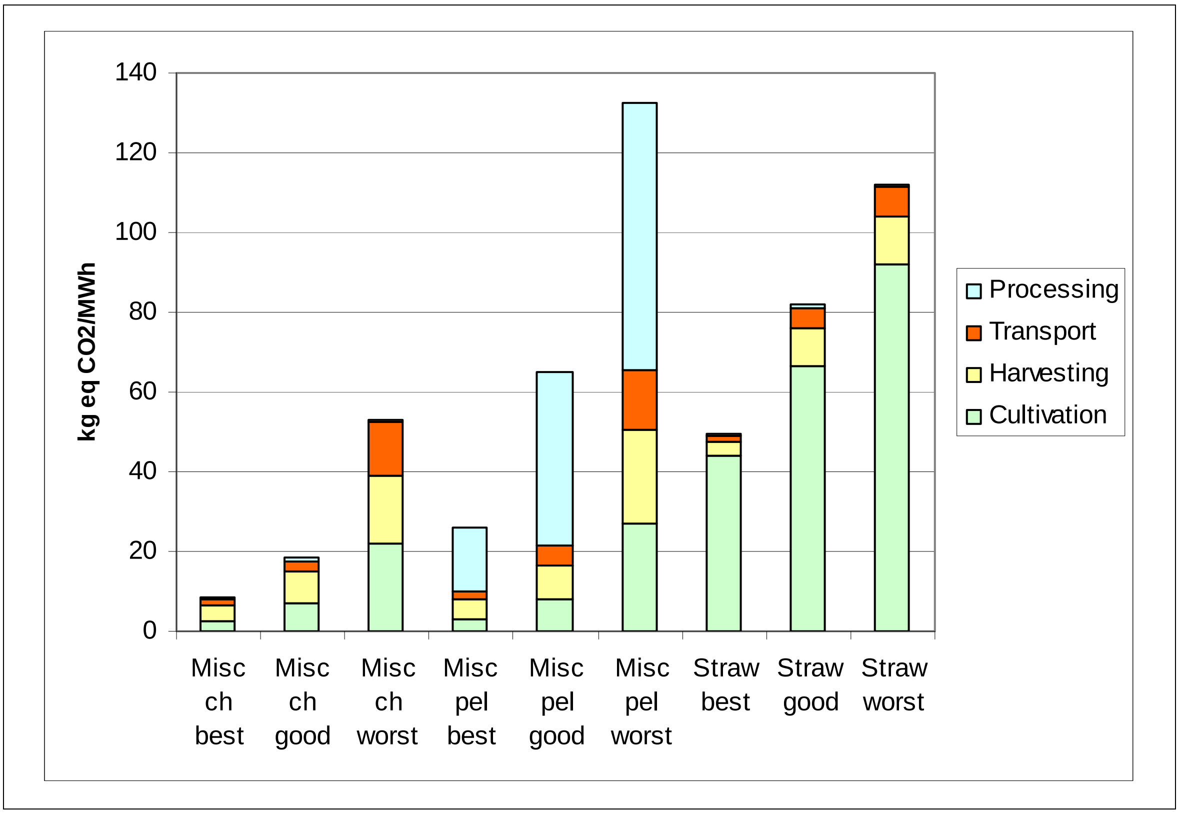
Figure 4.1 GHG emissions from different biomass fuels and production practices

How a fuel is produced, transported and processed has a significant impact on lifecycle emissions. Bad practice, such as transporting fuels very long distances and excessive use of nitrogen fertilisers, can reduce the emissions savings made by the same fuel compared to natural gas by between 15 and 50 per cent, as shown in Table 4.1.

In the case of forestry residues the change in emissions is due to changes in the distance the waste is transported; for example, the worst case assumes that the feedstock is imported from Canada. Figure 4.2 illustrates the reasons for the changes in emissions for miscanthus chips and pellets and straw. More detail can be found in Section 10.

Table 4.1 Percentage savings from biomass feedstocks compared to gas

	Best practice	Good practice	Worst practice	Difference between best and worst
Forestry residues (chips)	97%	90%	81%	17%
Waste wood (chips)	99%	97%	79%	19%
SRC (chips)	97%	93%	82%	15%
Miscanthus (chips)	96%	92%	76%	20%
SRC (pellets)	87%	56%	38%	49%
Miscanthus (pellets)	89%	71%	41%	47%
Straw	78%	68%	55%	23%
PKE	90%	64%	57%	34%



Key:
Misc ch Miscanthus chips
Misc pel Miscanthus pellets

Figure 4.2 Breakdown of emissions under best, good and worst practice

In the case of miscanthus, lower yields per hectare mean that more agrochemicals and diesel are used for every tonne of miscanthus produced, leading to higher GHG emissions per tonne. The decrease in emissions in the best case for pelletisation assumes that biomass is used to provide the heat for drying the miscanthus. The same would be true of SRC chips and pellets.

In the case of straw, the increase in emissions in the worst case is mainly due to the high emissions associated with fertiliser use if a poor yield is obtained, as can be the case on some chalky soils, particularly in dry years. In the case of straw, there is also a large improvement in GHG savings due to improved yields, and a lower fertiliser use per tonne of straw.

In the case of biogas from AD of animal manures, changes in operating practice tend to have very little impact on overall emissions from the scheme because of the compensating effect of the emissions saved due to avoided disposal of the manures. That is, a less efficiently operated scheme, which requires more manure as a feedstock, will have higher emissions from biogas production, but these will be matched by the additional emissions savings from not having to dispose of that extra manure.

5 The potential impact of land use change

There is increasing awareness that the impacts of direct and indirect land use change on GHG emissions should be taken into account when evaluating the GHG balance of bioenergy schemes. Direct land use change occurs when land is converted from one use to another (for example fallow land or grassland used to grow a crop). Indirect land use change occurs when an energy crop is grown on existing crop land, but land use change occurs elsewhere to allow production of the crop which has been displaced by the energy crop.

To date, most of the discussion and analysis of this issue has been in relation to the production of liquid biofuels, but the arguments also apply to biomass schemes for heat and power. On land which has been undisturbed for many years, such as permanent grassland, soil carbon levels are higher than on land which is regularly tilled. On land which has been cultivated but is then left undisturbed, such as fallow land, or land in permanent set aside, soil carbon levels gradually increase for a number of years before reaching a new equilibrium level. If such land is then disturbed by ploughing, some of this soil carbon is lost as an emission of CO_2.

Cultivation of perennial, lignocellulosic energy crops such as SRC and miscanthus can help to build up organic soil carbon. During the lifetime of the plantation (10 to 20 years) the ground is left undisturbed, allowing soil carbon levels to rise. In addition carbon from leaf loss is returned to the soil and carbon is stored in the root mass. However, at the end of this period, when the ground is deep tilled to remove the crop, carbon is released that could negate the previous increase in soil carbon.

In the absence of specific data on the emissions associated with conversion of land to energy crop plantations, an indicative calculation of the impact of GHG emissions from direct land use change has been made. This uses generic data on the GHG emissions associated with the conversion of permanent grassland to perennial crop land and cultivation of fallow land/land in permanent set aside taken from the Renewable Fuels Agency (RFA) (2008). This is shown in Figure 5.1, which illustrates the impact of direct land use change on GHG emissions savings for energy crops in comparison to gas. The category 'no land use change' assumes that the energy crop is grown on land which is – or has very recently been – under arable cultivation. Emissions from land use change have been averaged over a 20 year period: the lifetime of the energy crop plantation.

Figure 5.1 shows that GHG emissions associated with the conversion of fallow land into energy crop production reduce emission savings by up to 10 per cent depending on the crop and type of scheme. However, conversion from grassland could potentially reduce GHG savings significantly and, in many cases, negate them totally, leading to a net increase in GHG emissions. Another way of considering the impact of land use change is to calculate the time that it takes for the 'carbon debt' incurred by ploughing up the land to be repaid from the carbon savings made by using the energy crop. In the case of conversion from fallow land, the carbon debt is repaid in 3 to 5 years depending on the energy crop. But in the case of conversion from grassland, the carbon payback time can vary from 14 years for straw and miscanthus chips to 23 years for SRC chips and 35 years for SRC pellets: well beyond the expected 20 year lifetime of the plantation.

Estimating the impact of indirect land use change, when energy crops are grown on existing cropland resulting in displacement of the crop production to elsewhere, is more complex. Assumptions must be made as to which crop has been displaced, whether the agricultural markets require that production to be replaced, where that replacement production will occur (which, given the global nature of the agricultural commodities markets, could be outside the UK), and what type of land will be cultivated. If energy crops were grown on existing arable land, and additional arable production took place on permanent grasslands or fallow lands to make up for displaced production, then the impacts on GHG savings could be similar to those shown in Figure 5.1.

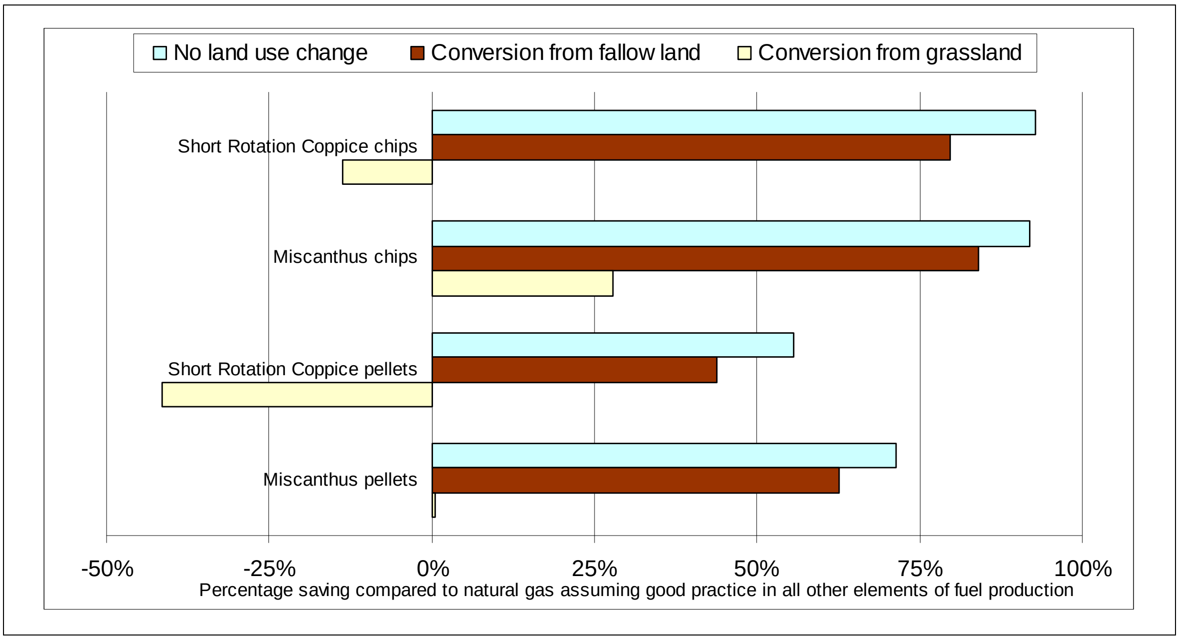


Figure 5.1 Potential impact of land use change on GHG savings

6 Minimum standards for GHG savings from feedstocks

It is clear from the analysis above that utilising biomass feedstocks in heat and power plants can offer good GHG savings, but that a number of factors, including poor yields for energy crops, long transport distances and land use change can substantially reduce or even negate these savings. A number of policy options are available to help mitigate the risk that savings will be eroded by these factors. These include voluntary or mandatory reporting of GHG savings, incentives for best practice that maximises GHG savings, and enforceable minimum standards. Given the focus of this research to support the Environment Agency's aim of developing a sustainable bioenergy industry, this section examines what appropriate minimum standards for GHG savings from biomass feedstocks might be.

Such minimum standards need to be demanding enough to prevent the loss of GHG savings through poor operations and bad practice, but must also take into account the practicalities of feedstock production schemes and the realities of the marketplace. This means that any standards should be set at a level that ensures:

- A wide variety of energy crops are included, as different crops are suitable for different types of soil and climatic conditions.
- The use of pellets is not excluded, as they are practical, particularly for smaller schemes.
- A wide enough range of feedstocks can qualify to allow operators of biomass schemes flexibility in their choice of feedstock, for example in responding to changes in relative prices.

Based on this analysis and the considerations above, we recommend the minimum standards for lifecycle GHG savings from biomass fuels shown in Table 6.1. In specifying percentage savings, it is obviously necessary to indicate the fossil fuel used as the comparison, and the values in the second column of Table 6.1 are based on a comparison with gas. An alternative would be to set a standard in terms of the maximum GHG emissions the feedstock could have in kgCO_2e per MWh of energy in the fuel. This has the advantage that it is not necessary to specify the fuel used as a comparator and is therefore perhaps clearer. These values are also shown in the table. For biogas it is recommended that the avoided disposal of animal wastes is allowed for in calculating the emissions associated with the feedstock.

Table 6.1 Recommended minimum standards

Fuel form	Minimum GHG saving compared to gas	Maximum GHG emission for biomass feedstock (kgCO_2e per MWh)
Pellets	65%	79
Other solid and liquid forms	70%	68
Biogas (except for that derived from poultry waste)	90%	23
Biogas (derived from poultry waste)	50%	113

Where the fuel will be co-fired in existing power plants, the fuel replaced will almost certainly be coal and the above standards would therefore deliver higher emissions savings in absolute terms. Consideration could thus be given to setting a less stringent minimum standard for fuels which are co-fired in a coal-fired power station. For example, a feedstock with a GHG saving of 50 per cent compared to gas gives a GHG saving of about 70 per cent compared to coal. However, if the aim is to maximise GHG savings achieved from a unit of biomass then setting a single, more stringent standard, for all feedstock uses is more desirable.

Another alternative would be to take a more differentiated approach, setting different standards for several different fuel types. This would enable more stringent minimum standards to be set for specific fuels, rather than setting the standard at a level that is achievable by most fuels. This would however create a more complex system.

These suggested minimum standards are based on the system boundaries in $BEAT_2$. As $BEAT_2$ assesses the full life cycle emissions associated with feedstock production, these boundaries are set to include emissions associated with the production of farm machinery used for cultivation. These emissions are, however, excluded from the calculation of GHG emission savings from liquid biofuels in the methodology set out in the draft Renewable Energy Directive. While these ‘embodied’ emissions are not an insignificant component of overall emissions from feedstock production, their exclusion does not have a significant effect on the savings achieved in percentage terms, suggesting that even with a change in methodology the recommendations in Table 6.1 would still be valid. For example, for SRC chips the emissions associated with the production of machinery, vehicles and stores used for cultivation, harvesting, transport and storage of the feedstock are about $3kgCO_2e$ per MWh (accounting for about 20 per cent of total emissions from feedstock production). Excluding these emissions increases the percentage saving compared to gas from 93 per cent to 94 per cent.

6.1 Incentivising ‘Best Practice’

The need to set minimum standards so that some fuels are not excluded means that other fuel types could still qualify, even when worst practice conditions existed in the supply chain. One way to prevent this might be to use a mechanism to reward feedstocks which achieve higher greenhouse gas savings. However, it is not clear what the cost of implementing improved practices might be and any benefits are likely to be subject to diminishing returns. A more detailed assessment is necessary to judge whether an incentivisation scheme would be a cost-effective way of delivering additional GHG savings.

6.2 Assessing compliance with minimum GHG saving standards

The principle of setting a minimum level for GHG savings from biomass feedstocks as part of sustainability criteria for biomass schemes requires that methodologies and tools are available to allow savings to be easily yet rigorously assessed. AEA has recently carried out studies (for example see AEA, 2008, 2009) which have reviewed and/or collated data from life cycle analysis (LCA) studies of biomass systems. The reviews found that a large number of LCA studies assessing GHG emissions and savings from both biofuels and bioenergy schemes for heat and power have been carried out throughout Europe. Some studies consider a number of types of schemes. For example, the European Commission’s Joint Research Centre (JRC) at Ispra, which has carried out detailed analysis of the GHG savings from liquid biofuels for transport, has recently extended its analyses to include about 20 bioenergy schemes using municipal solid waste, manures, dry and wet manures, waste wood and ‘farmed wood’ for electricity, heat and combined heat and power production (EC JRC, 2009).

All of the life cycle studies, however, are a ‘static’ assessment of the GHG emissions associated with generic bioenergy schemes. This means that while they may report the results of sensitivity studies to assess the influences of changes in yield, or conversion efficiency or other parameters, they do not allow the assessment of a particular bioenergy scheme. In contrast, $BEAT_2$ is an interactive tool, which, while containing default values representing typical good practice, also allows all key parameters that define a scheme to be set by the user, thus allowing the specific savings that could be expected from that scheme to be assessed. The UK and other EU Member States have developed methodologies and interactive tools for assessing GHG savings on a lifecycle basis for transport biofuels, which allow input of user values to meet the requirements of the Biofuels Directive[2]. However, these do not include solid biomass for heat and power.

The analysis above demonstrates the potential of the $BEAT_2$ tool to model a variety of bioenergy schemes and to examine the sensitivity of emissions results to variations in a wide range of scheme characteristics. The calculations within the tool are fully transparent and results are available at both an aggregated and detailed level, allowing a clear understanding of the contribution of different operations to emissions.

The Environment Agency is currently funding AEA to develop a web-based version of $BEAT_2$ that can be used voluntarily by generators to calculate the GHG emissions savings from electricity generated from biomass feedstocks under the Renewables Obligation. It is hoped that in the future, as more biomass feedstocks are considered for use, and as technology and best practice develops, it will be possible to update $BEAT_2$ to ensure that all types of schemes can be evaluated as accurately as possible.

[2] See for example, the UK’s Renewable Fuels Agency Carbon Calculator at http://www.dft.gov.uk/rfa/carboncalculator.cfm

7 Ensuring efficient conversion of feedstocks to heat and power

One way to ensure that overall GHG savings from a scheme are maximised is to set minimum GHG savings on the basis of the heat or electricity produced, rather than on the basis of the energy contained in the feedstocks as described above. An alternative is to set minimum GHG savings for feedstocks and to also set minimum standards for the energy conversion efficiency that must be achieved in boilers, CHP systems or power plants. At the request of the Environment Agency, the focus of this report has been on the latter option. This is because minimum standards for a variety of energy conversion technologies already exist and tightening these standards would seem a relatively simple mechanism to improve GHG emissions savings from biomass.

As discussed earlier, maximising the actual greenhouse gas savings that will be realised from the use of biomass for heat and power not only depends on producing and delivering feedstocks in a way which minimises GHG emissions, but also that these are converted efficiently to heat and power. Differences in energy conversion efficiency can have a very large impact on the GHG emission reductions achieved. Figure 7.1 shows the range in greenhouse gas emissions produced over the lifecycle of a number of biomass fuels. This is the result of combining best and worst efficiency for electricity or heat production with the best and worst characteristics of feedstock production assumed in the earlier analysis.

In its advice to Government on future carbon budgets, the Committee on Climate Change (2008) recommended that the carbon intensity of electricity production should fall from the current level of 550kgCO_2 per MWh to 80kgCO_2per MWh by 2030 and 30kgCO_2 per MWh by 2050. These figures are plotted for comparison on Figure 7.1 because of the long lifetimes of power generation facilities. The heat sector will have to follow a similar trajectory, albeit over a longer time period as current options are more limited.

The range in energy conversion efficiency only reflects changes in the efficiency with which electricity is generated. It does not include the use of heat through a CHP system.

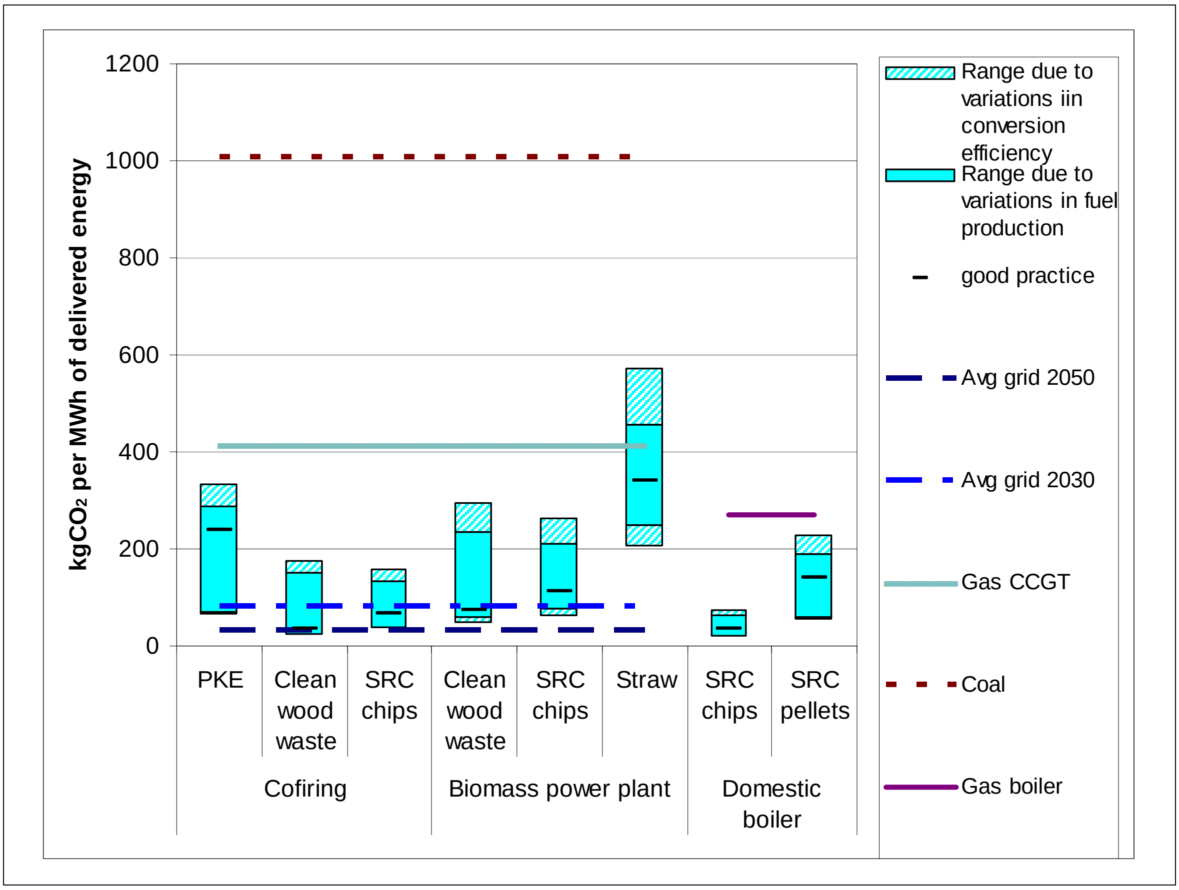


Figure 7.1 GHG emissions from different biomass fuels and energy technologies using best to worst practice

Figure 7.1 shows that including energy conversion efficiency in the life cycle analysis results in a greater range in emissions savings, especially for electricity only biomass plants. In particular it shows that GHG emissions from energy generated using biomass are not always lower than those from fossil fuels. For example, using short rotation coppice chips to generate electricity can produce 35 to 85 per cent less emissions than a combined cycle gas turbine power station per unit of energy delivered, whereas using straw can, in some cases, produce over 35 per cent more. However, this is still significantly lower than emissions from a coal-fired power station.

As efficiency standards already exist for many energy conversion technologies, we reviewed what level these are set at to see whether scope might exist for improvement. Section 11 provides more detail on existing legislation and voluntary labelling schemes in the UK, EU and some other Member States for different sizes of boilers and for CHP and power plants. A summary of this work is set out below.

New domestic biomass boilers, which are generally up to 50kW in size, must have an efficiency of between 65 and 70 per cent, depending on their size. These limits are set in a European (EN) standard which is compulsory under the Construction Products Directive. The UK's Energy Technology List, which sets a minimum standard that boilers must meet if they are to qualify for enhanced capital allowances, sets a level of 70 per cent, whereas voluntary national eco-labelling schemes in Norway and Germany set much higher standards of 83 per cent and 90 per cent respectively for pellet boilers, suggesting that standards in the rest of Europe could be set higher.

For **medium sized biomass boilers**, which are generally up to 500kW in size, there are no compulsory standards. The relevant EN standard classifies boilers based on minimum efficiencies but is not compulsory as it has not been harmonised across Europe. The highest efficiency class (3), which sets a standard of 79 to 82 per cent depending on size, is taken as the standard for the Energy Technology List, which as described above, aims to encourage take up of more efficient boilers. National eco-labelling schemes have set higher standards than this, for example the Nordic Swan label sets a standard of between 85 and 90 per cent depending on size and type of boiler, and the current revision of the EN standard is proposing higher standards of 84 to 92 per cent depending on size. Many medium sized boilers do already meet or indeed surpass the standards set for the Energy Technology List, and the best high efficiency boilers can meet the higher values being proposed in the EN standard, suggesting that a minimum standard could potentially be set as high as 90 per cent. Boilers up to 500kW will be covered by the Energy Using Products Directive; discussions as to what the Directive should stipulate are currently ongoing, but it is possible that they could set a minimum efficiency standard, and that there would be some link with the EN standard.

For other **large combustion plants**, such as large boilers and electricity generating plants, there are no minimum efficiency standards. Energy efficiency is a requirement under the Integrated Pollution Prevention and Control (IPCC) directive and the relevant Best Available Techniques Reference (BREF) document suggests minimum efficiencies of 20 to 30 per cent for electricity generating plants, depending on technology, and 75 to 90 per cent for CHP plants, but the note is advisory. There are, however, a number of other drivers in this sector which would encourage high standards of energy conversion efficiency such as inclusion in the EU Emissions Trading Scheme (ETS), Climate Change Agreements (CCAs) and financial incentives for generating plants selling electricity to the grid. So, for example, the Environment Agency's guidance on energy efficiency for combustion plants specifies participation in the EU ETS or CCAs as a way of demonstrating that energy efficiency is being addressed.

Our review therefore suggests that:

- Minimum standards for domestic boilers could be raised above those currently set in the UK building regulations and EN12809.
- Minimum standards for medium sized boilers should and could be set higher than the existing Class 3 efficiencies in the EN standard. A value of around 90 per cent, as proposed for Class 5 in the revision of EN303-5, would seem to be an achievable standard.
- The Energy Using Products Directive could be a suitable EU-wide vehicle for setting standards as it covers all boilers up to 500kW. However the timetable for this process is still not fixed.
- For CHP and power plants, there are a number of policy instruments which, coupled with the economic driver to produce as much power as possible, should encourage high efficiency plants. However, the introduction of a minimum standard for power plants could help to ensure that reasonable efficiency standards are always met, particularly in smaller plants.

8 The implications of moving to good practice in feedstock production and energy conversion efficiency

Figure 8.1 illustrates what impact moving from poor to good practice in fuel production and energy conversion efficiency could have. It takes a notional 250MW biomass plant located in the UK and assumes that it generates only electricity, at 27 per cent efficiency, using wood chip imported from Canada or the eastern United States.

To move this plant from poor to good practice would require: using the heat generated during electricity production, which would bring its energy conversion efficiency up to 80 per cent; ensuring all the heat produced was utilised; and importing 75 per cent of its fuel from the Baltic states, with 25 per cent derived from UK sources. More detail on the parameter values used can be found in Section 10.

Switching from gas to biomass results in impressive reductions in emissions per MWh of delivered energy. Switching from a biomass plant that generates just electricity to one that also utilises heat again reduces emissions substantially. Improving the ‘carbon efficiency’ of the biomass feedstock still results in large savings but these are smaller relative to the other two options.

This highlights the urgent need to ensure that new biomass (and fossil fuel) plants are designed to produce usable heat from the outset. But it also shows that even in a plant that has already been designed to generate only electricity, good practice in biomass fuel production could reduce emissions significantly.

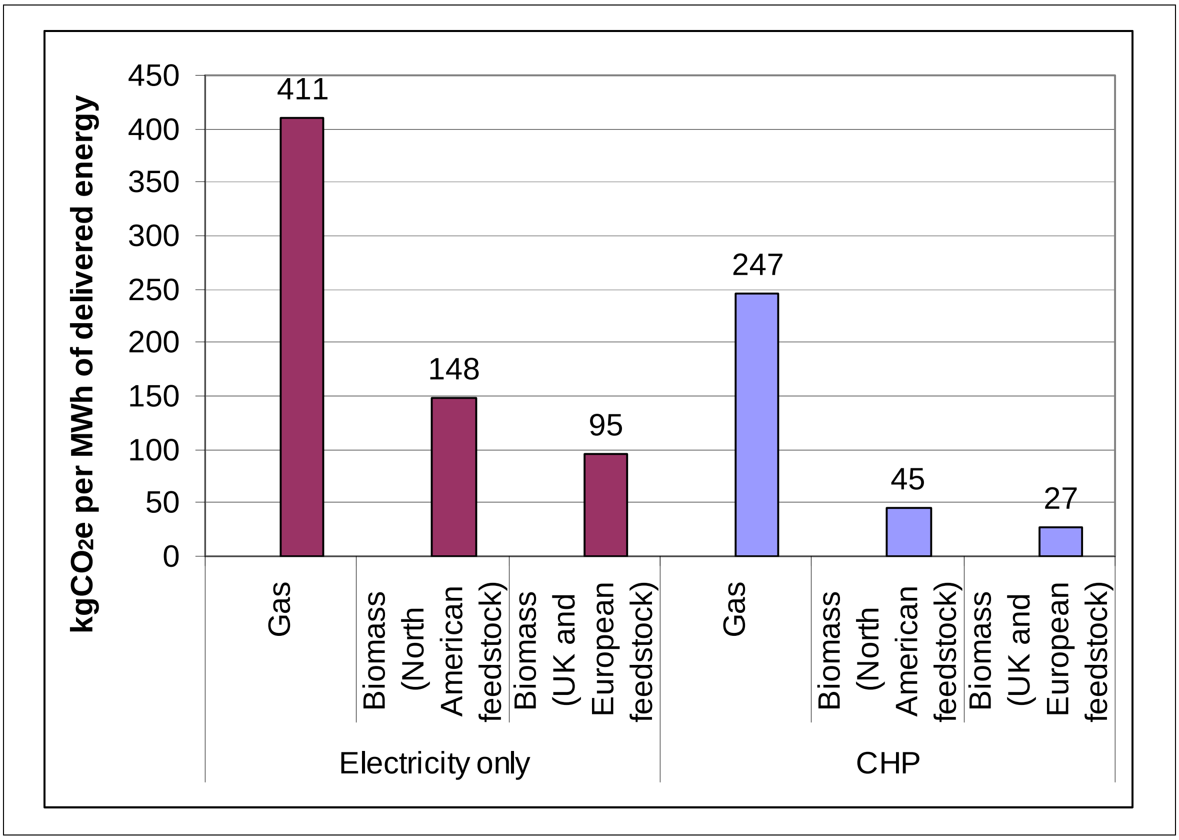


Figure 8.1 Comparison of emissions from biomass and gas-fired power stations

9 Conclusions

This analysis has resulted in the following conclusions.

Greenhouse gas emissions from energy generated using biomass are generally, but not always, lower than those from fossil fuels.

For example, using short rotation coppice chips to generate electricity can produce 35 to 85 per cent less emissions than a combined cycle gas turbine power station per unit of energy delivered, whereas using straw can, in some cases, produce over 35 per cent more.

How a fuel is produced has a major impact on emissions.

Transporting fuels over long distances and excessive use of nitrogen fertilisers can reduce the emissions savings made by the same fuel by between 15 and 50 per cent compared to best practice.

The treatment of avoided emissions from the disposal of wastes is critical and needs to be further developed.

We consider that in cases where it is clear that a single route accounts for most of current disposal and is likely to do so into the future, then an allowance could be given for emissions avoided from disposal. This would be the case, for example, with animal manures where the final point of disposal is almost always spreading to land. For waste feedstocks such as waste wood, where there are a number of potential alternative uses for the wood, as well as disposal, it will be more appropriate to take an average of emissions savings over these routes, or the disposal route with the lowest GHG saving, to ensure that savings are not overestimated.

Land use change can negate any emission savings.

Using formerly fallow land to grow bioenergy crops can reduce emission savings from a fuel by up to 10 per cent. Planting on permanent grassland is worse, with emissions savings significantly reduced and in some cases reversed.

Setting minimum standards for GHG savings could help maximise emissions savings from bioenergy production.

We consider that appropriate minimum standards for GHG savings for biomass feedstocks would be as set out below:

Table 9.1 Recommended minimum standards

Fuel form	Minimum GHG saving compared to gas	Maximum GHG emission for biomass feedstock (kgCO_2e per MWh)
Pellets	65%	79
Other solid and liquid forms	70%	68
Biogas (except for that derived from poultry waste)	90%	23
Biogas (derived from poultry waste)	50%	113

An alternative to setting standards as a percentage saving, which requires identification of the fossil fuel being used for comparison, would be to simply set a maximum value for the GHG emissions associated with production of the feedstock, avoiding the need to specify the fossil fuel to be used as the comparator. These values are also shown in the table above.

The standards recommended are achievable by most feedstocks and energy crops, but are stringent enough to ensure that large reductions in savings do not occur due to poor operating practice or land use change.

Energy conversion efficiency is an important factor in reducing emissions.

We consider that if minimum standards are to be set for the GHG savings that biomass feedstocks can deliver, rather than for the heat and power they produce, then they should be complemented with minimum standards for conversion efficiencies in boilers, power plants and CHP plants. A review of existing legislation and voluntary schemes in the UK and other EU countries, together with AEA's knowledge of the efficiencies being achieved by some new boilers suggests that:

- Minimum standards for domestic boilers could be raised above those in current legislation to at least 75 per cent and possibly 80 per cent. Minimum standards for medium sized boilers should be set, and a value of around 90 per cent would be an achievable standard.
- The introduction of a minimum standard for power plants could help to ensure that reasonable efficiency standards are always met, particularly in smaller plants.
- The Energy Using Products Directive could be a suitable EU-wide vehicle for setting standards for boilers as it covers all boilers up to 500kW.

Emission reductions of several million tonnes of greenhouse gases per year could be achieved by following good practice.

Based on current market projections, we estimate that by 2020 the emission of greenhouse gases equivalent to several million tonnes of carbon dioxide per year could be avoided if good practice in fuel production, processing and transport, and energy conversion efficiency were to be followed.

10 Appendix: Assumptions

As well as the changes listed in the table below, the $BEAT_2$ tool was modified to model the use of wood as the fuel supplying heat for drying in the case of best practice production of pellets, rather than diesel in the good and worst practice cases.

Estimates of GHG emissions per MWh of fuel delivered (Table 10.1) only consider emissions associated with fuel production, process and transport to the point of delivery at the boiler or power plant. Emissions from combustion, construction of the power plant and ash disposal were not included. This was modelled in $BEAT_2$ by setting the conversion efficiency of the plant to 100 per cent and subtracting emissions from conversion and ash disposal from the total emissions for the plant.

Table 10.1 Parameter values used to calculate GHG emissions from feedstock production (per MWh of energy contained in the fuel)

Feedstock	**Parameter**	**Values that have been changed from default values in $BEAT_2$ (a blank space indicates that the default value was used)**		
		Good practice	**Best practice**	**Worst practice**
Imported forestry residues	Road transport round trip distance – chipping point		50	200
	Road transport round trip distance – electricity plant (Stage 1)		50	200
Waste wood chips	Moisture content		30	50
	Road transport – transport to chipping point (Stage 1)		50	200
	Losses – transport to chipping point (Stage 1)		0	3
	Losses – chipping	5	0	10
	Losses – drying, cooling and storage		0	5
	Bulk drying			Yes
	Moisture content – stored chipped waste wood		20	35
	Percentage ash content of oven dry wood – stored chipped waste wood		0.5	2
	Road transport – transport to heating plant (Stage 1)		0	200

Feedstock	Parameter	Values that have been changed from default values in $BEAT_2$ (a blank space indicates that the default value was used)		
	Rail transport – transport to heating plant (Stage 1)		50	
SRC (chips and pellets)	Yield – cultivation		29	12
	Nitrogen fertiliser application		0	10
	Moisture content		45	55
	Losses – harvesting and chipping		0	5
	Road transport – transport to plant (Stage 1)		50	200
	Losses – transport to plant (Stage 1)		0	5
	Road transport – transport to plant (Stage 2)			200
	Rail transport – transport to plant (Stage 2)		50	
SRC(chips only)	Moisture content of wood fuel – stored wood fuel		20	50
	Ash content of dry wood fuel – stored wood fuel		0.5	2
SRC (pellets only)	Losses – milling		1	5
	Losses – pelletising		0	5
	Ash content of dry wood pellets – wood pellets		0	2
Miscanthus (chips and pellets)	Planting density		15,000	25,000
	Length of production cycle		30	10
	Yield – cultivation		28	12
	Establishment nitrogen fertiliser application		0	80
	Moisture content		20	50
	Losses – harvesting and chipping		5	10
	Road transport round trip distance – transport to storage		50	200
	Losses – transport to storage		0	0
	Losses – drying cooling and storage			15
	Road transport round trip distance – transport to plant			200

Feedstock	Parameter	Values that have been changed from default values in $BEAT_2$ (a blank space indicates that the default value was used)		
	Rail transport round trip distance – transport to plant		50	
Miscanthus (chips only)	Moisture content of miscanthus fuel – Stored			35
	Ash content of Dry miscanthus fuel – stored		1.5	7
Miscanthus (pellets only)	Moisture content		45	50
	Losses – harvesting and chipping		0	10
	Road transport round trip distance – transport to storage		50	200
	Losses – transport to storage		0	5
	Wood fuel used to dry pellets		Yes	No
	Losses – drying cooling and storage		0	15
	Losses – milling		0	5
	Losses – pelletisation		0	5
	Ash content of dry miscanthus fuel – stored miscanthus fuel		0.5	7
	Losses – transport to plant		0	5
Straw	Sowing rate		175	210
	Yield – cultivation		6	3
	Nitrogen fertiliser application		20	250
	Moisture content		10	30
	Losses – harvesting and baling		0	5
	Road transport – transport to storage		50	200
	Losses – transport to storage		0	5
	Moisture content of straw fuel – stored wheat straw fuel		10	20
	Ash content of dry straw fuel – stored wheat straw fuel		3	7
	Road transport – transport to plant		0	200
	Rail transport – transport to plant		50	0
PKE	Moisture content		5	10

Feedstock	Parameter	Values that have been changed from default values in $BEAT_2$ (a blank space indicates that the default value was used)		
	Losses – transport from palm oil mill to overseas port		0	5
	Road transport round trip distance – transport from palm oil mill to overseas port		50	200
	Losses – transport from overseas port to UK port		0	5
	Ship transport round trip distance – transport from overseas port to UK port		12,200	42,000
	Losses – transport from UK port to power plant		0	3
	Road transport round trip distance – transport from UK port to power plant		0	600
	Rail transport round trip distance – transport from UK port to power plant		50	
AD dairy centralised	Losses – transport from farms to plant			1
	Loses farm transport to lagoon			1
	Losses – waste reception pit			1
	Losses – substrate mixing tank			1
	Losses – spreading dairy manure on land			3
	Losses – heating mixed substrate			1
	Losses (biogas) – continuously stirred tank reactor			3
	Losses (digestate) – continuously stirred tank reactor			3
	Losses – biogas desulphurisation			1
	Losses (biogas) – digestate and biogas storage tank		0	3
	Losses (digestate) – digestate and biogas storage tank			3
	Losses – transport from plant to farms			1
	Losses – spreading digestate on land			1
Pig on farm	Losses – farm transport to lagoon			3

Feedstock	Parameter	Values that have been changed from default values in BEAT$_2$ (a blank space indicates that the default value was used)		
	Losses – waste reception and pre-mixing			3
	Losses – spreading pig manure on land			3
	Losses (biogas) – continuously stirred tank reactor		0	5
	Losses (digestate) – continuously stirred tank reactor			1
	Losses – biogas cleaning and storage			2
	Losses – farm transport to lagoon			5
	Losses – storage lagoon			1
	Losses – spreading digestate on land		0	5
Imported waste wood chips	Round trip shipping distance (Stage 1)	4,000		
	Losses from chipping	20		

Table 10.2 Parameter values used to add energy conversion efficiency to feedstock production to give GHG emissions per MWh of delivered energy

	Best	Good	Worst
Cofiring	36%	35%	30%
Biomass power plant (electricity)	30%	25%	20%
Domestic boiler chips	85%	80%	70%
Domestic boiler pellets	88%	85%	70%

Table 10.3 Parameter values used to calculate the implications of moving to good practice in feedstock production and energy conversion efficiency

	Parameters changed	Good	Poor
Large electricity plant	Thermal input (MWth)	929	929
	Forestry residues import distance (km)	75% imported (Baltic region 4,000km), 25% UK	100% imported (from Canada 9,000km)
	Net generating efficiency	27%	27%
	Annual load factor	85%	85%
CHP plant	Thermal input (MWth)	929	929
	Overall efficiency	80%	80%
	Heat to power ratio	1:3	1:3
	Annual load factor	85%	85%
	Forestry residues type and import distance (km)	75% imported (Baltic region 4,000km), 25% UK	100% imported (from Canada 9,000km)

11 Appendix: Existing and proposed legislation on minimum fuel conversion efficiencies

Table 11.1 Existing and proposed legislation on minimum fuel conversion efficiencies

Legislation / Standard / Scheme Title	Plant type, including size	Minimum efficiency (based on LHV of fuel)	Status	Existing or pending
Domestic boilers				
UK Building Regulations Part L – Domestic Heating Compliance Guide	Boilers in new domestic dwellings using wood pellets, chips or logs	**65%**	Mandatory	Existing
EN12809	Residential independent boilers fired by solid fuel up to **50kW**	Varies with boiler size[1] 5kW – **65%** 50kW – **70%**	Mandatory	Existing
UK Energy Technology List	Biomass combined room heater and hot water boilers	**70%**	Voluntary	Existing
EN14785	Residential space heating appliances fired by wood pellets up to **50kW**	**75%**	Voluntary	Existing
Blue Angel 111 and 112 (Germany)	Wood pellet boilers up to **50kW**	**90%**	Voluntary	Existing
Nordic Swan – Ecolabel	All boiler sizes up to **300kW**	Varies with size Manual feed boilers: 50kW - **83%** Automatic feed boiler: 50kW – **86%**	Voluntary	Existing – Valid until 30 June 2011
Energy Labelling Framework Directive (92/75/EEC)	To be defined	No details – only a proposal at the present time – may not cover biomass boilers	Advisory	Pending

Legislation / Standard / Scheme Title	Plant type, including size	Minimum efficiency (based on LHV of fuel)	Status	Existing or pending
Domestic boilers				
UK Building Regulations Part L – Domestic Heating Compliance Guide	Micro CHP	Not yet set - guidance for micro-CHP is still under development.		Existing (legislation)/ pending (guidance)
Medium sized boilers (under 500kW)				
EN303-5: 1999	Heating boilers up to **300kW**	Defines three classes of boiler: minimum efficiency in each is dependent on size: **Class 1**: 100kW – **59%** 300kW – **61.9%** **Class 2**: 100kW – **69%** 300kW – **71.9%** **Class 3**: 100kW – **79%** 300kW – **81.9%**	Advisory	Existing
Energy Technology List (for Enhanced Capital Allowance)	Hot water and steam boilers up to **300kW**	Based on formula used for lass 3 under EN303 i.e. 100kW – **79%** 300kW – **81.9%**	Voluntary	Existing
Energy Technology List	Steam boilers above **300kW**	**82.0%**	Voluntary	Existing
Energy Technology List	Hot water boilers above **300 kW**	**85.0%**	Voluntary	Existing
Nordic Swan - Ecolabel	Up to **300kW**	Varies with size Manual feed boilers 100kW - **85%**; 300kW – **87.2%** Automatic feed boiler: 100kW – **87%**; 300kW – **89.8%**	Voluntary	Existing – Valid until 30[t] June 2011

Legislation / Standard / Scheme Title	Plant type, including size	Minimum efficiency (based on LHV of fuel)	Status	Existing or pending
Medium sized boilers (under 500kW)				
EN303-5: Current revision	Would be extended up to **500kW** in line with EUP	Propose adding 2 more classes Class 4: 100kW – **84%**; 300kW – **86.9%** Class 5: 100kW – **89%**; 300kW – **91.9%**	Advisory	Pending
Energy Using Products Directive Lot 15 – Solid Fuel Small Combustion Installations	Up to **500kW** (may also cover domestic boilers)	Under discussion	Mandatory	Pending
Large combustion plant (CHP and Electricity Generation)				
Cogeneration Directive (2004/8/EC)	CHP plant – all fuels	**75 to 80%** depending on the technology used to convert the fuel to heat and power	Mandatory	Existing– implementation by Member States at different stages
CHPQA – UK Scheme for assessing Good Quality CHP	CHP Plant	For plant >25MW – **70%** (plus a requirement to achieve 10% primary energy savings compared to reference values defined in the Cogeneration Directive. For plants under 25MW there is no minimum standard for efficiency, only a requirement to meet certain primary energy savings compared to reference values defined in the directive. Typically, plants need to have an efficiency of about 65% to meet the energy saving requirement.	Mandatory	Existing

Legislation / Standard / Scheme Title	Plant type, including size	Minimum efficiency (based on LHV of fuel)	Status	Existing or pending
Large combustion plant (CHP and Electricity Generation)				
UK Building Regulations Part L – Non-Domestic Heating, Cooling and Ventilation Compliance Guide	CHP Plant	Minimum CHPQA Quality Index of 105; that is, would be required to meet the requirements set out above for the CHPQA.	Mandatory	Existing
Integrated Pollution Prevention and Control Directive (EU)	Boilers, CHP and generating plant **>50MW** (input rating)	Electricity generation: 20-30% CHP: 75-90% (values suggested in BREF note which outlines Best Available Technology; suggested efficiencies vary depending on type of technology used).	Directive is mandatory but BREF note is advisory	Existing
Pollution prevention and control (UK regulations)	Boilers, CHP and generating plant **>50MW** (input rating)	All must meet basic energy requirements. Additional energy efficiency requirements can be met either through participation in a Climate Change Agreement or Emissions Trading Scheme Direct Participant Agreement with the UK Government, or through compliance with further permit-specific requirements determined by the Environment Agency.	Mandatory	Existing

Notes: [1]Based on higher heating value of fuel.

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List of abbreviations

AD – Anaerobic digestion

$BEAT_2$ – Biomass Environment Assessment Tool, version 2

BREF - Best available techniques reference

CCA – Climate Change Agreement

CCGT – Combined cycle gas turbine

CHP – Combined heat and power

CHPQA –Quality assurance for combined heat and power

ETS – Emissions Trading Scheme

GHG – Greenhouse gas

IPPC – Integrated pollution prevention and control

kgCO2e – Kilograms of carbon dioxide equivalent

kW – Kilowatt

LCA – Lifecycle analysis

MWh – Megawatthour

PKE – Palm kernel expeller

SRC – Short rotation coppice

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