# Review of Power Production from Renewable and Related Sources

R&D Technical Report P4-097/TR

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Research Contractor
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ISBN 1 844320 022



**Dissemination Status**
Internal: Released to Regions
External: Released to Public Domain

**Statement of Use**
This report reviews currently available information on the environmental impacts of biomass production and its use in electricity and heat production activities. Specifically those energy conversion activities which will be regulated by the Environment Agency under Statutory Instrument 2000 No 1973 Pollution Prevention and Control (England and Wales) Regulations 2000 (PPC Regulations). Some key issues are identified for consideration by the Environment Agency and other organisations involved in biomass production and use.

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## ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the biomass industry and the researchers working with biomass. Their help is greatly appreciated.

## EXECUTIVE SUMMARY

Worldwide, biomass is one of the key sources of energy used today. Much of this is as a fuel for domestic heating and cooking, but in some countries significant quantities are used for power generation and district heating.

Biomass power is now a priority area in the Government's strategy to meet its policy that 10% of the UK's electricity requirements should come from renewable sources by 2010. To achieve this strategy there are a number of support mechanisms to help the development of biomass power:

- The Renewables Obligation (England and Wales);
- The Climate Change levy (UK);
- The DTI Sustainable Energy Programme (UK);
- The Energy Crops Scheme (England only);
- The Bio-energy Capital Grants Scheme (UK).

As a consequence of these policies it is likely that development of biomass plants will be accelerated. Co-firing of biomass with coal in conventional power stations is a prospect in the near future, but the Bio-energy Capital Grants Scheme will encourage a whole range of biomass heat and power plant in the short to medium term. Both the Renewables Obligation and the Capital Grants scheme require a significant proportion of the input fuel to be supplied from energy crops.

These developments will have wide ranging implications for the environment, some positive, some negative, some global and some local. Examples that require consideration include release of pollutants to the environment, odour, traffic, visual impact and the contribution to global climate change compared to other energy sources.

The Environment Agency will be required to regulate the environmental performance of biomass power plants that fall under Part A(1) of IPPC. The Agency will also have a role as a statutory consultee in the planning process. To fulfil these duties the Agency needs to have a sound understanding of biomass power plants and their associated fuel supply chains.

This report describes:

- Production, collection, harvesting and conversion options for the main biomass fuels for the UK;
- Currently available information on the key environmental implications and, where possible, a quantitative analysis;
- The economics of biomass energy and the influence of emissions abatement on those economics.

It also examines key policy issues for consideration by the Agency.

The general conclusions of this analysis are:

1. The biomass fuels most likely to be used in the UK are: forestry residues, agricultural residues (including straw and poultry litter), wood waste, energy crops (e.g. short rotation

coppice and miscanthus) and other sources of biomass such as arboricultural residues and food processing wastes.

2. Currently around 1,500 ha of short rotation coppice (SRC) and 350 ha of miscanthus have been established in the UK for commercial use. However, the Government initiatives listed above could increase these areas considerably. There are guidelines for the planting of large areas of energy crops and as a condition of the Energy Crops Scheme an Environmental Impact Assessment (EIA) may be required. Nevertheless, understanding of the environmental implications of large-scale planting of energy crops and optimisation of any environmental benefits remains an important issue.

3. The ecology of farming is a major conservation issue. It is important to understand the implications for wildlife and studies are underway to monitor plantations for the ARBRE project. Preliminary results indicate that SRC has a positive effect on wildlife compared to nearby arable crops. If plantations replace existing woodland, natural grassland or other environmentally sensitive habitats, the overall effect can be negative. However, this is unlikely to happen. The guidelines mentioned in (2) examine these issues and make recommendations about the siting of energy crops.

4. It is recognised that SRC is likely to be a low input crop (with respect to nutrient requirements), although good site preparation is important and further work is needed on low nutrient soils. Use of sewage sludge as a fertiliser and as a source of water for energy crops has been trialled. However, careful consideration of subsequent land use, the build up of contaminants in the soil and the impact on emissions from conversion plant is important. SRC can have high water demand. Further work on the water use of SRC and its influence on hydrogeology is underway as part of the DTI's Sustainable Energy Programme.

5. Further work is required on the development of equipment for the establishment, harvesting and collection of biomass fuels. Harvesting equipment is being developed as part of the ARBRE project and under other initiatives. Equipment for the collection of forestry residues is available but requires further testing under UK conditions. Establishment of miscanthus remains an issue.

6. Storage and supply infrastructure is being developed by the biomass industry. The impact of collection and storage techniques on the need for subsequent fuel drying and on emissions from plant are important considerations and should be taken into consideration in development of collection and storage strategies.

7. Generation of heat and power from biomass fuels by thermal conversion is technically proven, both in the UK and abroad. There are a number of other conversion options open to the biomass developer, including gasification, pyrolysis or co-firing with another fuel. These technologies are at the demonstration stage in the UK, and there are examples abroad. It is an aim of the bio-energy capital grant scheme to encourage advanced conversion. Advanced conversion technologies offer key advantages, such as higher conversion efficiency, improved control of environmental emissions and flexibility of fuel use. These are of key environmental importance.

8. Biomass is generally accepted as a “green” fuel for energy production because $CO_2$ emissions are greatly reduced compared to fossil fuels. This is because the $CO_2$ released on conversion equals the $CO_2$ sequestered as the plant grows. The associated fossil fuel emissions from production and utilisation of biomass fuel have been assessed on a life cycle basis and found to be 2-8% of those from a gas fired CCGT (combined cycle gas turbine) plant.

9. Other emissions from biomass plant are generally lower than from fossil fuel plant. Nevertheless there are issues, noticeably with NO, $NO_2$ and VOCs from all biomass plant; $SO_2$, particulates and cadmium for straw and poultry litter; HCl and mercury for straw plant; and lead for poultry litter. Emissions will depend on the composition of the biomass fuel, which in turn can vary with soil and production and harvesting conditions. These emissions can all be abated using available technology.

10. There are major issues for plant siting, including noise, visual impact and odour. These issues can all be mitigated by careful design and planning. However, they will be important to the local community and community liaison is important to discuss the community’s concerns. The environmental impact of emissions should also be an important consideration at the siting/planning in order to minimise impact, optimise design and location. These issues are considered in detail in Chapter 9.

11. Stack height may influence deposition of emissions to soil. It is also an important visual impact. Careful design and consultation with the local community is required to resolve these issues.

12. Another local impact will be traffic movements. Siting near existing main roads will minimise this impact. Use of alternatives, such as rail and water transport, require careful investigation, development of infrastructure and handling equipment.

13. Ash disposal is an important issue. Some ash is currently used as a fertiliser, but there must be a market for the product for this to work. In addition the build-up of trace contaminants in the soil requires further investigation. Ash from co-firing is a particular issue, because a lot of coal ash is currently re-used in the cement and building industry.

14. Biomass fuel costs range from £1.8-3/GJ or £30-45/odt. The costs for production of energy crops include grants from the Energy Crops Scheme and assumes the crops are grown on land that has been set aside and for which set aside payments are being received. These fuel prices are higher than those for natural gas or coal.

15. Economic analysis indicates that the cost of electricity from biomass schemes is higher than current prices using conventional fuels, unless grant support and the Renewables Obligation (RO) is taken into account (including the recycled buy out monies). The most significant impacts on the competitiveness of biomass were found to be availability and load factor. Not only does capital cost have an important influence on economics, but the efficiency of plant operation is also important.

16. Economic data for abatement costs are not readily available and are frequently quoted in ways that do not allow ready comparison. In addition the issue is complex. However, some comments can be made. It is generally true that bolt-on emissions abatement is more expensive than abatement included in the design of the scheme. Thus it is important

to the developer to understand potential emissions and necessary abatement at the design stage of the project. More advanced combustion techniques allow flexibility and better emissions control but they are more expensive than conventional grate combustion and cannot easily be retro fitted. Advanced conversion technologies (e.g. gasification and pyrolysis) are expensive and there is little experience in this country. Nevertheless they promise greater conversion efficiencies and more flexibility in conversion to energy (in particular the value of pyrolysis is that it allows separating out production and use). This is of key environmental importance for the long term. Emissions abatement should be much improved once these processes are fully developed. This is because individual chemical reactions can be separated and then operated under optimal conditions for each. It must be understood that at this stage of development unexpected results may be obtained, such as higher than expected generation of ammonia in some gasification reactions, so ongoing development is essential and unavoidable. For this reason it is likely to be some time before the full potential of advanced conversion processes can be realised and this applies to both plant performance and emissions. In the short term this means there is risk in their development, but the long-term gain will be significant improved efficiency.

17. The economic analysis indicates that the RO and other Government initiatives are likely to be highly influential in the development of biomass fuel. The RO has stimulated a lot of immediate interest in co-firing. In the short to medium term the Bioenergy Capital Grant Scheme will bring in a number of heat and power schemes using state of the art and advanced conversion technologies. Industry will look to maximise its competitiveness by using the cheapest possible feedstock and maintaining flexibility in negotiating with fuel suppliers. However, there may be a tendency to build larger installations to achieve economies of scale. A further factor will be the need to secure long-term contracts for a proportion of the fuel to guarantee sufficient revenue to repay the loans used to finance the project. These factors may favour flexible installations that can burn a range of fuels, both separately and in combination.

18. There are a number of issues that need resolving (e.g. relating to climate change, effects on air, soil and water). These are outlined in Chapter 11 of this report.

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# 1 INTRODUCTION

## 1.1 Biomass Development

Worldwide, biomass is one of the key sources of energy used today. Much of this is as a fuel for domestic cooking and heating. Certain countries also use significant quantities of biomass for power production and district heating. Figure 2.1 shows the percentage of electricity from biomass sources in a number of countries. In the USA, the 3% represents about 7,000 $MW_e$ of capacity.

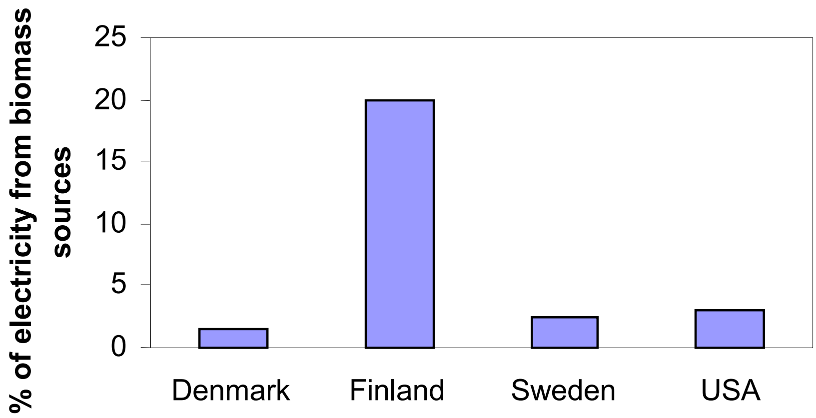


**Figure 2.1 Use of biomass for electricity production (1997/98)**

**Currently there are few biomass power plants operating in the UK**. Examples are:

| | | |
|---|---|---|
| ▪ | Wood | 8 $MW_e$ Eggborough, North Yorkshire (not in full operation) |
| ▪ | Straw | 36 $MW_e$ Ely, Cambridgeshire |
| ▪ | Chicken litter | 13 $MW_e$ Eye |
| | | 13 $MW_e$ Glanford |
| | | 38.5 $MW_e$ Thetford |
| | | 10 $MW_e$ Glenrothes, Fife |

However, there is considerable interest in developing further plants in the UK and biomass power is a priority area in the Government's strategy to meet its policy that 10% of the UK's electricity requirements should be met from renewable sources by 2010.

There is also the EU Renewable's Directive (EU 2001) which defines the framework within which renewable energy should be developed. This directive "recognises the need to promote renewable energy sources as a priority measure given that their exploitation contributes to environmental protection and sustainable development".

There are a number of key issues that will affect the development of biomass power:

***Why biomass?***

There are two key drivers for the development of biomass power. The first is global climate change and the **need to switch energy production from fossil fuel to renewable sources that have significantly lower contribution to increased levels of greenhouse gases in the atmosphere**.

The second driver is the **pressure to move to sustainable agriculture** in the UK. This is likely to mean that farmers will switch from food crops to crops for industrial and energy uses and that farmers will be seeking crops that require low inputs of agrochemicals. Other interest groups will also be looking for crops that have the potential for increased biodiversity.

***Mechanisms to support development***

As a result of Government strategy, **a number of support mechanisms will help the development of biomass power**. These include[1]:

- the Renewables Obligation;
- the Climate Change Levy;
- the DTI Renewable Energy Programme;
- the DEFRA Energy Crops Scheme.

***Technology***

Most biomass power plants currently operating are based on combustion of the fuel with steam cycle electricity generation. This type of system can achieve electrical conversion efficiencies of almost 30%. Combustion is currently the only technology that can be considered fully proven both technically and economically. Greater efficiencies may be achieved through combined heat and power, if a use can be found for the heat.

There are other technologies being developed, such as pyrolysis and gasification, that produce an intermediate gaseous or liquid fuel that can then be used in combined cycle gas turbines to achieve higher efficiencies (up to 40%). Also, there is considerable interest in using biomass fuels in existing fossil fuel power plant to displace some of the fossil fuel. **Successful technology development, both for efficient production and processing of fuel and for conversion of fuel to energy, is important if the full potential of biomass is to be realised**.

***Public perception***

Whilst biomass power has a key role in Government and EU strategies to promote more sustainable energy supplies and agriculture, which have regional and global benefits, developments will have an impact on the lives of people at the local level. Some of the local impacts, such as opportunities for employment, will be perceived as positive and others, such as changes to the visual landscape, may be perceived as negative. Many proposed biomass

[1] More information on these policies may be found on the DTI web site: www.dti.gov.uk, the Ofgem web site: www.ofgem.gov.uk; and the DEFRA web site: www.defra.gov.uk

power plants in the UK have aroused public opposition based on perceived local disbenefits, including visual impact, potentially polluting emissions and additional noise from the plant and vehicles serving the plant**. If biomass power plants are to become more widely deployed, conflicts between global/regional and local interests, whether real or perceived, will need to be resolved**.

Part of resolving such conflicts is to have readily available, unambiguous and authoritative sources of information on the environmental implications of biomass power plants.

## 1.2 Key Environmental Implications of Biomass Power Plants

The **development of biomass power plants will have wide ranging implications for the environment**. Some of these implications will be positive and some negative, some will be global and some local, some will be readily quantifiable and some will be subjective. Examples that require consideration are releases of pollutants to the environment, noise, odour, traffic movements, visual impact and the contribution to global climate change compared to other energy sources. This study aims to present currently available data on these implications.

## 1.3 Background to this Study

The Environment Agency will be required to regulate the environmental performance of biomass power plants that fall under Part A(1) of IPPC (as described in Chapter 2). Also, the Agency will have a role as a statutory consultee in the planning process. To fulfil these duties, **the Agency needs to have a sound understanding of biomass power plants and their associated fuel supply chains** with particular emphasis on the environmental implications.

As there are very few biomass power plants currently operating in the UK, there is limited experience of the environmental implications of such plants or their fuel supply chains. Hence the Environment Agency have commissioned this report to summarise current understanding on this subject and to identify the key issues the Agency should consider in carrying out its duties.

**This report describes currently available information on the key environmental implications and, where possible, provides quantitative analysis. The report also recommends key policy issues for consideration by the Environment Agency**.

# 2 SCOPE

This report describes the currently available data on the environmental impacts of electricity and heat production from renewable and related sources that will be regulated by the Environment Agency under Statutory Instrument 2000 No 1973 Pollution Prevention and Control (England and Wales) Regulations 2000 (PPC Regulations). The report also discusses wider issues that are of relevance to the Environment Agency, for example in their role as consultees during the planning process.

## 2.1 Activities and Installations Regulated by the Environment Agency

Under the PPC Regulations, the Environment Agency will regulate Part A(1) activities and installations as defined by Schedule 1. The relevant parts of Schedule 1 are:

- *Section 1.1 Combustion Activities:* burning any fuel in an appliance with a rated thermal input of 50 MW or more and burning any fuel manufactured from, or comprising, waste in an appliance with a rated thermal input of 3 MW or more but less than 50 MW;
- *Section 1.2 Gasification, Liquefaction and Refining Activities:* activities involving the pyrolysis, carbonisation, distillation, liquefaction, gasification, partial oxidation, or other heat treatment of coal (other than the drying of coal), lignite, oil, other carbonaceous material or mixtures thereof otherwise than with a view to making charcoal.

## 2.2 Renewable and Related Sources

The Directive of the European Parliament and of the Council on the Promotion of Electricity from Renewable Energy Sources in the Internal Electricity Market (EU 2001) defines renewable energy sources as:

> ***"Renewable non-fossil energy sources shall mean wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases. Biomass shall mean the biodegradable fraction of products, waste and residues from agriculture (including vegetable and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste."***

Combining this definition of renewable energy sources with the activities and installations that will be regulated by the Environment Agency under the PPC Regulations effectively means that this report is limited to electricity and heat production through thermal conversion activities (such as combustion, gasification and pyrolysis) with biomass fuels[2] (the biodegradable fractions of industrial and municipal waste are not included in this report as the have already been dealt with in other work commissioned by the Environment Agency). However, in this report we also consider activities associated with the delivery of fuels to

[2] From the definition in the Renewable Energy Directive quoted above, biomass fuels include forestry residues, agricultural residues that are suitable for combustion to generate heat and power (such as straw and chicken litter) and energy crops (such as short rotation coppice and various grasses).

thermal conversion installations and, where a secondary fuel is produced through thermal conversion, the report considers the end use of this fuel.  The activities covered in this report are shown in Table 2.1

Biomass fuels covered by the EU definition have been grouped into 4 categories as shown in Table 2.1.  Fuels covered by these categories are described in Chapter 4.

### 2.3 Environmental Impacts

The Environment Agency's vision for the future identifies a number of key indicators against which to measure its performance in improving and protecting the environment:

- a better quality of life;
- enhanced environment for wildlife;
- cleaner air for everyone;
- restored, protected land with healthier soils;
- improved and protected inland and coastal waters;
- wiser, sustainable use of natural resources;
- a greener business world;
- limiting and adapting to climate change;
- reducing flood risk.

In this report environmental impacts of electricity and heat production from biomass fuels are related to these indicators (with the exception of "a greener business world", as all of the impacts considered are covered by the other indicators).  The environmental impacts that are considered in this report, and their relationship to these indicators, are shown in Table 2.2.

**Table 2.1 Activities and fuel categories considered in this report**

| | Establishment and growing | Harvesting /collection | Storage | Transport | Fuel processing | Conversion process | End use |
|---|---|---|---|---|---|---|---|
| **Energy crops** | √ | √ | √ | √ | √ | √ | √ |
| **Forestry residues** | | √ | √ | √ | √ | √ | √ |
| **Agricultural residues** | | √ | √ | √ | √ | √ | √ |
| **Wood Waste** | | | √ | √ | √ | √ | √ |

**Table 2.2 Environmental impacts of activities considered in this report**

| | Establishment and growing | Harvesting /collection | Storage | Transport | Fuel processing | Conversion process | End use |
|---|---|---|---|---|---|---|---|
| **A better quality of life** | | | | | | | |
| Noise, odour, traffic, visual impact | √ | √ | √ | √ | √ | √ | √ |
| **Enhanced environment for wildlife** | | | | | | | |
| Habitat changes | √ | √ | | | | | |
| **Cleaner air for everyone** | | | | | | | |
| Emissions to air | √ | √ | √ | √ | √ | √ | √ |
| **Restored, protected land with healthier soils** | | | | | | | |
| Contamination, soil erosion, soil nutrient status, soil structure | √ | √ | | | | √ | |
| **Improved and protected inland and coastal waters** | | | | | | | |
| Eutrophication, oxygen demand, releases of dangerous substances | √ | √ | √ | | | √ | √ |
| **Wiser, sustainable use of natural resources** | | | | | | | |
| Resources use, waste production | √ | | | √ | | √ | √ |
| **Limiting and adapting to climate change** | | | | | | | |
| Greenhouse gas emissions | √ | √ | √ | √ | √ | √ | √ |
| **Reducing flood risk** | | | | | | | |
| Changes to hydrology | √ | √ | | | | | |

# 3 METHODOLOGY

This report is based on a desk-based study that reviewed existing published sources. The work was carried out using the following methodology:

| **Activity** | **Method** |
|---|---|
| A. Information gathering | We have used our comprehensive knowledge of past, current and future developments in the field, our wide-ranging contacts and our in-house library service to gather relevant information. |
| B. Develop list of environmental characteristics | From the information gathered, a list of potential pollutants and environmental characteristics associated with biomass power plants was developed. |
| C. Develop descriptions of conversion processes and biomass fuels. | From the information gathered, fuels and conversion processes likely to be used in the UK were identified and described. |
| D. Match fuels to processes | Based on the experiences of technology suppliers and our knowledge of the characteristics of fuels and technologies we matched the two to give the most likely combinations. |
| E. Identify representative examples | Environmental characteristics were developed for a number of generic biomass power plants. |
| F. Assess emissions and impacts | Using the methodology described in the Agency's draft Technical Guidance Note H1, the emissions and impacts associated with the generic plants were assessed. |
| G. Strategic assessment of the environmental impact of siting | Using the output from applying H1, we assessed the likely impact on ambient environmental quality for a range of situations, drawing conclusions as to the strategic implications of this. |
| H. Economic assessment | A discounted cash flow model was used to assess the economics of biomass power plants in the UK. |
| I. Policy implications | Based on work carried out under the other activities and in discussion with the Agency, policy implications were considered. |

# 4 BIOMASS FUELS LIKELY TO BE USED IN THE UK

Biomass fuels can be divided into two types; energy crops and residues. Energy crops are plants that are grown specifically to produce fuel. Examples in the UK are willow and poplar coppice and energy grasses such as miscanthus and switchgrass. Any crop can potentially be used as a fuel, but to be a commercial proposition the crop must be fast growing under UK conditions to produce high yields, since the fuel is a low value product. Both forestry and agricultural residues are suitable as fuels. The residues are low value products that remain after the primary product has been harvested. In the UK, both forestry residues, thinnings and trimmings from trees, and straw are used as fuels. Residues from poultry production, food processing and wood processing industries are also suitable as fuels. The residues are generally low value products, but to be useful as fuels they need to be available in sufficient quantities and to be collected and transported at low cost to the point of use. Table 4.1 shows a summary of the main biomass fuels that are likely to be used in the UK.

**Table 4.1 Biomass fuels likely to be used in the UK**

| | Fuels currently being considered | Fuels that may be considered in future |
|---|---|---|
| **Energy crops** | short rotation coppice, miscanthus | switchgrass, reed canary grass, single stem trees and annual crops |
| **Forestry residues** | woody residues from felling, thinning and other forestry operations | |
| **Agricultural residues** | poultry litter and straw | |
| **Wood Waste** | untreated wood waste from sawmills, packaging, from wood products industry etc | |
| **Other** | wood from arboricultural operations and food processing wastes | |

Recent studies have shown that annual crops such as oil seed rape, wheat and rye are unlikely to be profitable energy crops for electricity and heat production at the current prices achieved for biofuels (ECOTEC 1999, Christian 1999). However, annual crops are familiar to farmers, and can be produced now with reliable yields. They may therefore have a role in providing an immediate source of biomass. In the longer term, annual crops may also have a place as part of a portfolio of biofuels since they offer producers flexibility of land use and can be included as part of existing farm rotations. From the customers point of view they could provide an alternative fuel supply at a different time of year from the perennial crops thus improving security of supply and reducing storage requirements. Low input crops such as rye and triticale are likely to be more acceptable from an environmental point of view than high input crops such as oil seed rape. This is because high agrochemical input reduces the environmental benefits, including the fossil fuel substitution potential and carbon abatement potential of the biofuel. There are also ethical/moral considerations with the use of food crops for energy.

## 4.1 Fuel Costs

The economics of biofuel production depend on the price the end user is prepared to pay for the fuel, and the cost of producing and delivering the fuel. For residues such as forestry residues and straw, the fuel is a by-product and the cost assigned to production is therefore usually low. However, the cost of collecting, processing and transporting the fuel can be substantial. For energy crops, the full cost of growing the crop must be incorporated into the cost of the fuel, making production costs higher.

Table 4. gives a summary of recent data available on yields and costs for a range of biofuels. At the present time only straw and forest residues are traded as biofuels, and so have known prices. We assume that the price obtained for short rotation coppice (SRC) and energy grasses will be similar to that paid for straw and forest residues. The table shows that with current production practices none of the energy crops can be produced economically when compared with fossil fuels. The table also shows the estimated cost of production, processing and transport of the energy crops. The production cost assumes a level of income to the farmer, which is comparable with that achieved with other arable crops. At present, support mechanisms are in place to make the production of SRC and miscanthus worthwhile for farmers (MAFF 2000). In time the support may be extended to other energy crops. Costs for energy grasses are the most speculative, since these crops are just beginning to be grown at commercial scale (→ Chapter 10).

**Table 4.2 Yields and costs for some biofuels**

| Fuel | Yield odt/ha/y | Delivered fuel £/odt | Typical gross calorific value[2] GJ/odt | Energy cost £/GJ |
|---|---|---|---|---|
| **Forest residue** | 2[1] | 25-45 | 20 | 1.8 |
| **Straw** | 3-4 | 35[3] | 18 | 2.0 |
| **Willow SRC** | 8-12[4] | 40-60[5] | 20 | 2.5 |
| **Miscanthus** [6,7] | 12-18 | 50-60 | 19 | 2.9 |
| **Switchgrass** [6,7] | 8-11 | 50-60 | 19 | 2.9 |
| **Reed Canary Grass** [6,7] | 6-9 | 50-60 | 18 | 3.0 |

Notes: [1]Matthews and Mortimer 2000, [2]Christian 1999, [3]Newman 2001, [4]Boyd *et al* 2000, [5]Bullard and Nixon 1999, [6]Bullard 2001, [7]Christian and Riche 1999
Odt= oven dried tonnes.
For comparison, the energy cost of coal is typically £1.2/GJ (DTI 2001).

## 4.2 Short Rotation Coppice (SRC)

Short rotation coppicing is the production of biomass for energy from **fast growing tree species that are grown intensively and harvested every 2 to 5 years**. Harvesting of the stems at these regular intervals encourages the vigorous regrowth of multiple stems in certain species, and these species are suitable for coppicing.

SRC is the energy crop that has been most researched in Northern Europe. In the UK, large-scale trials of SRC for energy production began in 1986 at ten sites and continued for 12 years (Mitchell *et al* 1998). These trials aimed to obtain information on cost, logistics, productivity and basic biology of SRC. More recently a network of 49 small-scale trial sites was set up around the UK to assess the performance of a range of SRC varieties under different soil and climatic conditions (Armstrong 1999). **SRC is now becoming a commercial crop in the UK**, with planting of 1,100 ha to date in support of the ARBRE power production plant in Yorkshire. SRC has also been extensively researched in Sweden (Danfors *et al* 1998), and is grown as a commercial crop with 16,000 ha of willow coppice growing in 1997.

Several comprehensive guides to the growing and utilisation of SRC for energy are currently available (e.g. Armstrong 1999, Danfors *et al* 1998, Boyd *et al* 2000). Below is a short summary of the most recent thinking on production of SRC for energy.

***Suitability for energy use***

SRC is suitable as an energy crop because it **can produce high yields of biomass with low inputs of fertiliser**. The two most promising species for UK conditions are poplar and willow. **At the present time willow is the preferred species** because it naturally produces multiple stems and so is easier to adapt to a coppice system than poplar. Willow has also been found to be more able to cope with rust disease than poplar under coppice conditions. As an illustration of the rate of growth of willow coppice, typical heights of the crops are 2 m after 2 years, 4 m after 3 years and 7 m after 4 years.

SRC can be grown in a range of soil types, but to thrive **there must be adequate water**. About 600 mm is required in the growing season between April and October. The site must not be waterlogged in winter, since this is the harvesting season and access by harvesting machinery will be required. There must be access to a road to allow collection of biomass. Plantation slopes of greater than 15% will make harvesting by machine difficult.

***Establishment and growing***

SRC is established from unrooted cuttings, which are planted in spring. A density of about 15,000/ha is recommended. **The site must be well prepared** to give good soil/cutting contact after planting. The site must also be clear of weeds, since the cuttings do not compete well with weeds in the first season of growth. Weed clearance is usually achieved by herbicide application. Planting at the commercial scale is by a specially designed mechanical planter. Cheaper planting techniques, such as the lay flat-technique are currently under development. After planting the ground is rolled to press the soil around the cuttings.

Willow SRC is susceptible to a range of pests and diseases. Although these can be controlled by application of pesticides, routine application is not economic. Also, it is not practical in a tall and dense coppice plantation, and reduces the environmental benefits of the coppice crop. Instead, **integrated pest management (IPM) strategies are recommended** (Sage and Tucker 1998). Such strategies include avoiding planting near existing sources of pests and diseases where possible and monitoring the crops routinely so that appropriate response can be made when outbreaks of pests or diseases occur. Generally coppice plantations have a high economic threshold to pest damage. This is because the impact of damage is only important if the growth of the coppice is affected.

The most common diseases of willows are rusts, which affect leaves and stems and lead to premature leaf fall and damage to stem tips. This reduces the yield of biomass and in severe infestations can cause death of the stool (coppice plant). There is an ongoing willow breeding programme in the UK and Sweden, which has produced a range of willow varieties, some of which are more resistant to rust. **The most effective strategy to minimise damage from rust has been found to be planting of an intimate mixture of at least five willow varieties**. This reduces the spread of the disease and discourages the selection of aggressive strains of rust (McCracken and Dawson 2001, Armstrong 1999).

Beetles are the most common pest on willow coppice, and cause damage by eating the willow leaves. Fortunately large numbers of beetles have to be present before leaf loss will significantly affect coppice growth. Sage and Tucker (1999) advise that the threshold should be about 25% of leaves eaten. If this threshold is exceeded, IPM does not preclude use of pesticides and suggests that local application of insecticide should be considered (Sage 1999).

In the UK it is common to cut back willow to ground level at the end of the first year of growth. This encourages the plants to produce multiple stems, and was particularly beneficial for older varieties of coppice. However, cutting back is not normal practice in Sweden, and may be of limited benefit for the newer willow varieties.

***Fertilising***

Because it is harvested in winter, after leaf fall, and when the stems contain the minimum nutrients, **SRC requires limited amount of fertiliser**. However, annual fertiliser applications of nitrogen, phosphate and potash at low levels have been recommended in Sweden to replace nutrients removed with the stems at harvest. Fertilising with phosphorous (P) and potassium (K) is done prior to planting and after each harvest as long as the easily available phosphorous and potassium correspond to the medium class (P=4.1-8.0 mg/100g soil and K=8.1-16.0 mg/100g soil) or lower. The amounts of phosphorous and potassium supplied should be about 30 kg/ha and 80 kg/ha, respectively, for a production level of 10 odt/ha/year. This would effectively compensate for the nutrients removed during the harvest (Danfors *et al* 1998).

Another option is to **use sewage sludge as fertiliser** (→ 0, 7.1.5). This can be done prior to planting and the amount spread should be around 5 to 8 t dry matter/ha. Sewage sludge can also be spread after harvest. In a study by Moffat *et al* (2001) it was found that application of sewage sludge did not effectively increase the biomass yield. Instead, it was found that irrigation with final effluent wastewater had significant effects, probably due to the water component. The study by Riddell-Black *et al* (1996) showed increased yields for willow while for poplar the increase was not statistically significant, and yields were even reduced on some plots when compared to plots with no sludge application. However, it is stated that research carried out in other countries strongly suggest that **sewage sludge can be used to improve the productivity of SRC**. Moffat *et al* (2001) also found that modest application (100 $m^3$/ha/y) was environmentally acceptable. ($\rightarrow$ 0)

***Harvesting***

Harvesting of coppice takes place every 2 to 5 years, depending on the growth rate and demand for fuel. **In the UK a three-year cycle is typical**. The coppice is harvested between November and February, choosing a time when the ground is suitable for machinery access. **The two most common methods of harvesting are cut and chip harvesting and stick harvesting**. In the cut and chip system the coppice is harvested and chipped in one pass. This is the cheapest option as it minimises the handling of the wood. It also produces chips that are easy to transport and handle. If the chips are to be used quickly, this is the best option. However, the fresh chips have high moisture content and are difficult to store safely unless they are dried first. The second harvesting option is to harvest sticks. These can be stored easily on field, and will dry naturally. However, they are more difficult to transport, and will require a separate chipping operation before use. At the present time the question of whether to harvest as chips or sticks is not resolved.

**Figure 4.1 Cut and chip harvesting of SRC**

**Figure 4.2 Stick harvesting of SRC**

### *Storage*

Both large and small-scale conversion plants are likely to keep a maximum of 1 to 2 weeks store of fuel on site. **Long-term storage is therefore likely to take place at the energy production site**. Storing fuel under cover adds to the storage cost. Therefore, at least when harvested as sticks, **SRC is likely to be stored on field**. However, chips will probably need to be stored under cover, i.e. in a barn. Small-scale plants usually expect the fuel to be delivered as chips, to an agreed specification. In this case the SRC must be chipped prior to delivery, either directly from harvest or from the stored sticks. For large conversion plant it is likely that the plant will have a large-scale energy efficient chipper on site. This type of low speed chipper is likely to be run on electricity from the plant, which will reduce the fossil energy requirement and noise of the chipping, and ensure that the wood fuel chip quality is maintained.

Small-scale conversion plants are likely to have a local wood supply, and transport of wood chips may be by trailer directly from the field. However, for longer distances and for large-scale conversion plants transport will be by HGV from the producer store to the plant. HGV trailers are available for both wood chips and bales of sticks. Currently the density of chips and bundles of sticks are too low to enable the full load capacity of the HGV to be utilised. In addition, bales of sticks are less uniform than straw bales, and would be less stable in transit. Work is underway to compact chips for transport, and to improve baling techniques for sticks. About 12 HGV movements per day would be required to supply a 5 MW biomass power plant.

### 4.3 Miscanthus

Miscanthus is a rhizomatous perennial grass that originates mainly from Asia. In Northern Europe the annual pattern of growth is as follows. Multiple shoots are produced from the rhizomes in April/May. Growth during May, June and July is extremely rapid producing cane-like stems which may reach 3 to 4 m in height. The lower leaves begin to die off in August, but shoot growth continues until the first frosts of autumn. At the end of the growing season nutrients are translocated from the leaves and stems to the rhizomes. The dead standing stems dry out through the winter, and it is these stems and any remaining attached leaves that are harvested in February/March. New shoots are produced in April/May completing the annual cycle.

To date there is an estimated 420 ha miscanthus in Europe (Lewandowski 2001). The majority of this miscanthus is used for purposes other than energy production. Examples are animal bedding, thatching and fillers for plastic panels. However, in England there is now support for miscanthus production for energy purposes under the DEFRA Energy Crops Scheme (MAFF 2000), and there has already been interest in commercial production for UK developers.

***Establishment and growing***

The feasibility and basic agronomic requirements for growing miscanthus in the UK have been established at the small scale by long term studies at ADAS and IACR (Bullard and Kilpatrick 1997, Christian 1999). At the small scale, miscanthus can be established by hand planting of rhizomes or micro-propagated plants. **A well prepared and weed-free seedbed is required**, and weed control will be necessary in the first year until the plants are established. **After the first year, only an early season application of weed-killer should be needed**, as the dense canopy of the miscanthus stifles weed growth.

The successful commercial establishment is seen as the key to miscanthus as a fuel. Several methods have been trialled in the UK. As for hand planting, a well-prepared and weed-free seedbed is essential for good establishment of the planting material. All the commercial trials have used chopped rhizome pieces as the planting material, since these are currently cheaper than micro-propagated plants. This material is harvested from existing fields of rhizomes, chopped and transported to the planting site. The rhizome pieces are then planted mechanically. Methods tried to date include a modified potato planter, a farmyard muck spreader and a specialised rhizome planter that is under development in Europe (Bullard 2001). Preliminary results of miscanthus establishment trials suggest that precision planting methods such as the potato planter and specialised planter give higher establishment rates than the muck spreader. However, these methods are currently slow and so there is so far **no cost effective way of establishing miscanthus at the commercial scale**. The trials also show that the storage conditions for rhizomes are very important in maintaining rhizome viability prior to planting (Nixon 2001). Work on planting methods and rhizome viability is ongoing in the UK.

In the UK, small-scale studies have shown that the yield of miscanthus for winter harvest is about 1.5 odt/ha in the first year, 7.5 odt/ha in the second year and between 12 and 15 odt/ha thereafter. Results of EU studies (Lewandowski *et al* 2001) show yields in the range of 5 to 17 odt/ha for winter harvest of stems in Northern Europe, in line with the UK studies. This study also showed that yields from 17.7 to 25.5 odt/ha maximum were achieved in year 3 for autumn harvest in Northern Europe. Autumn harvest is higher yielding than winter harvest because more leaves remain attached to the plants. However, the moisture content of material harvested in autumn is higher, and additionally there is a higher concentration of nutrients in the stem. This will reduce the quality of the material for combustion, and may also reduce the vigour of re-growth of the plant the following spring. Some studies also report a higher yield of miscanthus because they include the leaf litter in the yield. Use of litter presents some challenges. The litter must be collected, and it is likely to be contaminated with soil. Also, the nutrient recycling from the litter is lost so that additional fertiliser input will be required.

***Fertilising***

There have been no problems with loss of plants overwinter in the UK, although these problems have been reported in Sweden, Denmark and Germany. In UK studies to date, there has been no clear decline in the annual yield of the miscanthus, and the current assumption is that the yield of 15 odt/ha can be maintained for 15 years. Over the period of the studies, application of nitrogen fertiliser has not improved the yield of miscanthus, and this is supported by European experience. However, based on conditions in Germany, the study by Lewandowski *et al* (1995) suggests that dose of 200 kg $K_2O$ and 50 kg $P_2O_5$ per hectare would match the nutrient uptake of miscanthus. To satisfy the nitrogen demand the amounts required would be 50, 70 and 100 kg/ha in the first and second year and from the third year onwards, respectively. Applications of fertiliser at these rates should therefore maintain soil nutrient levels. Furthermore, there have been few problems with pests or diseases, so at present miscanthus is seen as a low input crop. Commercial scale planting of miscanthus may result in greater pest and disease problems.

***Harvesting and storage***

Commercial harvesting of miscanthus is also currently being researched in the UK. Small-scale trials to date have used a mower conditioner, including a crimper to cut the miscanthus. After cutting, the crop is left on the field to dry down naturally and is then baled. There have been no problems using this system, but more cost-effective methods are being investigated, and ways of maximising the amount of material collected for baling are of a particular interest. It is assumed, however, that existing farm machinery can be used for harvesting, and that this may be adapted or adjusted for miscanthus. At present, storage is assumed to be in bales, either under cover or in the field. Work is underway to assess dry matter losses for these options and any environmental impacts such as mould growth or drainage.

Miscanthus bales can be transported in the same way as straw bales (→ 4.6). However, miscanthus is more dense than straw and this must be accounted for in vehicle loading and crane operation.

### 4.4 Switchgrass and Reed Canary Grass

Switchgrass and reed canary grass are both rhizomous perennial grasses. In contrast to miscanthus, both switchgrass and reed canary grass **can be established from seed**, which is cheaper than either SRC cuttings or miscanthus rhizomes, and is more familiar to farmers. However, the **work to date suggests that the yield potential of these grasses is lower than that of either SRC or miscanthus** (Christian 1999).

***Switchgrass*** is a native North American prairie grass and has been grown in North America for many years as a forage grass. Recently its **value in improving soil conservation and quality** has been recognised, and this together with its high yield potential and **compatibility with existing farming practices** has led to it being chosen as the model grass for trials for bioenergy production in the US. These trials have taken place over the last seven years (McLaughlin *et al* 2001), and have shown that under North American conditions an average of 16 t/ha switchgrass can be obtained, and that **significant gains in soil carbon have been measured** at the test sites. Work is underway to develop varieties of switchgrass which have characteristics such as high cellulose and low ash content most appropriate to biofuels, rather than the traditional requirements for a fodder crop of nutritional value.

Small-scale trials of switchgrass have been in progress in the UK since 1993 (Christian 1999) and an EU project on switchgrass has recently been completed (Elbersen *et al* 2001). The purpose of the EU and UK work was to determine if switchgrass is suitable as a biofuel in European conditions. The EU work evaluated 20 varieties in a range of European conditions over 3 years (Elbersen *et al* 2001a). This work showed that different varieties were best suited for different conditions in Europe, but that it was **possible to find a suitable switchgrass variety for each region of Europe**. The UK trials have covered a smaller number of varieties, but have been running since 1993. They have shown that the best performing varieties can reach 10 to 12 odt/ha yields and that 2 to 3 years is needed to reach this yield. The trials are still ongoing, but annual yields to date have remained close to the maximum values.

***Reed canary grass*** has a wide adaptive spread both in the UK and continental Europe. This native grass is **cold tolerant and can be grown in either wet or dry conditions**. It has traditionally been used as a forage crop and in rural industries. It has recently been investigated in Sweden and Finland for use as a biofuel and for paper pulp (Olsson 1996, Paavilainen 2001). In the UK, small-scale trials have been running since 1993. In these trials reed canary grass has been found to become productive much more quickly than the other grasses, with a first year yield of about 6.5 odt/ha and a maximum yield of 12.5 odt/ha in the second year. However, after this the yield dropped off slowly until it was back to about 6.5 odt/ha in the fifth year (Christian 1999). Cumulatively, therefore, **the yield potential is not as great as for the other grasses**, and we assume that it will require replanting every five years (Bullard 2001), which is of course an additional cost. However, the shorter rotation does allow greater flexibility in land use.

### *Fertilising*

Like miscanthus, switchgrass and reed canary grass have not shown a response to nitrogen fertiliser. To date switchgrass has not been subject to pests and diseases, but reed canary grass has been attacked by moth larvae. Both switchgrass and reed canary grass have lodged, i.e. fallen over, probably due to the less stiff stems in these species. Lodging and pest attack are currently being investigated, as they lead to reduced biomass yield and quality (Christian 1999, Bullard 2001).

### *Harvesting and storage*

Harvesting of the grasses should be straightforward; they **can be cut and baled in a conventional fashion**. In addition the crops can be easily removed at the end of the rotation, and indeed we believe the remaining organic matter will improve soil quality. Current assumptions are that these grasses **will be stored as bales on field or under cover**, and transported in the conventional manner. However, there have been no tests to date on the harvesting, baling or storage characteristics of the grasses. In 2001, a UK site/ yield trial on switchgrass and reed canary grass was started. Planting was done at field scale in Spring 2002. The plots in this study are larger than studies done before and include the most promising varieties identified from the EU trials. Studies on harvesting and storage are planned for later in these trials.

## 4.5 Annual Crops and Biodiesel/Bioethanol

Annual crops are attractive as a source of biofuels in the UK because they are already extensively grown, so their agronomy is well understood and seed is readily available. They are also able to fit in with existing farm rotations and are removed after one year. This allows farmers maximum flexibility in land use. However, these crops have been developed as food or forage crops, and typically receive high inputs of fertiliser and pesticides to produce a high quality and high value crop. Moreover the grain cereals have been bred to produce a high quality and proportion of grain. This is not necessary for a biofuel, where the whole crop is utilised, and indeed the high nitrogen content of the grain can be a disadvantage in combustion.

The use of annual crops as biofuels has been investigated in the UK in a small-scale study since 1993 (Bullard *et al* 1996). Rye, wheat, triticale and maize were grown for a screening trial. **The whole crop yields of the annual crops were found to equal that of the specialist biomass crops**. Thus, these crops merit consideration as biofuels if they can be grown cost effectively with reduced agrochemical inputs. Following the screening trial, trials of whole crop rye were continued until 1999. Rye was chosen because it is adapted to less fertile soils, is hardy and gives better yields in dry conditions. The yield of rye was found to vary from year to year from 6 to 13 odt/ha according to the influence of the weather conditions and incidence of weeds and diseases associated with cereal growing (Christian 1999, Christian and Riche 1999). However, the cumulative yield over the period 1994–1999 was similar to the perennial grasses. The rye is harvested in July or August and so has a low moisture content at harvest, 13 to 16%, and is suitable for direct baling. In the five years of the trial there was a response to nitrogen fertiliser in only two years. However, averaged over the five years the nitrogen fertiliser did increase the biomass yield by about 15%, suggesting that nitrogen inputs should be considered if economically and environmentally acceptable. Averaged over the period of the trial most biomass was produced by an annual application of 90 kgN/ha. Similar results were found in Danish trials of rye, wheat and triticale (Jørgensen *et al* 1996).

Unfortunately, an economic analysis of rye production showed that it was **unlikely to be economic** to produce as a biofuel with a value of £30 per odt (Christian and Riche 1999). However, this would change if rye were included in a support mechanism for biofuel production. A recent German study also concludes that annual crops for biomass are not currently economic (Stülpnagel *et al* 2001).

The study by Stülpnagel *et al* (2001) also investigates a 'double cropping system' whereby autumn sown cereals are harvested in June, before maturity, and a second crop like maize or sunflower is immediately sown without cultivation and then harvested in autumn. The system gives additional yield of biomass, up to 30% per hectare, but the crops have a higher moisture and nutrient content because they are harvested before maturity. To counteract these disadvantages, the crops are made into silage. This removes the problem of storing wet material and there is an opportunity to remove some of the nutrients in the crop by mechanical dehydration prior to using the fuel, thus reducing slagging and fouling. The disadvantage is that the production of silage and mechanical dehydration is currently not economic. So far this system has not been investigated in the UK. However, there is continuing interest in the UK in conventional production of annual crops for biomass production due to their familiarity, particularly in the light of recent difficulties in achieving the yield potentials of perennial grasses in the commercial situation.

Certain annual crops (e.g. oil seed rape or sugar beet) could be converted to biodiesel or bioethanol. However economics and the poor carbon balance mean that it is highly unlikely that these liquid fuels would be used for energy production.

## 4.6 Straw

Straw is a residue from the production of cereal and seed crops. The most common straws in the UK are cereal straws from wheat, barley and oats and straw from oil seed rape and linseed crops. The crops are harvested between July and October, and typically yield between 3 and 4 tonnes/ha of straw. The straw is typically quite dry at harvest, with a moisture content of 14 to 20%, and so is suitable for immediate baling. Baling is done with existing farm equipment, or by contractors.

***Availability***

About 12.5 million tonnes of straw are produced annually in the UK (DTI 1995). The main use of this straw is for agriculture in the form of animal bedding or feed, with significant quantities also used as frost protection for crops. About 4.5 million tonnes of straw are surplus to these needs. Excess straw is currently chopped on site and incorporated into the soil. The incorporated straw has value as a fertiliser and as a soil conditioner. However, it is also a potential source of biofuel. The surplus straw is mainly available in the east of England, hence the siting of the EPRL 36 $MW_e$ straw-fired plant at Ely in Cambridgeshire. At this time the Ely plant is the only large-scale straw-fired bioenergy plant in the UK. It uses 200,000 tonnes of straw per year. There are, in addition, a number of small-scale heating schemes on farms. We estimate that the small-scale schemes use a total of about 170,000 tonnes/y straw. There is therefore potential for significantly more energy production from straw in the UK.

***Requirements for energy use***

For use in a large-scale combustion plant the straw **must be presented in bales of a uniform size, shape and density** for the handling system. It **must also be within a specified moisture range** for efficient combustion. In both the UK and Denmark the bale specified is the 0.5 tonne Hesston bale, and the moisture content must be below 25% (Newman 2001, BTG 1998). At present straw is baled directly after harvest and, in the UK, it is stored on field with a specially designed 'roof' to reduce moisture ingress. It is then transported by HGV to the conversion plant, where it is stored for up to a week before use. Typical transport distance is 40 miles. Although there is potentially enough straw for continuous operation of the power plant within the catchment area, the system is vulnerable to poor straw harvests or to increased demand for straw from the agriculture sector.

For use in small-scale on farm boilers, the straw is usually presented in smaller bales. The straw is sourced locally, thus reducing transport distances. Also, the requirement is seasonal and so storage requirements are not so high.

Straw has a **higher chlorine content** than SRC or most fossil fuels, which gives rise to corrosion in both small and large scale combustion units. There has been recent work in Denmark to **pre-treat the straw by washing** prior to use in order to reduce the corrosion. Although this adds to the cost of fuel preparation, it increases the working life of the conversion plant (BTG 1998, Knudsen *et al* 1998).

## 4.7 Forest Residues and Arboricultural Residues

***Availability***

The wood fuel resource from forest sources and arboricultural residues for England, Scotland and Wales was estimated to be 1.1 million odt in 1998, rising to 1.7 million odt in 2013 (FCA 1997). Of the wood fuel resource, 309,000 odt/y is estimated to be available from residues, 142,000 odt/y from dedicated wood fuel plant (specialist wood fuel producers harvesting wood from premature clearfell and undersized stemwood), 203,000 odt/y from broadleaf woodland and 484,000 odt/y from arboricultural arisings. An 8 $MW_e$ biomass power plant, such as project ARBRE, requires about 43,000 odt wood fuel each year for operation (Matthews and Mortimer 2000). The **available wood fuel resource can therefore make a significant contribution to power production** in the UK. However, there is some debate about resource figures, as they may be an over-estimate of the actual available resource. To clarify this, a consortium of agencies

(including the DTI and Forestry Commission) have funded the Forestry Contracting Association to re-examine the resource potential, taking into account restraints such as amenity, protection of habitats and movement of forestry equipment.
Two examples of conventional forestry management in the UK illustrate where forest residues arise (Matthews and Mortimer 2000):

- Sitka spruce, no thinning operations, clear-cut after 45 years, followed by replanting;
- Scots pine, plantation thinned eight times, clear-cut after 67 years followed by replanting.

In the first system **residues arise when the plantation is clear-cut** at the end of the rotation. The branches and tops of the trees (brash) are removed from the logs in the forest, and the logs are removed and sold as the primary product. The brash typically comprises almost 33% of the biomass. The brash can be removed from the forest in a second pass operation and used as wood fuel.

In the second system trees are removed in **thinning operations** at five-year intervals beginning in year 27. For the first four thinnings the trees are too small to be sold as logs or for pulpwood, and are normally left in the forest. For the next four thinnings the trees are large enough to be sold. At clear-cut the brash is again left in the forest. The total amount of biomass available for wood fuel from pre-commercial thinnings and brash is about 40% of cumulative growth.

The two main considerations for the removal of the forest residues for wood fuel are the cost and the environmental effects of the operations (→ 7.2). In the way clearfell operations are carried out in the UK at the moment, the tops and branches are removed from the trees in the forest, and left in-situ. Recovering the brash therefore requires a separate collection operation, a so-called second pass operation. Usually the material is removed to the roadside and chipped there. Studies have shown that the cost of wood chips produced by this method is in the region of £28 per odt (Hudson and Hudson 1998). This is comparable with other sources of biofuels in the UK. The removal of brash can be beneficial in that it removes a substrate for some fungal diseases. However, the brash also provides a source of nutrients (→ 7.2.4) and organic matter for the soil. If the brash is removed these nutrients and organic matter may need to be replaced by another means, particularly on poor soil. In Denmark this problem is minimised by felling between January and March, and allowing the material to dry naturally and drop its leaves over the summer before removing it for wood fuel (BTG 1999). Brash left in the forest also produces a useful mat over which forestry machinery can travel without causing undue compaction (→ 7.2) and rutting of soil. Finally, brash may have a role to play in maintaining the biodiversity of the forest fauna.

There is an opportunity to reduce the cost of wood fuel harvesting, and also reduce the impact from machinery traffic. This is to use **whole-tree or integrated harvesting**. In this system, the whole tree is extracted to the roadside, and then separated into the various products, including wood fuel. This is therefore a one-pass system. Another benefit of this system is that brash is less contaminated from earth/stones. However, an investment in equipment is needed, and to be viable large blocks will be needed for harvesting. This system is used in Denmark but not the UK at present. However, if the market for wood fuel expands then this forestry system may be adopted.

**Early thinning** of plantations is often not carried out in the UK, because it is a costly operation and there is no market for the small diameter trees produced. Leaving thinning until later in the rotation can cause problems with windthrow in the remaining trees. If the early thinnings can be sold for wood fuel, it may be financially viable to carry out these operations, thus providing more wood fuel resource and also improving the quality of the remaining trees. The cost of wood chips from thinnings is estimated to be £34 to £40/odt (Hudson and Hudson 1998).

***Storage***

The wood fuel is **likely to be stored in the forest prior to transport** to the conversion plant. The wood **can either be stored whole or in chips**. The wood is likely to be stored in the open or under tarpaulins. Chipped wet wood stored under these conditions is likely to contain fungal spores, and large heaps are prone to overheating. Therefore wood for chips should be dry initially and should be stored on dry standing and covered if it is to be stored for more than two weeks. The best option is to store the wood whole in stacks, so that the moisture content is reduced from the initial value of about 55% to about 20%. The wood can then be chipped just prior to use, either before transport or at the conversion plant.

As for coppice, the wood will be transported by HGV, except for very local use. The wood can be transported chipped in a container, or on a flat bed as bales or sticks.

***Undermanaged and small-scale plantations***

In addition to the large conifer plantations, there is currently an estimated 350,000 ha of privately owned woodland of less than 10 ha in size in the UK (Forestry Commission 1999). Large proportions of these woodlands are broad-leafed in nature and are often under-managed. Although the timber value in these woods is often low due to the mix of species and lack of management, they have a high landscape, wildlife and amenity value. **Government policy is to encourage owners to bring neglected woodland back into management to provide income and rural employment.**

Wood fuel could be an important market for the low-grade timber and woody material available. A particular market that matches the dispersed nature of the resource is small-scale wood heating applications. The local resource is usually sufficient for these applications so that transport distances can be minimised. Harvesting in these woodlands relies on existing machinery and skills, but is not highly mechanised and does not generally have high outputs. Typically felling is by motor manual methods, and extraction by farm forwarder or winch. The wood is normally stored as sticks until the moisture content has reached an acceptable level, often 1 to 2 years after felling. Chipping then takes place prior to delivery using available machinery. One of the problems often experienced with these small-scale heating schemes is the unsatisfactory nature of the wood chip delivered, which is often due to inappropriate chipping machinery.

The costs of harvesting and extraction range from £18 to £35/odt. Including chipping and transport gives a delivered cost of £26 to £47/odt.

Trees and woodlands are managed intensively in urban areas due to the proximity to roads, buildings, structures and services (Armstrong 1999). There are limited options for the disposal of the **arboricultural residues** arising in these situations. Some use is made of the chipped material in parks, but much of the material is currently disposed to landfill. The high cost of disposing of the material to landfill gives an opportunity to utilise the material as wood fuel; in addition the material may be classed a biodegradable municipal solid waste and therefore disposal to landfill will be restricted under the Landfill Directive (EU 1999). However, the material is diverse in nature and only small amounts are available from any one location. There will also be no storage available at the point of production of the arisings. The logistics of the collection, storage and processing of the material will therefore be a crucial part of any scheme utilising arboricultural residues.

Three recent studies on use of arboricultural arisings have been reported:

- a Polish study described the use of urban arisings (Wisniewski *et al* 2001);
- an Italian study described the of fruit and olive tree prunings (Pari and Sissot 2001);
- a study for London quantified the availability of urban arisings as about 100,000 tpa (Econergy 2001).

These studies all indicate substantial quantities of arisings, provided that the storage and collection can be organised.

## 4.8 Poultry Litter

This is the bedding material from broiler houses. It usually comprises material such as wood shavings, shredded paper or straw, mixed with chicken droppings. As received, the material has a calorific value slightly lower than that for wood at 9-15 GJ/t. It has a highly variable moisture content of between 20% and 50% depending upon husbandry practices. Most technical issues associated with using this fuel have now been resolved by the key players in the industry, and two UK plant of 12.6 $MW_e$ and 13.6 $MW_e$ have been in operation for many years. A third plant has recently started operation at Thetford with a NFFO-3 contract to generate 38.5 $MW_e$ from a mixture of poultry litter and forestry residues. The technology used is conventional steam cycle plant with the litter and wood chips being blended and fed onto a grate. Transport and storage of the fuel is carefully controlled so that odour from the system does not escape into the surrounding environment. The fourth poultry litter plant is operation is the Westfield Power Station, near Glenrothes, in Fife. The plant has a bubbling fluidised bed boiler and generates around 10 MW of electricity.

Unlike other biomass fuels, poultry litter has not been excluded from the Waste Incineration Directive. This will have important repercussions for some of the UK poultry litter plant.

## 4.9 Wood Waste

This category includes waste wood from sawmilling, furniture manufacture, scrap from board manufacture and other woodworking operations. It can comprise sawdust, shavings and offcuts. Depending upon the origin, there is a risk of contamination due to resins, glues and coatings. Wood containing halogenated organic compounds or heavy metals as a result of treatments or coatings and wood from construction and demolition will come under the Waste Incineration Directive and as such is not covered in this report.

Wood waste from industry is often used on site to fire small boilers for space heating or process steam. The material is typically a good fuel being dry and often in small uniform particles. The presence of significant quantities of dust means careful handling is required (often dust remains within an enclosed system and is blown from the machinery producing it to the boiler).

# 5 CONVERSION TECHNOLOGIES

## 5.1 Introduction

***Combustion, gasification or pyrolysis***

The three technologies that are most likely to be used in the UK are based on combustion, gasification and pyrolysis. Each is characterised by the way that the fuel is oxidised to produce energy.

When biomass enters a high temperature environment it will first dry and then decompose, or pyrolyse, into volatile (tars and gases) and char components. This stage is common to all three processes.

A **combustion** (→ 5.2) appliance is always supplied with an excess of air so the char and volatiles will burn completely in the appliance. The full calorific value (CV) of the fuel is released into the reactor and the sensible heat of the flue gases. This heat can be used to raise steam for power generation with a steam turbine.

**Gasification** (→ 5.4) processes use a limited supply of oxidant, usually air, to maintain both combustion and reducing reactions in the same reactor. Some of the char and volatiles burn to supply the heat needed for pyrolysis and for further reactions that produce carbon monoxide (CO), hydrogen ($H_2$) and other fuel gases. The energy in the biomass is thus largely transferred into the heating value of the gas leaving the reactor, which is then burned in a gas turbine or engine to generate power or in a boiler to raise steam.

In a **pyrolysis** (→ 5.5) process there is no oxygen and the char and volatiles remain largely unchanged. The energy in the biomass is thus transferred to the heating value of the volatiles and char removed from the reactor. These can be burned separately in turbines, engines or boilers to generate power. In some cases, the volatiles can be condensed to give a liquid that can be used as a fuel. The proportion of gas, liquid and char will depend upon the heating rate applied and the temperature of the reactor. The heat for the pyrolysis reactor is usually supplied by burning some of the product gas in a separate heater.

As is apparent from the short descriptions above, the result for each of the processes is ultimately the same; the energy value in the biomass is released by oxidation through combustion to produce heat, which in turn can be used to produce electricity. **Gasification and pyrolysis are a means of gaining more control over this process by converting the inhomogeneous solid fuel into a consistent liquid or gaseous intermediate fuel.**

The key advantages an intermediate fuel brings for electricity generation are:

- **The ability to use combustion engine cycles or gas turbine combined cycles**. These give much higher conversion efficiencies than combustion/steam cycles at the scale of operation appropriate to biofuels;
- Where the feedstock contains wastes, **gasification will retain many pollutants in the ash** and allow acids and similar pollutants to be removed from the relatively small intermediate flow.

Set against the promised advantages of the advanced processes are the **long track record and commercial availability of direct combustion systems**.

## 5.2 Direct Combustion

Biomass residues have been used in power generation boilers since the latter half of the 19$^{th}$ century. The cane sugar, timber and pulp industries all contain thousands of examples. Typically, the emphasis has been on supplying energy for the process rather than energy sales, therefore there has not been a focus on efficiency and electrical efficiencies can be below 20%. From the 1980s onwards more modern plant has become available with better emissions performance, more fuel flexibility, and efficiencies up to 30%. These efficiencies vary: for straw-fired electricity power generation the efficiency will be ~25%; for wood fired generation it will be over 30% (32% has been achieved with fluidised beds); for pyrolysis figures of 28-30% are quoted for 15 $MW_e$. For gasification it is thought the matured technology will achieve up to 41% efficiency with combined cycle gas turbines. In addition use of the heat will increase the efficiency of conversion.

Most of the more efficient modern boilers have been deployed into the Nordic CHP market. This is because there is a niche market within the forestry and wood industries in these areas such that the fuel can be used to generate heat and power relatively close to its source of origin and thus more economically than in the UK.

The steam turbine and its associated equipment are very much the same for all boiler systems - the differences lie mainly in the design of the firing system. There are two main categories, grate and fluidised bed. The first has evolved from designs that have been used widely throughout this century whilst the second is a fairly recent innovation, although fairly well established.

In grate-firing the fuel burns in a layer on a grid. Air for combustion is blown both through the grid and over the top of the fuel layer. Various types of grids or grates have evolved to move the fuel through the boiler and eventually remove the ash. Some grates vibrate, some move slowly forward on chains whilst others have a reciprocating action. The processes of drying, pyrolysis and combustion of the volatiles and char take place sequentially as the material proceeds through the boiler on the grate. Whilst reliable, and relatively inexpensive, grate-firing systems are also somewhat inflexible and are usually designed to cope with a limited range of fuels.

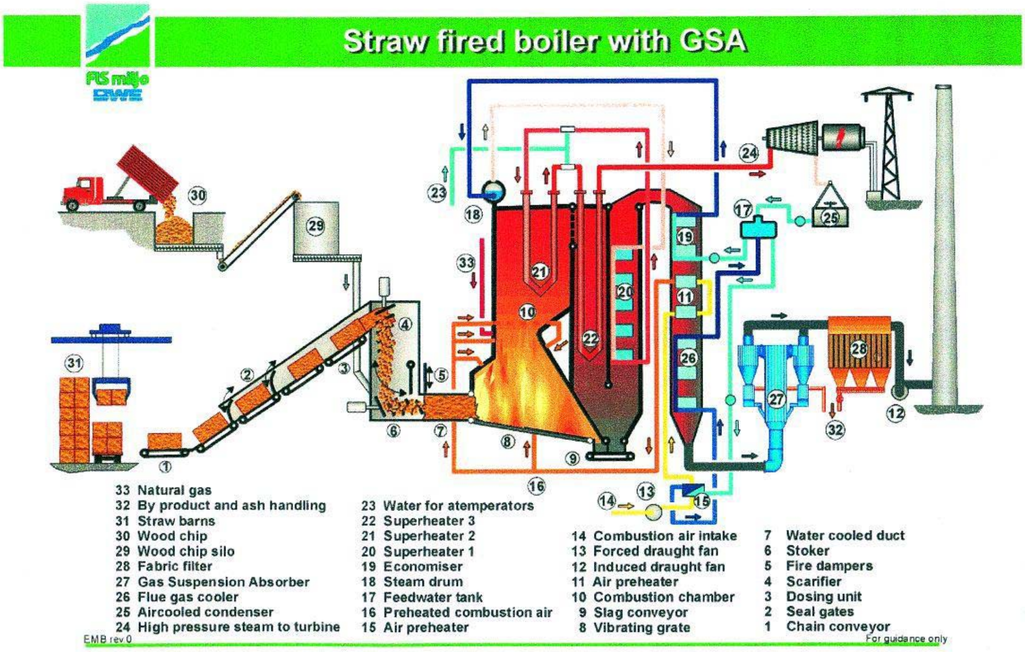


**Figure 5.1 Schematic of Ely straw-fired power plant (EPRL)**

In a fluidised bed boiler, the fuel burns in a bed of sand or other mineral that is violently agitated by the combustion air. The fuel is fed at a controlled rate to keep the temperature of the bed at 800 to 900˚C. Heat is removed and steam is raised by tubes in the bed of sand and in the exhaust flue. This type of boiler is proving very popular for medium to large industrial boilers for coal and other solid fuels and is taking an increasing share of this market.

A great advantage of the fluidised bed to the power plant operator is its fuel flexibility. This feature has been used to great advantage by CHP plants in the Nordic Countries, where it is common practice to fire wood chips, coal, peat, oil and wastes both together and separately. This flexibility allows them to maintain their returns on a long-term capital investment in response to short term fluctuations in fuel market prices and shifts in energy policy.

## 5.3 Co-firing with Fossil Fuels

The concept of co-firing biofuels with coal, as a means of increasing biomass take up without excessive capital cost, in an existing power plant has been receiving increased attention recently, particularly in the Nordic countries, the Netherlands and USA. There are around 150 plants for co-combustion of biomass with waste and fossil fuels in Denmark, Finland and Sweden (Alakangas and Veijonen 1998).

The way in which the biomass is fired depends on the proportion of the energy supplied:

- for minor quantities, 2 to 5% (by energy content), the biomass can be mixed with the coal at the mill inlet;
- for larger quantities 5 to 25% shredded biomass is typically fired through dedicated burners;
- quantities above 25% will have such a substantial impact on the furnace and ash behaviour that new concepts will be needed, such as gasifying the biomass fuel and firing the resulting gas (there is a successful example of this in Finland at the Lahti installation and a further demonstration is planned in the Netherlands) or combusting the biomass in a separate boiler and combining the steam raised with that from the main fossil fuel boiler (as done at Avedøre, Denmark).

Biomass fuels could also be potentially used for reburning[3]. The normal reburn fuel is natural gas but there is increasing interest in using biomass because of its environmental benefits. Zamansky *et al* (2000) report that, in tests and modelling studies, biomass is broadly comparable with natural gas at 15% fuel input but somewhat less effective at higher inputs. Harding and Adams (2000) report $NO_x$ reduction as high as 60-70% and found wood to be as effective as natural gas. Other work has indicated there may be problems with nitrogen species in the gas that contribute to rather than reduce levels of $NO_x$. In addition cost may be an issue and further work is needed in both these areas (Gale 1995).

In the UK the decision to implement co-firing will depend on the balance of the value of the Renewable Obligation Certificates (ROCs), the capital expenditure involved in the implementation and the view of the operator and regulator as to whether the reductions offered by reburn are adequate. The large size of utility boilers in the UK will also present issues with 20% of the fuel input requiring in the order of 500,000 odt biomass/y.

There could be a number of advantages in co-firing:

- **Reduced capital cost**. With many co-firing strategies much of the equipment will remain unchanged, e.g. boiler, turbo-generator, condensers, cooling towers, ash removal and disposal systems;
- **High conversion efficiency**. Many existing coal fired-plants are larger than could be specified for biomass fuels alone. They operate with efficiencies in the range of 30 to 40+% (depending on plant age and operational factors) and this is comparable to the conversion efficiencies anticipated from advanced conversion methods in the medium term, and considerably better than those achieved for dedicated steam cycle biomass plant;

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[3] Reburn is a way of reducing nitrogen oxides emissions by staging the combustion in a coal-fired utility boiler into primary combustion, reburn and secondary combustion zones. To achieve this up to 20% of the fuel input is fired above the primary combustion zone as reburn. Up to 65% reduction in nitrogen oxides can be achieved by this method. Combustion will follow the following pattern:

- main combustion zone: approximately 80% of the total heat input, fuel lean conditions, typical temperature ~1600°C, $NO_x$ is formed;
- reburning zone: reburning fuel injected, fuel rich zone, reducing conditions lead to conversion of some $NO_x$ to $N_2$, typical temperature ~1400°C;
- burnout zone: air added to complete the combustion, typical temperature ~1200°C.

- **Reduced emissions of nitrogen oxides**. Biomass fuels often have a low nitrogen content compared to coal giving at least the possibility of $NO_x$ reduction by simple displacement. There is also some evidence of a synergistic effect reducing levels still further (Tillman 2000, Wieck-Hansen *et al* 2000);
- **Reduced emissions of sulphur dioxide**. Biomass fuels usually have a lower sulphur content than coal. Substituting wood for coal will reduce stack sulphur dioxide emissions on a pro rata basis. There may also be an additional reduction in sulphur dioxide emissions caused by the reaction of the high levels (32-65%) of calcium oxide in some biomass fuel ashes (Tillman 2000).

There may also be some potential disadvantages of co-firing:

- **Ash from coal-fired power stations may loose its market**. Ash from coal-fired power stations is typically sold for use. However this ash needs to meet the customers' specifications and co-firing with biomass could change the nature of the ash. For example, levels of carbon in ash may increase resulting in changes in strength, deformation and permeability of cement products made from co-fired ash. Further work is needed to understand the impact of co-firing on ash re-use;
- **Emissions to atmosphere may not be optimised**. Compared to utilising biomass in modern dedicated power plant, such as the gasification combined cycle plant being commissioned in Yorkshire, emissions to atmosphere associated with the use of biomass may be higher, e.g. HCl and some trace heavy metals. This will depend on the method of co-firing and the nature of the fossil fuel fired plant being used.

European experience of co-firing with fossil fuels exists mainly in Denmark and The Netherlands. This experience is almost entirely with coal. In the United States the Electric Power Research Institute (EPRI) has co-funded several projects into the use of biomass and waste fuels. This has included investigations into use of these fuels in existing coal-fired power stations (Tillman 2000).

There has been some interest recently in integrating biomass into large natural gas fired combined cycles. Whilst it is technically feasible the financial and technical guarantee implications are substantial. Using natural gas in an advanced biomass plant to increase the output may have benefits in minimising the modifications needed to the gas turbine and improving the availability of the whole system. This last point will be particularly important under the new electricity trading arrangements.

Using natural gas to fire the superheaters of straw and waste fired plants has been tested with some success in Denmark and in Spain. This practice allows higher steam conditions and efficiencies without the corrosion problems that would normally occur with these fuels at high metal temperatures.

## 5.4 Gasification

Gasification is the conversion of a solid or liquid feedstock into a gas by partial oxidation under the application of heat. Partial oxidation is achieved through a restricted supply of oxidant, normally air. For organic based feedstocks the resultant gas is typically a mixture of carbon monoxide, carbon dioxide, hydrogen, methane, water, nitrogen and small amounts of higher hydrocarbons. The gas, often called producer gas, has a relatively low CV, typically 4 to 7 MJ/Nm$^3$ (compared to around 38 MJ/m$^3$ for natural gas).

Although air is usually used as the oxidant, oxygen enriched air, oxygen or steam can also be used. When not using air, the resulting gas will have a higher CV (typically 10 to 15 MJ/Nm$^3$) than that formed using air due to the absence of nitrogen.

The 'cold gas efficiency' for a gasification process is the proportion of the energy content of the waste being treated that is in the cooled fuel-gas. This is typically about 80%. To achieve 80% there must not be significant energy losses in any tars produced. Tars can contain up to about 30% of the energy in the incoming waste for updraught gasification, whereas tars from fluidised bed gasifiers will typically contain about 10%. Tar cracking can be used, as a fuel-gas conditioning process, to break down the tars' long-chain molecules to smaller molecules which can be combusted. This effectively allows recovery of the energy content of the tars.

***Practical gasification systems***

Figure 5. shows the main elements of a gasification process for biomass, identifying where there are material outputs. A gasification system for power generation can be considered as four linked processing operations:

**Fuel preparation and feeding.** These are the operations that are needed to modify the incoming feedstock into a form suitable for use in the gasification reactor and to meter it into the reaction zone. The equipment used is governed by the reactor and the nature of the biomass, but will typically include drying and size reduction followed by some form of air lock device. This equipment can produce solid residues consisting of materials unsuitable for input to the gasification reactor (oversized biomass, stones, metallic objects etc). There may also be emissions of volatile organic compounds to atmosphere as a result of biomass drying.

**The gasification reactor**. This is the operation in which the thermochemical reactions take place. They can be classified depending on the method of gas solid contact and the operating pressure. The reactor can produce residues consisting of items that are not gasified e.g. ash, char, stones, metallic objects.

**Product gas clean-up.** This is the process step or steps required to remove the contaminants from the raw gas in order to meet the specification set by the engine or other prime mover. Typically this will include tar and dust removal for woody biomass and would be extended to acid gas removal for wastes. The gas clean-up or gas conditioning equipment is likely to produce solid and possibly liquid residues.

**Product gas utilisation**. This step converts the clean gas to saleable product. For electricity generation an internal combustion engine, gas turbine or boiler is used. Exhaust gases will be emitted from this phase and there are likely to be residues from exhaust gas cleaning equipment.

Next, each of these steps and the options available within them will be described in more detail, starting with the reactor as its performance has a major influence on the preceding and following process steps.

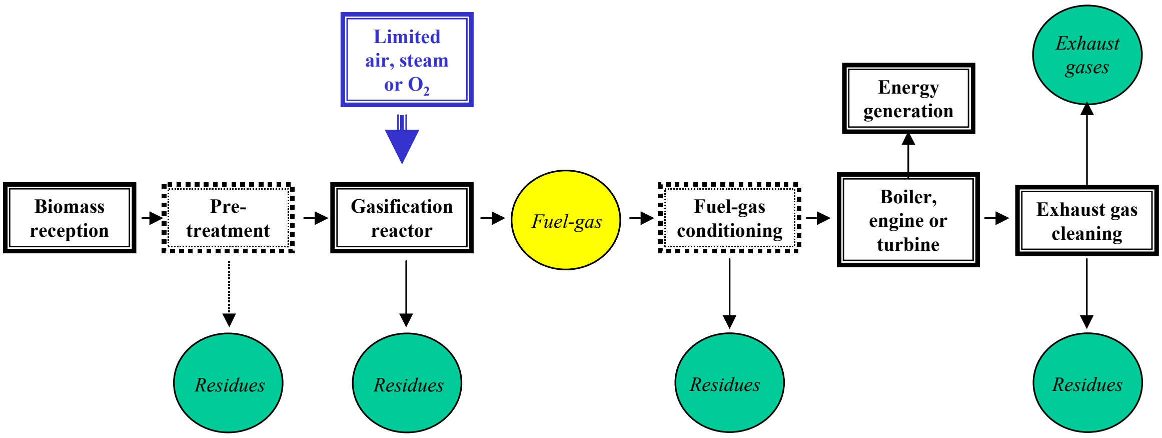


**Figure 5.2 Schematic of an installation for gasification of biomass**

### *The gasification reactor*

The technology of solid fuel gasification is very old and many types of reactor have been used or investigated covering all permutations of solid and gaseous reactant and the means of bringing them into contact.

The gasification process is conventionally viewed as a stepwise process of:

- drying - to release water vapour;
- pyrolysis - to give gas, vaporised tars, and a solid char residue, finally;
- gasification - or partial oxidation of the solid char, the pyrolysis tars, and the pyrolysis gases;
- combustion - local to the point where the oxidant enters the reactor the fuel will burn, this provides the heat for the endothermic gasification reactions.

The first two steps will be completed in all reactors but tar gasification may not. **Differences in geometry and flow direction in each reactor type will vary the tar content of the product gas**. A typical composition for most (air-blown) gasifiers is given in Table 5.1.

**Table 5.1 Biomass gasification product gas composition**

| | 1* | 2 | 3 | 4 | 5 | 6 | 7* | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **CO %-Vol** | 19.4 | 15 | 19 | 17-28 | 16.4 | 14.3 | 13 | 17 | 17-22 | 23 |
| **$CO_2$** | 12.7 | 6 | 13.5 | 8-12 | 16.3 | 12.1 | 16 | 12 | 11-14 | 9 |
| **$H_2$** | 14.9 | 8.5 | 12 | 11-17 | 3.3 | 2 | 8 | 14 | 7-13 | 15 |
| **$CH_4$** | 1.1 | 1.5 | 4 | 1.5-5 | 6 | 3.1 | 6 | 3 | 1.4-2.8 | 2.5 |
| **$C_2H_4$** | | | 1 | | 0.4 | 0.6 | | | | |
| **$N_2$** | 42.2 | 30.8 | 47 | 50 | 56 | 65.7 | | 46 | 54-57 | |
| **$H_2O$** | 9.7 | 38.7 | 3 | | dry | dry | dry | 10 | dry | dry |
| **$O_2$** | | | | | 1.4 | 2 | | | | |
| **Tar g/m$^3$n (cleaned)** | | 28 | | | | | ~17 (dry) | 30 | | |
| **LHV dry, MJ/m$^3$n** | 4.69 | 4.2 | 5.8 | 4-6 | | | | 4.5 (wet) | 4.5 | 5.4 |

*conditions (temp, pressure) not clear
[1]Pfab *et al* 2001, [2,3]Felsvang and Salo 2001, [4]Adams *et al* 2000, [5]Tchouate Heteu 2001, [6]Abeliotis *et al* 2001, [7]Wang *et al* 2001, [8]Ising *et al* 200, [9]Hammerer and Pogoreutz 2001, [10]Martin *et al* 2001.

For power generation the main options are:

- small systems < 1 $MW_e$ — fixed bed downdraft;
- medium size systems 1–15 $MW_e$ — fixed bed updraft;
- large size systems 15–50 $MW_e$ — atmospheric pressure fluidised bed or pressurised fluidised bed.

The characteristics of each are briefly summarised below.

*Fixed bed, throated downdraft*

These simple units are almost exclusively based on wartime designs developed in Germany, France and Sweden for automotive power. The biomass moves by gravity successively through four reaction zones - drying, de-volatilisation, combustion and gasification. The geometric shape of the reactor base ensures that the combustion and subsequent gasification reactions take place with sufficient intensity to completely destroy the pyrolysis products. It is this ability to destroy tars without resorting to extensive external equipment, which makes this unit so attractive for small-scale power generation with internal combustion engines.

From reported experiences with these gasifiers it can be concluded that for stable operation with an engine with acceptable levels of maintenance:

1. The maximum size for power generation via an engine is 200 $kW_e$. Above this size the gas flow through the bed becomes unreliable and tars will pass through into the engine. Tars can carbonise in the inlet manifold and on the valve stems of the engine leading to excessive maintenance.
2. The wood feed needs to be accurately and consistently sized to ensure even gas and material flows through the reactor and a consistent product gas quality.
3. Wood moisture content needs to be less than 15% to maintain combustion zone temperature.
4. Wood ash contents need to be low to avoid slagging problems.

Due to its simplicity and low cost this gasifier will probably be the unit of choice for developers and manufacturers of small-scale generator sets. The small size makes it unlikely that this type of unit will be regulated by the Agency but there is interest in aggregating units and developing larger units.

*Fixed bed updraft*

This is the classic fixed bed reactor as used for many years in the Town Gas industry. The updraft gasifier is able to accept a somewhat wider range of fuel sizes than the downdraft and can successfully use moisture contents up to 50% as received. It is still restricted to wood chip and similar materials, however, because of the need to allow uniform gas passage through the material in the reactor. Typically the maximum unit size would be 10 MW fuel input with a minimum of 2 MW determined by economics. The reactor is relatively compact and self-contained. This means that larger capacities can be built up fairly easily using multiples of the basic reactor. This was common practice in the coal's town gas industry (Wellman 2000).

In the biomass field, the most successful fixed bed updraft reactor in recent times has been the Bioneer unit from Finland. Ten gasifiers were installed between 1982 and 1986 in the district heating market operating on wood chips and peat where the gas is burned in a hot water boiler. The units are reportedly working well with one in Sweden operating automatically.

In common with the downdraft gasifier, the biomass moves through the four discrete reaction zones of drying, de-volatilisation, combustion and gasification but in this case the fluid flow is counter current to the biomass. This means that the gas exits the reactor at a lower temperature and containing a significantly higher content of tars and other volatiles. This high volatile content has so far precluded its use with internal combustion engines or turbines although there is some development of catalytic cracking techniques which will allow their removal. Wellman in the UK are in the forefront of these developments and hope to have a commercial demonstration plant in operation in the next two years.

The simplicity and robustness of the updraft gasifier will make it a natural candidate for medium scale plant at around 5 to 15 $MW_e$, if the problem of tar removal can be solved. Above this size the multiple units required will probably make it less economic than the fluidised bed.

*Atmospheric pressure fluidised beds*

In this case the biomass is injected into a bed of hot granular mineral such as sand or dolomite which is fluidised by an upward current of air. The temperature of the bed is maintained by burning part of the feedstock.

Most commercially operating biomass gasifiers over 10 $MW_{th}$ are of this type. The two most common variants correspond to the two fluid bed boiler types from which they are derived - the bubbling bed and the circulating bed. The bubbling bed operates with an air velocity sufficient to maintain fluidisation without excessive material being blown out of the reactor. The circulating bed however operates with a higher velocity, blowing large quantities of material into a dust collector from where it is recycled to the reactor.

A particularly successful application of circulating fluidised bed gasifiers is the use of bark and wood waste to produce low calorific value gas for lime-kiln firing. Seven are now operating in the paper industry with the largest rated at 35 $MW_{th}$.

In 1992 two 15 $MW_{th}$ circulating bed gasifiers were commissioned in Chianti in Italy to process pelletised RDF. Both are now operating successfully and supplying gas to a boiler for steam based power production. The gasifier technology is Swedish from TPS. TPS have operated a 0.5 $MW_e$ pilot plant incorporating a diesel engine for extended periods. The TPS view is that the technology is suitable for plant sizes up to approximately 65 $MW_{th}$. They feel that diesel engines are most suitable at the lower end of this range and gas turbine combined cycles at the top end.

**Project ARBRE** in the UK will be the first demonstration of a full power generation system using this technology. This project is supported by a capital grant from the EC THERMIE Programme and was also awarded an electricity contract under the NFFO 3 arrangements. The main highlights of this project are:

- 1500+ hectares of short rotation coppice will give 8 $MW_e$ power[4];
- advanced technology using atmospheric pressure circulating fluidised bed gasifier, dolomite tar cracker and gas turbine combined cycle;
- participants are First Renewables Ltd and TPS (S);
- £9.4m THERMIE award from the European Commission;
- commercial operation 2002.

The size of Project ARBRE at 8 $MW_e$ is not optimal for this technology but was chosen as a result of constraints on the funding and the difficulty of developing a larger fuel resource with no experience.

*High pressure fluidised bed*

Again the biomass is injected into a bed of hot granular mineral such as sand or dolomite which is fluidised by an upward current of air. The temperature of the bed is maintained by burning part of the feedstock. No commercial units of this type are in operation but they are the subject of a number of R,D&D programmes in Nordic countries and the USA. The objective of these is to develop a power generation process using a gas turbine, combined with a steam turbine to recover exhaust heat, which will give conversion efficiencies well in excess of 40%. The advantages of pressurisation are:

- a compact plant;
- product gas compression is not needed before use in the turbine, the product gas can be led directly to the turbine at a high temperature conserving heat;
- any tar will be consumed in the gas turbine combustion chamber;
- a high combined cycle efficiency.

[4] The intention is to use 1,500 ha of coppice = 15,000 dry tonnes per year from an overall requirement of 36,000 dry tonnes or 41%. The balance is forestry residues. The percentage may increase in future depending on relative prices.

These advantages are bought, however, at the cost of a feed system which is expensive to purchase and operate and a main plant which is complex.

The most advanced of the development programmes is the Bioflow project at Värnamo in Sweden. This is a private venture by the Swedish utility Sydkraft and the Finnish boiler manufacturer Foster Wheeler Oy to develop pressurised biomass gasification for power generation on a 6 $MW_e$ pilot plant. The plant comprises a circulating fluid bed gasifier, a hot gas filter and a modified Alstom Typhoon gas turbine. The plant successfully completed its demonstration phase in 2000. This included 8,500 hours of gasifier operation and 3,600 hours of gas turbine operation. The key findings were that:

- after initial teething problems the plant operated in a very steady and predictable manner;
- gas turbine performance was good and maintenance times for a commercial unit would be similar to conventional applications;
- a wide range of feedstocks could be gasified successfully;
- emissions performance was very good, although with some feedstocks $NO_x$ may be a problem;
- the developed technology should be cost competitive with direct combustion;
- the high pressure feed system remains a significant technical problem.

***Feedstock preparation and feeding***

The preparation of the feedstock and the feeding system depends upon the type of reactor chosen.

**Throated downdraft fixed bed units** are much more stringent in their requirements with a maximum moisture content of 15% and a size specification limited to 25 mm cube equivalent with no fines. As with the updraft unit straw, MSW flock or finely divided material would need pelleting or some other form of compaction to keep stable gas flows. The small size of these units usually makes the use of any method of feeding other than manual batch charging superfluous.

For **updraft fixed bed** units little preparation is needed for wood feedstocks other than chunking to a nominal 50 mm and moderate drying to 30%. Sawdust, shavings and other small wood are not too much of a problem in moderate quantities. In larger quantities straw, or finely divided material would need pelleting or some other form of compaction to keep stable gas flows. The feed system usually comprises a bell valve arrangement similar to that used on a blast furnace.

**Atmospheric pressure fluidised beds** require a feedstock dried to approximately 15 to 20% moisture with a maximum size of 20 to 30 mm cube. Fines are acceptable in moderate quantities. Straw, MSW fluff or finely divided material could probably be fed in their original form but compaction would greatly assist materials handling. The feed system is usually a simple lock as in the fixed bed updraft unit discharging to a screw conveyor which controls the feed rate.

**Pressurised fluidised bed** systems are much more problematical. Feedstock specifications are much the same as the atmospheric pressure process but the feed system is regarded as a major technical barrier by the developers of the technology. Two options are generally thought to be the most promising, the lock hopper system as developed from the atmospheric gasifiers and the screw extruder as used to feed pulp digesters in the paper industry.

It can be seen from the above that the **feedstock needs to be of a fairly uniform size and, if possible, composition**. For most gasification plants, the fuel will need pre-treatment to reduce size and mix the fuel to increase homogeneity. As part of this process, materials that are not suitable (e.g. metals, glass, stones, and bricks) and items that would damage or jam down-stream equipment may be removed.

Size reduction will most likely be by drum chippers, as used in forestry operations, or where more appropriate waste shredders. The high-speed variants can give rise to noise emissions (→ 7.5.1, 7.6.1) and all have the potential to produce dust (→ 7.5.1).

With the exception of the updraft gasifier, a dryer for the incoming feedstock will be needed. This will have its own potential for emissions in the form of steam plume (→ 7.6.1, 9.1.4), dust and volatile organic compounds (→ 9.1.2, 9.2.1, 9.2.3). There are a number of well-proven dryer technologies that could be used typically directly and indirectly heated rotating drums. In view of the high energy costs associated with this step developers may well look to use low-grade heat rejected from the power generation step. This will significantly reduce the potential for volatile organic emissions and should reduce plume.

***Gas conditioning***

This is the process step, or steps, required to remove contaminants from the raw gas from the gasifier to meet the specification set by the power generation device for reliable operation.

The contaminants present that are of concern are:

- **Condensable tars.** These build up and carbonise on the manifolds and valves of internal combustion engines. Their acidity can degrade lubricating oils giving excessive wear. Many of the negative experiences surrounding the use of engines with gasifiers can be traced to ineffective tar removal processes. Tars will also foul the fuel gas compressors of gas turbines.
- **Particulates.** These increase wear in engines. Erosion and deposits are caused in gas turbines.
- **Alkali metal salts.** These are particularly damaging in gas turbines where they can cause deposition and corrosion on blades.
- **Hydrochloric acid.** This is formed during the processing of MSW, plastics and straw. It causes corrosion in boiler tubes and other equipment. Dioxin formation is also possible from combination with trace organics.

**Tars** can be removed by three methods:

- catalytic cracking;
- thermal cracking;
- scrubbing with oil and/or water.

Although some process development is still required, cracking is generally to be preferred in modern plant as it avoids the contamination of wastewater generated by scrubbing processes. Cracking is the breaking down of the complex organic tar into smaller molecules which will not condense at low temperature. Tar cracking is the first step in the gas clean up process treating the hot gas directly from the gasifier. Dolomite catalytic cracking has been developed in Sweden by TPS at the 0.5 $MW_e$ scale and work is progressing in Finland with the use of a commercial nickel based catalyst. Wellman in the UK are developing a thermal cracking process coupled to their proposed fixed bed gasifier unit.

**Ash particulates** must be removed by either scrubbing after tar removal or by a filter media to achieve the standards required by engines or turbines. Atmospheric gasifiers present no problem as the gas can be cooled prior to filtering. Pressurised gasifiers, however, must filter the gas hot to gain maximum economic advantage so ceramic or refractory metal filters are needed. High temperature filters are to be tested in all of the high-pressure gasifier pilot programmes. Most advanced clean coal technologies are also dependent upon the development of hot gas filters so this will undoubtedly accelerate development in this area.

**Alkali salts** are removed by cooling to below 600°C, at which temperature they will condense on any ash particles present and be removed with them.

**Hydrochloric and other acids** can be removed by washing with an alkali solution or contacting with dry lime. This is relatively conventional technology derived from flue gas cleaning practice. TPS of Sweden use crushed limestone in their gasification process, which absorbs acids in the dust filter.

Gas conditioning is recognised as a crucial issue in the commercialisation of biomass gasification technology for power generation. Biomass gasification reactors are commercially proven in other applications, as are the power conversion devices. It is the gas cleaning step that is still relatively unproven.

### *Product gas utilisation*

The options available for power generation depend on the scale of operation envisaged. Internal combustion engines are appropriate to small and medium scale operation whilst, for larger plants, gas turbines are more suitable. Definite boundary lines are difficult to draw and are subject to considerable discussion at present.

Internal combustion engines are the most likely choice at scales below 5 $MW_e$ and a body of experience has been gained over the years with their use on producer gas. Diesel and gas engines are available in numerous size increments and large turbo-charged diesel units are in common use at sizes up 45 MW shaft power in marine drive and power generation applications.

The power conversion efficiency of a diesel or gas engine lies within the interval of 30 to 46% with the lower figure applicable to smaller high-speed engines and the upper to very large, slow speed marine or power generation engines.

Gas turbines are the alternative to internal combustion engines for larger plant. They have a lower conversion efficiency in an open cycle at smaller sizes than the internal combustion engine but require less maintenance and are available up to 150 $MW_e$. Some experience is available on the use of turbines with low calorific value blast furnace gas and at Värnamo.

It is important to note that gas turbines open the way to the use of biomass in combined cycles or 'Biomass Gasification Combined Cycles' BIG-CC. This technology uses gas turbines with steam generation from exhaust gas heat recovery. By using a combination of gas and steam turbines a higher overall thermal efficiency can be obtained. Typically the electrical efficiency will be 30 to 50% higher than a similarly sized combustion plant with correspondingly lower emissions of $CO_2$.

***Summary of gasification technology***

The gasifier systems available and their appropriate scale of operation is shown in the table below:

**Table 5.2 Summary of gasification technology**

| Scale $MW_e$ | Gasifier | Gas clean up | Power generator |
|---|---|---|---|
| **<1** | Throated downdraft | Filter | Engine only |
| **1–15** | Fixed bed updraft | Tar cracking and filter | Engine |
| **15–50** | Atmospheric fluidised bed | Tar cracking and filter | Engine or gas turbine combined cycles |
| **>30** | Pressurised fluidised bed | Hot gas filters | Gas turbine combined cycle only |

## 5.5 Pyrolysis

Pyrolysis is thermal degradation of a material in the complete absence of an oxidising agent (e.g. air or oxygen). This means that most pyrolysis plants involve some form of chamber (or reactor), sealed to prevent unwanted air ingress, which is heated from the outside. In practice, complete elimination of air is very difficult and some oxidation is likely to occur. A mixture of gas, liquid and solid products are produced but the proportion of each can be varied depending on the reaction conditions. The three critical parameters are temperature, residence time, and heating rate and it is permutations of these that give rise to the reactor types used.

*Pyrolysis technology*

Figure 5. shows the main elements of a pyrolysis processes that can be used for biomass. The figure shows where material outputs occur and hence where there is potential for impact on the environment. The key process steps are similar to gasification: pre-treatment, pyrolysis, gas conditioning and power generation, but with the potential addition of pyrolysis liquid storage and handling.

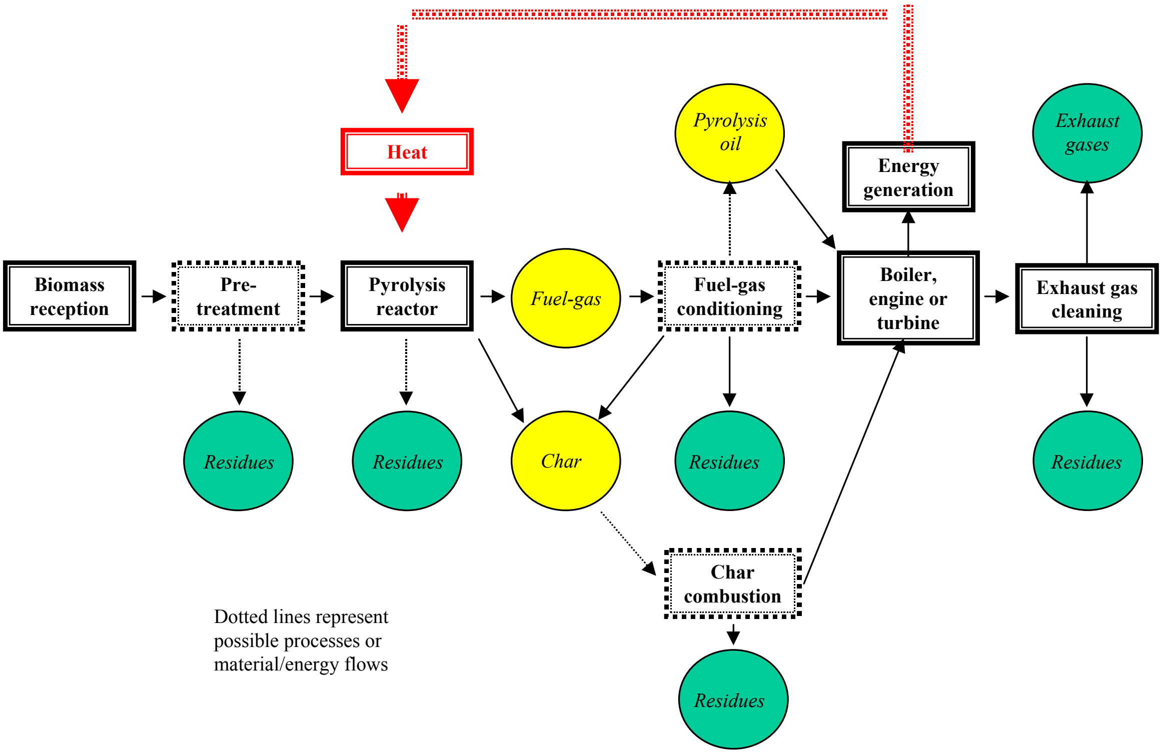


**Figure 5.3 Schematic of an installation for pyrolysis**

*The pyrolysis process*

Typically the process occurs at temperatures in the range of 400 to 1000ºC. When applied to biomass, the action of heat breaks complex molecules into simpler ones. In all cases, this results in the production of gas and char. Also, the gas produced will contain compounds that can be condensed out to give a liquid at ambient temperatures. The relative proportions of gas and char, and the proportion of compounds that will be liquid at ambient temperature, will depend on the temperature the material is subjected to, the time that it is exposed to that temperature and the nature of the material itself. There is insufficient data to calculate the energy content of each product as the published data does not make clear either the calorific value (CV) or composition. However, there is a considerable amount of char that will have a significant carbon, and hence energy content. So, the type of pyrolysis process used will dictate the nature of the products produced.

Flash pyrolysis, as the name suggests, is carried out with a short residence time (<1s) and high heating rate, usually in a fluidised bed at approximately 500ºC. If the resulting vapour is cooled rapidly to freeze the reactions the major product will be a liquid. Such flash pyrolysis liquids can be produced with yields of up to 75% by weight of the incoming biomass. For power generation the liquid product can be burned directly in boilers, engines or turbines. As a liquid fuel, pyrolysis oil can be stored and transported giving some flexibility in the time and place of use. This feature is given great weight by project developers who see the separation of the revenue producing power generation and potentially troublesome thermal process as financially attractive.

A profitable, although economically sensitive, additional market for this technology is the preparation of speciality chemicals such as sustainable alternatives for formaldehyde resins. This is due to the high content of complex organics in the produced liquid.

Pyrolysis can also be carried with a much longer residence time, typically minutes, and higher temperature, usually in a rotating kiln or screw. Here the major product would be a gas, which could be used in an engine, turbine or boiler after cleaning. This gas typically has a CV of 15 to 20 $MJ/Nm^3$ (the CV of natural gas is about 39 $MJ/Nm^3$). The gas cleaning process will most likely be analogous to those used in gasification processes. Most processes appear to have selected a liquid scrubbing system which could give rise to a contaminated waste stream. This type of process will also generate a substantial by-product of charcoal, which, if not sold off site, could be burned in a boiler or gasified to produce more fuel gas. In the UK, Waste Gas Technology, Compact Power and CPL are all developing processes using this principle. Mitsui in Japan and Thermoselect in Europe are operating processes on a commercial scale for municipal solid wastes.

Carbonisation is carried out over a period of hours or days at low temperature in order to maximise charcoal production, usually in a retort. It has no reported uses in power generation systems.

All pyrolysis reactors will produce a solid material that can be broken down into two basic components:

- ash from inert solid material present in the fuel being treated such as glass, stones etc;
- carbon char.

The carbon char may have a variety of industrial uses or can be used as a fuel within the overall waste treatment installation. Some processes treat this char as a solid residue that requires disposal. It may also be useful as a fuel for co-firing with coal.

Having produced either a liquid or a gaseous material that can be used as a fuel, a variety of combustion processes can be used to generate energy. Boilers, internal combustion engines or gas turbines can be used to recover energy through combustion. Whichever is used, exhaust gases will be produced which are likely to need cleaning before release into the atmosphere. The cleaning processes will produce residues that require treatment and disposal.

The heat to sustain the pyrolysis reactions can be supplied in several ways. Typically this is by passing some of the combustion gases around the pyrolysis reactor, by burning some of the fuel-gas produced in a chamber around the reactor or by heating some other material (e.g. sand) and feeding this hot material into or around the reactor. These arrangements are likely to have their own flue arrangements that will need regulation.

***Pre-treatment***

Any pyrolysis plant will need a fuel reception area. The function of this area is to allow the free moment of delivery vehicles and to provide a means of feeding the fuel into the process. The nature of this area will vary depending on the fuels being treated, the delivery method and the process requirements.

Even and rapid heat transfer into the fuel material is required to ensure that the material is fully pyrolysed in the time that it is in the reaction chamber. This means that the feedstock needs to be of a fairly uniform size and, if possible, composition. For most pyrolysis plants, the fuel will need pre-treatment to reduce size and mix the fuel to increase homogeneity. As part of this process, materials that are not suitable for pyrolysis (e.g. metals, glass, stones, and bricks) and items that would damage or jam down-stream equipment may be removed.

All pyrolysis processes require material that is essentially dry. For wood this means below 10% moisture. A substantial dryer will therefore be necessary and this will have its own potential for emissions in the form of steam plume, dust and volatile organic compounds. There are a number of well-proven dryer technologies that could be used, typically directly and indirectly heated rotating drums. In view of the high energy costs associated with this step developers may well look to use low-grade heat rejected from the power generation step. This will significantly reduce the potential for volatile organic emissions and should reduce plume.

Flash pyrolysis processes all use finely divided material typically 3 to 6 mm. This implies that they will need a substantial grinding facility, probably using two stages of mills. These may give rise to emissions of dust and noise.

***The storage and handling of pyrolysis liquids***

Producing a liquid intermediate fuel has a number of attractions for power plant developers:

- It divorces the production of the liquid, where the most process problems could be expected to occur, and power generation, where the revenue is earned.
- It allows a number of satellite generating sets to be supplied from a central processing facility. The processing facility benefits from economies of scale and the satellite engines or turbines can be sized exactly to meet demand or where there is a heat market for CHP.
- Liquids can be stored cheaply in tanks and can buffer the revenue earning power generation from shortfalls in biomass feedstock supply. Operating storage at the processing plant can thus be optimised.

Pyrolysis liquids are not the same as hydrocarbon products and there are a number of concerns that must be addressed. The liquids contain a variable and complex mix of organic compounds, some of which may be toxic. They also contain a significant amount of acetic and other acids that make them corrosive and irritant. The liquids also have a distinctive and very penetrating wood smoke odour.

If pyrolysis liquids are exposed to higher than ambient temperature, they will begin a process of polymerisation that will eventually lead to the separation of a resin like phase in the base of the tank. Special piping arrangements also need to be used that allow for flushing and cleaning.

Diebold (1999) has produced a comprehensive review of the toxicity of pyrolysis liquids formed at low temperature. The key findings were that the toxicity of the oils was a function of the composition, which in turn depends upon the feedstock and process. The main classes of chemicals in the liquids are; organic acids, aldehydes, ketones, esters, phenolics and furfans. If the temperature of formation is maintained below 550ºC then the total of aromatic compounds is only 0.06% wt. Based on the known amounts of specific compounds in the oils and permissible exposure levels established by the US Occupational Safety and Health Administration it can be concluded that aldehydes, furfans and phenols pose the greatest toxic threat. The projected acute oral toxicity of the liquids would be around 700 mg per kg of body weight. Both chronic and acute toxicity was studied in this work. The results on chronic toxicity were however unclear with conflicting indications on mutagenicity.

In carrying out the review Diebold referred to the work on samples of pyrolysis liquids but also to other, similar materials in the historic literature such as smoke aerosol and distilled wood products.

An outcome from this work was a recommendation that a Material Safety Data Sheet (MSDS) for this material should contain a warning label stating that fast pyrolysis oils are a hazardous substance to the eye and to inhalation exposure but not to dermal exposure. The liquids can be handled safely using personnel protective gear such as rubber gloves goggles and clothing. A sample MSDS, developed by the IEA Bioenergy Pyrolysis Activity Group is given by Czernik (1999).

Work by Piskorz and Radlein (1999) has shown that pyrolysis liquids are biodegradable in both soil and aquatic environments. The pattern of degradation is similar to that of #2 diesel fuel but substantially faster. The process is accelerated in aquatic environments by neutralisation with lime or other alkali agents. Biodegradation in the soil environment does not seem to need neutralisation or nutrients.

It is important to emphasise that the work above, and the conclusions drawn from it, apply only to so called ‘fast pyrolysis’ liquids, produced in processes operating at modest temperatures below 550ºC and high heating rates. Higher temperatures and slower heating will produce a larger proportion of aromatic compounds that will substantially change the toxicity properties.

It is also important to realise that there are very few commercial fast pyrolysis plants in operation and none for energy production. All of the conclusions and projections are therefore based on samples from pilot plant production. A considerable amount of work remains to be done to confirm and extend these findings as the industry expands.

# 6 HOW THE INDUSTRY MAY USE BIOMASS FUELS AND TECHNOLOGIES

Power generation from renewable resources has largely been in response to government initiatives and this is likely to continue in the future. In the immediate future, the projects most likely to be regulated are those with Non Fossil Fuel Obligation Tranche 4 (NFFO4) contracts. As a condition of the contract, these must use forestry residues and/or energy crops.

The key driver for the industry after 2002 will be the Renewables Obligation, the incentive scheme for the production of renewable electricity that will replace the Non Fossil Fuel Obligation. The Renewables Obligation (RO) will allow generators to sell a 'green' certificate to electricity supplier companies for each unit of renewable electricity they produce. The suppliers can use these to meet their legal obligation to supply a certain proportion of their sales from renewable sources (DTI 2000).

A wide range of biomass feedstocks will be allowable but certificates can only be claimed for electricity generated from the renewable portion i.e. where the energy content comes from plant or animal material. The Obligation also imposes some constraints as to the type of technology used:

- electricity from combustion processes is not eligible where the biomass is mixed with fossil derived waste, such as plastics (unless this content is less than 2%);
- the biomass fraction of mixed wastes will be eligible however if advanced combustion technology (pyrolysis or gasification) is used;
- electricity from combustion processes will be eligible if the biomass is first separated from, or has never been associated with, the fossil components of a mixed waste;
- co-firing of biomass in existing fossil-fuelled installations is eligible but after 2006 energy crops must make up 75% of the biomass component. There is a cap of 25% of the supplier's obligation that can be contributed through co-firing schemes. The co-firing option ceases in 2011.

It may be expected that the industry will look to maximise its competitiveness in the new Obligation by using the cheapest possible feedstocks and maintaining flexibility in negotiating with fuel suppliers. However, there may also be a tendency to build larger installations, to achieve economies of scale, which will need the larger quantities of the more expensive fuels to maintain operation. A further factor will be the need to secure long-term contracts for a proportion of the fuel so as to guarantee sufficient revenue to repay the loans used to finance the project. These factors may tend to favour flexible installations that can burn a range of eligible fuels, both separately and in combination. Installations are likely to burn portfolios of fuels rather than a single feedstock and the distinction between wastes and 'clean biomass' may become less clear. Effectively this will bring the UK into line with operating practice in the rest of Europe, particularly Nordic countries where wood waste, energy crops and forestry residues are routinely burned together. This is a substantial change from projects that are operating and planned under NFFO where the feedstock was prescribed by the contract.

Wastes and residues have limited availability and any large-scale deployment of biofuels will depend on energy crops. The RO recognises this by providing extra incentives in the short term, so a limited number of projects will be developed initially.

There has been much interest in the inclusion of co-firing in the RO. Essentially this option allows co-firing of any biomass in the RO up to 2006, with the caveat that no more than 25% of a supplier's Obligation can be met using co-firing. To be eligible after 2006 the scheme must use 75% energy crops. Thus decisions to use energy crops must be made soon to ensure that there is adequate supply in 2006. After 2011 co-firing will no longer be eligible. The tight time-scales mean that decisions on co-firing will need to be made in the near future and that these are likely to be among the first biomass schemes stimulated by the RO. Co-firing will be primarily driven by economics, but other issues such as local biomass supply, transport and handling issues will also be important. It is likely in the short term that the industry will be interested in a wide range of biomass sources, including sewage sludge and meat and bone meal and that Ofgem will need to be satisfied of the eligibility of these sources. Once a supply chain has been established the industry may also consider advanced thermal conversion such as gasification, which will remain eligible for the RO. Economics are likely to drive this option. Further information on co-firing is provided in Appendix 5, which includes examples of plant in the EU.

Table 6.1 sets out the fuels that are likely to be of interest in the UK (in price order), what technologies are likely to be applicable and the key issues associated with their use. This table illustrates that, whilst energy crops, such as SRC, may be required as the bulk of the fuel for a power station, locally available clean wood waste would be economically very attractive. Section 10 gives more detail on the economics of various biomass fuels. As Table 6.1 also illustrates, there are technical issues associated with some of the lower cost fuels that may reduce their overall attractiveness. These arguments over choice of fuel equally apply to co-firing in existing fossil fuel fired plants.

**Table 6.1 Summary of fuels and implications for conversion technologies**

| Feedstock | Source | Indicative Price £/t | Conversion technologies | Key issues | Renewables Obligation | Waste Incineration Directive |
|---|---|---|---|---|---|---|
| **SRC** | Dedicated plantations on farm land | 45* | High efficiency combustion<br>Advanced conversion/co-firing | Slagging and fouling | Yes | No |
| **Energy grasses** | Dedicated plantations on farm land | 40* | High efficiency combustion<br>Advanced conversion/co-firing | Slagging and fouling<br>Chlorine | Yes | No |
| **Forestry residues** | Commercial timber plantations<br>Farm woodlands | 35* | High efficiency combustion<br>Advanced conversion/co-firing | Slagging and fouling<br>Nutrient export from forest<br>Near to forest | Yes | No?** |
| **Sawmill wastes including bark** | Processing plant | 30 | High efficiency combustion<br>Advanced conversion/co-firing | Slagging and fouling for bark<br>Small quantities in restricted areas | Yes | No?** |
| **Straw** | On field stores built during harvest. | 30* | Combustion<br>Co-firing | Slagging and fouling<br>Chlorine corrosion and emissions<br>Need to be near to cereal growing | Yes | No |
| **Clean Wood Waste inc. parks and gardens** | Furniture/pallet production, waste transfer stations, civic amenity sites | 20 | Combustion<br>Co-firing | Contamination and cheating<br>Metals in ash, Tramp materials | Yes | No?** |
| **Other agricultural and food residues including poultry litter** | Producer plants | 10* | Combustion<br>Co-firing | Odour<br>Proteins from MBM in ash and stack | Yes | Yes? |
| **RDF** | Private and LA facilities | 0 | Combustion<br>Advanced conversion/co-firing | Chlorine<br>Slagging and fouling<br>Odour, Metals in ash | Renewable fraction | Yes |
| **Business waste** | Private waste sector collection | -20 | Combustion<br>Advanced conversion/co-firing | Chlorine<br>Slagging and fouling | Renewable fraction | Yes |
| **MSW** | LA Collection | -40 | Combustion<br>Advanced conversion | Chlorine<br>Slagging and fouling<br>Odour, Metals in ash | Pyrolysis & gasification | Yes |
| **Special industrial waste** | Producer plants | -100 | Combustion<br>Advanced conversion | Depends on source | Depends on composition | Yes |

*Price in odt.

**Exclusions refer to plants only treating this waste, thus it is not clear if co-firing meets the requirements of exclusion.

### *Fuel preparation*

All installations will need some form of fuel preparation to ensure that they operate with an acceptable availability. All will need some means of removing stones, other tramp material and oversized pieces that can damage equipment or cause chute blockage. Depending upon the system, further steps such as drying, chipping, and possibly further size reduction may be necessary.

**Table 6.2 Fuel processing and feed**

| Fuel | Form as delivered | Fuel preparation necessary | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Grate boiler** | **Fluid bed boiler** | **Fixed bed downdraft gasifier** | **Fixed bed updraft gasifier** | **Kiln gasifiers** | **Low pressure fluid bed gasifiers** | **High pressure fluid bed gasifiers** | **Fast pyrolysis** |
| **Straw, grasses etc** | Half tonne square bales | tease | tease, chop. May need mixing with larger material | not suitable | tease, chop only small proportion of total feed | tease, chop | tease, chop | only suitable as a pellet | tease, chop |
| **SRC Chips** | 15-50 mm chips in bulk lorry | screen | screen | screen, dry | screen | screen, dry | screen, dry | screen, dry | screen, chip, mill, dry |
| **SRC Billets** | 150-300 mm lengths of stem in bulk lorry | chip, screen | chip or chunk | chunk, DS | chunk, screen | chip, dry, screen | chip, dry, screen | chip, dry, screen | chip, screen, dry, mill |
| **SRC Stems** | bundles or bales on flatbed or bulk lorry | tease, chip, screen | tease, chip or chunk | tease, chunk, screen | tease, chunk, screen | tease, chip, screen, dry | tease, chip, screen, dry | tease, chip, screen, dry | tease chip, screen, dry, mill |
| **Small roundwood** | short branch wood in bulk lorry | chip, screen | chip or chunk | chunk, screen | chunk, screen | chip, dry, screen | chip, dry, screen | chip, screen, dry | chip, screen, dry, mill |
| **Forest residue, chipped** | 15–50 mm chips in bulk lorry | screen | screen | screen, dry | screen | screen, dry | screen, dry | screen, dry | screen, chip, mill, dry |
| **Forest residue, baled** | half tonne circular bale 800 mm dia x 3,000 mm long on flatbed. | tease, chip, screen | tease, chip or chunk | tease, chunk, screen | tease, chunk, screen | tease chip, screen, dry | tease chip, screen, dry | tease chip, screen, dry | tease chip, screen, dry, mill |

The key handling operations in the table are as follows:

- tease - combing devices to break open the bale and present it steadily to the next piece of equipment;
- chop - rotating knives to cut fibrous material;
- mill - energy intensive hammer mill to reduce to sawdust size;
- chip - rotating cutters that produce pieces 15-50 mm;
- screen - remove oversize and tramp);
- chunk - a low speed cutter, often a spiral blade that cuts large pieces;
- dryer - usually designed for chipped material and uses waste heat from power plant.

# 7 ENVIRONMENTAL IMPACTS

This chapter identifies the environmental impacts that are likely to be associated with energy production from biomass. It deals with the impacts of each activity in the process of producing energy from biomass under headings as shown in Table 2.2.

## 7.1 Establishment and Growing

Since the environmental impacts associated with the establishment and growing of forests (and hence forestry residues) and straw occur whether or not these materials are used as fuels, they are not considered in this report. Hence **this section of the report concentrates on the environmental impacts associated with the establishment and growing of energy crops**.

Information on establishment and cultivation of new woodlands can be found in publications from the Forestry Commission, e.g. Cultivation of Soils for Forestry (Bulletin 119), Creating New Native Woodlands (Bulletin 112) and Guidelines on Forest and Landscape designs. Where relevant to SRC, forestry documents are referred to in this section.

### 7.1.1 Effects on quality of life

***Visual impact***

Changes to landscape can be expected as energy crops are established and grow. The significance of the visual change depends on the visibility of the area and on the number of people viewing it. The visibility of the area depends on a number of factors including its elevation, gradient and position in the landscape. These factors can be determined by ground observations supported by map studies. The number of people viewing the area can be estimated using knowledge on general level of population, number of houses and jobs in the area as well as the status and number of roads. High priority should be given to the opinions of the local people because of their long and intimate association with the area. On the other hand, visual impact is important for the tourist trade which is a major income generator in the countryside. Thus, opinions of visitors are also valuable since they are not affected by the familiarity of the scenery (Forestry Commission 1992).

*Short rotation coppice*

Willow SRC will typically resemble a relatively densely packed area of young trees. At the early stages, SRC plantation looks quite similar to annual crops in terms of height, colour and row planting, while towards the end of the cycle (due to its height and loss of leaves in winter) it has characteristics closer to forestry plantations. Images of willow SRC are shown in Figures 7.1 and 7.2 (further description of SRC→ 4.2).

**Figure 7.1 Mature willow SRC**

**Figure 7.2 Mature willow SRC during winter**

At the earlier stages of the cycle, SRC does not obstruct the view across the countryside, whereas at later stages it **can affect views and also hide the existing landscape features** (Fawcett and Fawcett 2000). However, **if the site is carefully chosen, the difference in height compared with arable crops is unlikely to be of overall significance**.

**Reduction in the diversity of the landscape is one of the main concerns related to SRC**. This constitutes a risk especially with large-scale planting. It is also feared that the landscape will appear saturated. Hence, it is most **important to recognise the characteristics of the landscape and take them into account** in the design of plantations (Bell and McIntosh

2001). Square, monotone plantations can be considered unattractive and unnatural (Fawcett and Fawcett 2000, Sadler 1993). On the other hand, the **use of different species of SRC and variation of the age structure** within the plantation can help create diversity of appearance. Long, straight lines can be avoided by using natural topography and introducing open spaces within the plantation (ETSU 1997, Bell and McIntosh 2001). Some local shrub and woodland edge species could be included on the edge of the crop and other strategic locations. This could be beneficial especially for winter landscape (Fawcett and Fawcett 2000).

The easiest way to reduce visual impact of short rotation coppice plantation is to **choose the site carefully**. It is difficult to give general instructions on site selection, since the criteria depend strongly on regional characteristics (Fawcett and Fawcett 2000).

According to a study in which 13 study cases were investigated in Yorkshire and Nottinghamshire, **SRC relates well to existing features in a lowland landscape** (Fawcett and Fawcett 2000). On the other hand, it was found to be **often inappropriate in upland landscapes**. This is because some general upland characteristics, such as elevation, low level of tree cover, and openness and exposure, are likely to be altered by planting of SRC. SRC has been most successfully applied in areas with high levels of tree and woodland cover and arable and mixed farming regimes (Fawcett and Fawcett 2000).

In areas where permanent grassland is widespread, SRC could provide a welcomed variation in the landscape. Willows are also easily associated with lowlands as historically the growing of willows for basketry is strongly associated with riverside locations. Thus, from the landscape point of view, growing SRC in these locations might be more acceptable (Fawcett and Fawcett 2000).

SRC is not recommended to be grown in areas where drystone field walls are a distinctive feature on the landscape as these can easily be hidden from view by high crops. Neither is it recommended near residential properties, as SRC plantations can obstruct views and shade gardens.

**Guidelines are available on the visual impact of SRC**. The most important are Forestry Commission Guideline Note: Short Rotation Coppice in the Landscape (Bell and McIntosh 2001) and Good Practice Guidelines: Short Rotation Coppice for Energy Production (British BioGen 1999). It should be noted that the Energy Crops Scheme has a provision for up to 20% open ground, so that within any 100 ha site, for example, there could be up to 20 ha of open ground provisions for headlands, rides, glades to help maximise the environmental benefits.

*Miscanthus and other grasses*

Whereas for SRC there have been studies considering visual impact in the UK context, for energy grasses this is not the case. However, some comments can be made based on visual appearance.

As shown in Figure 7.3, miscanthus is quite a tall crop growing to about 4 m, which is similar to the height willow SRC is likely to reach before harvesting. Plantations will be densely populated and will loose their green foliage in winter. Hence, miscanthus will have similar visual impacts to SRC. However, as miscanthus is not a native plant there may be additional issues regarding appropriateness in particular landscape contexts (further description of miscanthus → 4.3).

**Figure 7.3 Miscanthus in Southern Germany**

Switchgrass and reed canary grass will have a visual appearance more typical of arable crops. Their height is likely to be about 1 m and the crop will be harvested annually so fitting in with traditional farmland cycles. Figures 7.4 and 7.5 show the general appearance of switchgrass and reed canary grass (further description → 4.4).

**Figure 7.4 Switchgrass (IACR)**

**Figure 7.5 Reed canary grass (IACR)**

***Noise***

The main source of noise during establishment and growing of any energy crop is the machinery used during **site preparation and planting**. However, the noise, both in terms of intensity and duration, is similar to that experienced with normal agricultural activities.

Also, the effects of SRC on residential properties can include noise associated with the movement of the coppice in windy weather (Fawcett and Fawcett 2000). Other energy crops, as well as traditional arable crops, will also have noise associated with movement in windy weather. This should only be an issue were crops are being introduced into areas unused to similar agricultural activities.

***Odour***

There will be **odour associated with any spreading of sewage sludge** during establishment and growing of energy crops. This odour is likely to be similar to that associated with spreading of animal manures.

***Amenity***

Existing rights of way can, and should, be maintained through energy crops. However, the tall nature of many of the crops **may impair views,** at least at some stages of the growing cycle. Both willow coppice and energy grasses grow densely making the plantations largely unsuitable suitable for walking. However, there are indications that willow coppice is good cover for game birds (→ 7.1.2), and may enhance the quality of country sports. If the plantations are found to attract other wildlife as well, they may be of interest for groups watching/ studying wildlife.

Any changes in water yields as a result of planting energy crops may in turn result in **localised changes in streams and rivers** and could affect the amenity value of these watercourses (ERL 1987a) (→7.1.5).

Archaeological sites should be protected and damage avoided. **Archaeological advice** can be obtained from relevant national heritage agencies, CADW, English Heritage and Historical Scotland. The Forestry Commission has also published Forests and Archaeology Guidelines that explain the major issues to be considered. Since buried archaeological evidence is usually relatively near surface, it is vulnerable to damage from e.g. vegetation (tree roots), human activity (ploughing etc) and animals (Forestry Commission 1995). **Scheduled Ancient Monuments are nationally important sites and are legally protected from damaging operations.**

The main issues are:

- W*ill ground preparation for energy crops will damage archaeological sites?* Ground preparation for SRC and energy grasses is similar to many conventional crops. It is therefore unlikely to do additional damage to sites in areas that are already cultivated. Where energy crops replace existing improved or unimproved grassland then there is a danger that unmapped sites may be damaged;
- *Will the roots of energy crops damage sites?* SRC and miscanthus can both be deep rooting, although depth of rooting depends on local conditions. Moreover, grubbing of SRC at the end of the rotation can cause severe soil disturbance, particularly if grubbing is by mechanical excavation;
- *Will changes to the water table damage sites?* Energy crops, and in particular SRC, are known to have high water requirements. There is a danger that energy crops may lower the level of the water table locally, and cause damage to sites where artefacts have been preserved in anaerobic conditions.

Current advice is therefore that energy crops should not be planted on known sites of archaeological interest (British BioGen 1999), and that local organisations should be consulted to avoid areas which may be of high archaeological value.

***Key issues***

↪ ***Establishment and growing: visual impact***
*Need careful choice of site*
*Need to consider visual impact of energy crops in the context of the existing landscape*
*Need to consider design of plantation*
*Use existing guidance*

↪ ***Establishment and growing: noise***
*No major issues*

↪ ***Establishment and growing: odour***
*Spreading of sewage sludge*

↪ ***Establishment and growing: amenity***
*May provide some amenity value*
*Need to maintain rights of way and protect archaeological sites*

### 7.1.2 Effects on wildlife

*Legal framework on protection*

**Species and habitats found in a potential plantation area have to be checked against the EU Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora. The UK Biodiversity Action Plan (UKBAP) should also be considered**. If protected species are present, the EU Directive in particular **can cause restrictions to the land use**. In addition, various other national and international designations (SAC, SPA, NNR, SSSI, ASSI) may protect the area. Management plans for these areas usually need approval from nature conservation agencies. Also, in certain situations the Forestry Commission can prevent forestry projects that might damage certain types of peatland habitats.

*Principles of protecting wildlife*

**The UK Forestry Standard** (Forestry Commission and Department of Agriculture for Northern Ireland, 1998) requires evidence from Forest Management Units that "opportunities for nature conservation are considered and accommodated". It also requires that "conservation of biodiversity is not compromised unreasonably by other management objectives or methods" and that "impacts of forest operations on neighbouring environments are fully taken into account". Furthermore, it expects stable areas where trees can be retained for the long term, to be identified. These principles could equally be applied to SRC plantations and to some extent to other energy crops.

The Forest Design Planning Guide (Bell 1998) recommends that the **area considered for planting should be assessed in terms of special habitats** or vegetation communities and the value of all semi-natural vegetation. The occurrence of important or rare species should be noted and the implications for their survival or enhancement identified. Furthermore, the assessment should consider the area in its wider context rather than concentrating on what is known about the site alone. As well as the existing state, the potential for increasing biodiversity value should be considered. An example of this is the creation or improvement of some semi-natural habitats.

Enhancing habitats by careful design and planning (variety of crops, open spaces within the plantation etc.) and maintaining links between habitats of target species over a landscape scale are common to all plantations considered here. More specific issues will be discussed under separate headings below.

*Short rotation coppice*

**In areas previously under intensive agriculture or spruce plantation the establishment of an SRC plantation is likely to increase the diversity of wildlife.** This is mainly achieved by creating a greater diversity of habitats (ETSU 1994, Boyd *et al* 2000). Plantations of perennial woody coppiced crops can create floral diversity and a habitat for insects and birds as they allow development of understorey and ground vegetation. The margins at the edges of the plantation (headlands), as well as the wide paths through plots for harvesting, also help to increase the diversity of habitats. On the other hand, **the use of herbicides in the initial**

**stages can lead to loss in floral diversity, though as the coppice becomes established, diversity should return** (ETSU 1994).

**If plantations replace existing woodland, natural grassland or other environmentally sensitive habitats, the overall effect can be negative** (ERL 1987, ETSU 1997). For example, scrub woodland can include ground vegetation associated with remnants of ancient woodland and disadvantaged land may include sites of nature conservation interest. If these were planted with coppice, there could be a net loss in ecological terms. On the other hand, replacement of improved grassland that has little botanical interest and does not support birds of particular conservation value, would have low overall ecological impact (ERL 1987).

*Plants*

Vegetation in energy forests is dominated by species that usually grow as weeds in arable fields, gardens etc. In some cases woodland, fen, peat and bog species are also found (ERL 1987a). According to a recent study (Rich *et al* 2001) the 'weed' cover contained in SRC plots is higher than in arable plots whilst in the headlands the cover is lower. Furthermore, the percentage cover of weeds within SRC plantation is not affected by the distance from the edge of plantation. This is different from arable crop plantations where the weed cover declines towards the centre of the area. It is also suggested that **SRC crops provide a better opportunity for perennial plant species to become established than conventional crops**. Usually (except for annual species) more stable vegetative cover with greater diversity is found on headlands than within the crop.

The plant species found in SRC communities vary according to the age of establishment (related e.g. to canopy cover). The trend with age is towards a more stable and diverse community with fewer annuals and invasive perennials and with more slower-growing perennials. The previous use of the area can also have an effect on plant species. Naturally, there are also differences in species found between different geographical locations in the UK (Sage 2001). **Although traditional coppice has high floral diversity, the close spacing and rapid growth associated with energy forestry cannot provide the same opportunities for ground vegetation.**

*Songbirds*

**Breeding songbirds in general are abundant in the SRC plots compared to other crop types**. However, the density and composition of species are affected by the age and structure of the crop (Sage 2001). According to Rich *et al* (2001) SRC is attractive to a number of species nesting on open ground, especially in the establishment year and at the time after first cut-back. Examples of these species that are also of a conservation concern, are lapwing and skylark. On the other hand, species like finches and thrushes have been found to prefer conventional arable plots. Hence the overall advantage of SRC will be related the conservation importance of species preferring it to the original land-use relative.

The average density of birds recorded varies quite significantly in different studies. For example Rich *et al* (2001) recorded approximately 1.5 birds per ha was recorded while Sage (2001) found an average of 8.6 and 3.6 songbirds per ha for poplar and willow, respectively. **The number of songbird species and individuals has been found to increase with**

**increasing structural density or complexity of the coppice vegetation as well as with the age of the plantation** (Sage 2001).

No difference in total number of species was recorded between young SRC and arable crops (Rich *et al* 2001) although it has also been suggested that conversion of existing farmland to SRC will lead to general increase in overall songbird densities. This happens mainly through colonisation of new species while many species associated with open farmland are likely to decline (Sage *et al* 1994). In young SRC plantations, the location (edge or middle of the crop) did not have any effect on songbird species recorded. This, however, may change for more mature crops (Rich *et al* 2001).

Detailed information is available on which species have been monitored on coppice plantations as well as on species associated with existing habitats in areas likely to become available for energy forestry (ERL 1987a, Rich *et al* 2001, Sage 2001). A seminar on the environmental aspects of energy crops (Beale 2001) concluded that the edge habitats (e.g. the headlands, hedgerows and field boundaries) are likely to be important in the management of biodiversity.

*Game*

SRC can provide attractive winter cover for pheasants as well as suitable sites for male territories in spring. Observed breeding densities along the edges of SRC have been close to those found along the edges of more traditional woodland. Sites bordering cropland usually contain significantly more male territories than those bordering grassland (Sage *et al* 1994).

To be attractive to pheasants, special consideration needs to be given to the size and shape of plots, management of the edges (to make them windproof) and the inclusion of mixed age classes. However, **as the type of site (large, uniform blocks) that is beneficial commercially is not likely to be very attractive to pheasants, compromises may be needed if an increase in the number of gamebirds is sought**.

Other game birds recorded on SRC sites include red-legged partridge and grey partridge. Other wildlife, e.g. snipe, roe deer, muntjac and rabbits could favour the shelter provided by an established crop (Boyd *et al* 2000, Armstrong 1999).

*Other wildlife*

**The number of invertebrates found in SRC is high** and the dominant groups are *Hemiptera* (true bugs) and *Coleoptera* (beetles) (Rich *et al* 2001). However, since a full range of niches (mature bark, holes, rotting wood etc.) will not exist, the amount of invertebrates is likely to be less than in traditional coppice (ERL 1987a).

The abundance of butterflies is most affected by the geographic location of the plot (Sage *et al* 1994). **The number of butterflies (abundance and variety) in headlands of SRC has been found to be higher than in arable plots** while the number in uncut areas were quite low (Sage *et al* 1994, Rich *et al* 2001). Most of the species found were relatively common.

Research indicates that short rotation coppice **can be a poor habitat for small mammals unless the crop is allowed to be 'weedy'**. Since the presence of the coppice itself provides inadequate cover for small mammals, it is the weed flora that provide both cover and food. Levels of weed flora can also be related to abundance of earthworms and ground dwelling insects. However, there it is also thought that presence of large number of insects provides a food source for small mammals like shrews, hedgehogs and voles (Boyd *et al* 2000).

**Since afforestation generally results in lower water yields, this might affect fish in areas where the plantation is a significant percentage of the catchment area**. Water eutrophication due nutrient leaching can also cause decline in fish populations (ERL 1987a) (→ 7.1.5).

Overall, after one growing season, **SRC plantations seem to contain a wider range of wildlife than the existing adjacent farmland** (Rich *et al* 2001). On the other hand, **planting on certain land types, e.g. unimproved grassland or wetland, may lead to a net loss in biodiversity**. Habitat fragmentation is likely lead to reduction in species diversity. Thus, in certain situations, it could be beneficial to locate SRC close to woodlands to extend or link isolated scrub or woodland areas and to create ecological corridors for movement of fauna (Boyd *et al* 2000, Sage 2001).

***Miscanthus and other grasses***

In the UK, **limited work has been undertaken looking at plant and animal species supported by these grasses**. The DTI Renewable Energy Programme is about to commission a 3-year study on biodiversity in miscanthus, switchgrass and reed canary grass. The idea is to use a similar methodology to that used for SRC, so that the energy crops can be compared on a fair basis.

It is **likely that biodiversity will be increased under energy grasses compared to arable crops**, assuming of course that the planting site is ex arable land. Although the crop is harvested annually, it stands for most of the year only being harvested in winter, shortly before the next year's growth begins. There is therefore more cover for most of the year. Also, the base of the plant and the leaf litter remain, which provides a stable habitat for ground insects and allow a wider range of shade flora to become established. Lastly, the soil is not disturbed by annual cultivation, and the application of fertilisers, pesticides and herbicides is minimal. This will affect the flora and fauna living in the crop.

***Genetic modification***

At present there are no plans to investigate genetic modification of energy crops. This is mainly because of the feeling that such work would not be acceptable in the current climate for 'environmentally friendly' crops. However, there are clearly similar opportunities for energy crops as for conventional crops to improve the characteristics of the crop by genetic modification should this technique become acceptable.

***Key issues*** ***Establishment and growing: effects on wildlife***

↪ *If appropriately designed and located, SRC can contribute to improved biodiversity.*

*Replacement of existing woodland, natural grassland and other environmentally sensitive habitats should be avoided.*

*Energy grasses are likely to improve biodiversity compared to conventional arable crops.*

### 7.1.3 Effects on air

Emissions to air are likely to be similar to those from other agricultural crops. There will be dust from ground preparation e.g. ploughing and exhaust emissions from agricultural machinery. Aerosols can be created by the spraying of agrochemicals, although the use of agrochemicals is anticipated to be lower than for conventional crops.

Emissions to air may also result from the spreading of sewage sludge. Assuming minimal fertiliser is used on energy crops, there should be a reduction in $N_2O$ emissions (Bullard 2001). However, it is possible that organic fertiliser will be used on energy crops. In particular, where the primary objective is disposal of organic fertiliser, such as for sewage sludge, then quite large quantities of sludge may be applied to the crop. $N_2O$ and methane emissions could then be significant. MAFF guidance (MAFF 1998) suggests that nitrogen applications should be matched to crop requirements to help minimise emissions of $N_2O$ (→7.1.7)

***Key issues*** ***Establishment and growing: effects on air***

↪ *Sewage sludge spreading*

### 7.1.4 Effects on soil

Establishing any new plantation on previously uncultivated land can enrich the nutrient status of the soil by enhancing aeration and the rate of oxidation of organic material. Ploughing (related to cultivation) can disrupt the natural profile of the soil. Sometimes drainage may also be required. This can lead to destruction of existing flushes and bogs thus prevent their use for encouragement of wetter woodlands (Rodwell and Patterson 1994).

***Short rotation coppice***

With good management, **soil nutrient capital and soil structure are likely to improve if disadvantaged or previously cultivated land is planted with coppice**. The **rates of nutrient export are expected to be less than for many common agricultural crops** but much higher than for conventional forest species (in similar regions). In the long term, repeated harvesting may result in a decline in productivity. Effects are likely to be most severe on poor soils. However, whilst many studies have shown that fertiliser applications do little to improve the yield of energy crops over the medium term, they can be applied at rates appropriate to maintain soil nutrient capacity (→ 4.2).

**One option for fertilising is the spreading of sewage sludge** (→ 4.2, 7.1.5). The heavy metal content of sewage sludge can lead to accumulation in the soil and can cause problems if the land will later be used for food production. All these should be taken into consideration when planning the spreading (Danfors *et al* 1998). **Sewage sludge applications should be in accordance with Statutory Instrument 1989 No 1263 Sludge (Use in Agriculture) Regulations (as amended)**.

In a UK study, Moffat *et al* (2001) investigated the effects of sewage sludge application and wastewater irrigation on biomass production of two poplar varieties. The study concentrated on the last two years of a three-year harvesting period. Irrigation had a significant effect on the biomass yield of both poplar varieties used, but in contrast sludge application did not produce significant biomass increases. Although some of the post-treatment concentrations in soil (e.g. nitrogen, nitrate-N, total phosphorus and cadmium) followed the trends of sludge application, others did not show any detectable trend. However, all the concentrations of metals were within the limits set by SI 1989 No 1263.

MAFF (now DEFRA) have commissioned a number of studies to assess the long-term effects of sewage sludge applications on agricultural productivity and soil fertility. Work being carried out by ADAS is due to be completed in summer 2002.

Willow and poplar varieties are widely used for phyto-remediation purposes on contaminated sites to extract heavy metals from the soil (Aronson and Perttu 2001, Greger and Landberg 1998, Pulford and Riddell-Black 1998, Glimerveen 1996). In the Moffat *et al* (2001) study described above, it was determined that cadmium was indeed accumulated by the poplar varieties used. In contrast, for other metals it can be implied from the results that poplar SRC treated with sludge would have led to their long-term accumulation in the soil due to the relatively low observed rates of plant uptake.

The ability of willow and poplar clones to accumulate relatively large amounts of heavy metals from soils means their planting for SRC purposes on contaminated or brown-field sites should be approached with a degree of caution. If heavy metals from sewage sludge were taken up in the SRC this would affect the emissions from energy production. Increased levels of heavy metals in the fuel would subsequently result in increased levels in ash and flue gases (→ 7.6.3 and 7.6.4). High concentrations of heavy metals in the ash would therefore have implications on any possible use of the ash as a soil fertiliser product (9.4).

**Use of heavy machinery during ground preparation and planting can cause compaction on some soils**. Deep compaction will persist and effects can be expected to accumulate over many years. In agricultural crops, damaging soil compaction leads to considerable yield reductions. Therefore, a certain reduction in the yield of SRC plantations could also be expected over the years (Danfors *et al* 1998). Hence attention should be paid to soil type and timing when planning machinery use. The use of heavy machinery on wet soils (especially peaty soils) is mostly likely to cause problems. However, the root mat formed by SRC may give soils greater resilience to compaction than experienced with arable crops. Use of machinery with wide-tyres or tracks will help spread loads and minimise damage to soils.

Erosion by water may be of some concern, related mainly to the establishment phase and to some extent to the maintaining of bare tracks between rows for harvesting (ERL 1987a). The rate of soil erosion depends on climate, topography, soil characteristics and the crop. **Erosion is thought to be highest over the first two years from planting after which it will reduce substantially**. Over the life-time of an energy crop plantation **soil erosion is usually much lower than for arable land but higher than for established woodland** (ETSU 1997).

At the end of its life, an SRC plantation will need grubbing up if the land is to be replanted. This operation could have impacts on soil structure if done mechanically. An alternative might be to chemically kill the root structure and this approach would have implications for soil and water contamination.

***Miscanthus and other grasses***

These perennial grasses will have some similar impacts on soil to SRC. The soil will not be cultivated for the period of the rotation, and the **leaf litter will remain on the ground for recycling of nutrients**. This could be beneficial in reducing the loss of organic matter from the soil, but it could also adversely effect the soil profile, as has been observed in some forest systems.

The nature of the rhizomes is to store nutrients for overwinter. Nutrients should be translocated from the rhizome to the stems in spring and then back to the rhizome in autumn. This helps to reduce the need for application of additional nutrients to the system.

If the rhizomes remain in the soil at the end of the rotation, they will add to the organic matter and thus carbon content of the soil. Currently, it appears likely that **old rhizome material is not suitable for propagation**, so that at the end of the rotation the crop is likely to be sprayed off and left to decompose in the ground. Thus both rhizomes and SRC roots can potentially increase the organic matter content of the soil. The advantage of the grasses is that the rhizomes are smaller and easier to disperse than the roots of a tree. Therefore **return of the land to other forms of agriculture after a grass rotation should be straightforward**. With coppice, the roots can be dug up. This can disrupt the soil to depth and remove much of the topsoil with the roots as well as removing the organic matter from the soil. Alternatively the stool can be killed and then there is a wait of perhaps several years until the stool has decomposed sufficiently for normal cultivation.

For erosion, SRC and grasses are again similar. The main danger is in the establishment year, when there are bare patches of ground between the small plants. In subsequent years the grasses form a near continuous mat of roots that will stabilise the soil.

All the above comments relate to perennial grasses. Annual energy crops such as rye or triticale are grown in a similar fashion to annual food crops at the moment. The only advantages over food crops will be that the quality of the crop is not important for fuel, as long as the yield is there. So the threshold for applying pesticides should be higher, thus reducing inputs. If annual crops were to be pursued for energy crops, further research would be required to optimise the yield of biomass and to reduce the grain content or stem nutrient content. This should both reduce the inputs required and improve the combustion quality of the biomass.

***Key Issues*** ***Establishment and growing: effects on soil***

↪ *Nutrient status and soil structure can be improved if replacing disadvantaged or arable land.*
*Sewage sludge application can lead to metals accumulation.*
*Possible soil compaction problems*

### 7.1.5 Effects on water

Crop production can have a number of impacts on watercourses:

- soil erosion and runoff off into streams and rivers can include increased water turbidity, stream scouring, silting and increased concentrations of nutrients and pesticides;
- soil removed by erosion can settle in stream beds and reservoirs, where it can lead to an increased need for dredging and clogging of drainage ditches;
- cultivation and the application of fertilisers can lead to increased nutrient leaching;
- changes to soil hydrology and crop water losses can affect water levels.

Also, watercourses can be contaminated by careless use or accidental spillage of pesticides and herbicides. This may not reach the outlet for decades and can be difficult or impossible to restore causing major disturbances in drinking water supplies (Forestry Commission 2000).

***Short rotation coppice***

As an SRC plantation should develop an extensive root mat and accumulate leaf litter, the movement of water, fertilisers and other chemicals are likely be slower than through arable agricultural land (ERL 1987a). Also **erosion rates will generally be reduced and lower levels of agrochemicals will be used, both of which can improve the quality of local watercourses** (ETSU 1997).

It has been shown that use of inorganic fertilisers is unlikely to increase the yield, thus fertiliser use and nitrate leaching associated with the growing of (perennial) energy crops is usually less than with arable crop production. However, fertilisers might be required in certain locations and this could lead to eutrophication of streams, rivers and lakes (ETSU 1994). **Generally, nitrate and pesticide levels in groundwater beneath SRC should be much lower than beneath fertilised grassland or arable land** due to high uptake as well as reduced inputs. This can be particularly beneficial for tackling nitrate pollution in Nitrate Sensitive Areas or Nitrate Vulnerable Zones. SRC can also be planted as a buffer for retaining diffuse pollutants draining adjacent agricultural land. (Armstrong 1999).

**It has been suggested that nitrate leaching from established SRC could be comparable to unfertilised grassland**. In wetter parts of Britain, the average concentration of nitrate draining from established SRC plantations with minimal or no use of fertilisers is likely to be very low (<3 mg/l $NO_3$-N). On the drier parts (south east) where the concentration is critically dependent on rainfall, even low rates of leaching could lead to nitrate concentrations close to the limit (11.3 mg/l $NO_3$-N) for drinking water. Ongoing research, commissioned by DEFRA, includes work into nitrate leaching from SRC following establishment, harvesting and crop removal (project NT2309 due to complete in 2003).

**At sites where sewage sludge is applied, studies indicate that there could be some increase in nitrate leaching to surface and groundwater**, although the effect from single applications seem to be short-lived and will strongly depend on the amount of sludge applied. Results from 1 year of monitoring of a poplar plot (Moffat *et al* 2001) showed that annual applications rates in excess of 200 $m^3$/ha could cause water pollution with the soil type under study (existing levels of soil fertility meant that additional nutrient applications could not be assimilated in increased biomass production). It was concluded that annual application rates of about 100 $m^3$/ha would be environmentally acceptable posing little threat of water pollution for poplar SRC. However, treatment of sewage sludge in this way can reduce burdens to watercourses from other sources (Hall *et al* 1996, Moffat *et al* 2001).

Any application of nutrients to SRC or rhizomatous grasses should ideally avoid the first year before the root system is established to minimise leaching. Also, the best time to apply nutrients will be at the start of the growing season.

Both willow and poplar have high water use levels. Thus, **if large-scale planting is envisaged within a catchment, consideration should be given to the impact on local water resources** (Armstrong 1999). The reduction in stream flows and peak flows will depend on rainfall and on the land use the plantation replaces (usually greater reduction for agricultural crops than pasture). Studies have shown reduction of as much as 50% in water yield. The interception loss (precipitation intercepted by the vegetation is evaporated directly from plant surfaces) is dependent on the climate as well as on the extent and structure of plant canopy. The transpiration loss (water from the soil is transferred to the atmosphere through live plants) is controlled primarily by plants (physiological) responses to environmental factors, such as solar radiation, atmospheric humidity deficit and temperature. Tree age, species and canopy structure also have an effect on the transpiration loss (Hall *et al* 1996).

**If coppice plantations are located in contributing catchment areas, groundwater recharge could be reduced** (ERL 1987a). Special consideration may be needed in areas with low groundwater table and/or where groundwater is a major source of water supply. Springs and ephemeral streams may dry up sooner and for longer during the summer (Hall *et al* 1996).

***Miscanthus and other grasses***

As with SRC, no nitrogen should be applied in the establishment year as the uptake is low and applications can lead to increased nitrate leaching. The presence of fertiliser also encourages the competition from weeds. Perennial energy crops recycle nutrients, and so are by nature low input crops. Best current guidance is that fertiliser applied to optimise growth should be at the level necessary to replace exported nutrients (can be estimated from quantity of biomass removed and estimate of concentration of NPK in biomass). This applies to ex arable soils. Where soils are initially poor initial inputs may be required to enable crop growth.

Regarding water use of energy crops, it is accepted that energy crops have a water use greater than most arable crops and grassland, and second only to forestry plantations. In 'Review of effects of energy crops on hydrology (Stephens *et al* 2001), results for simulated mean hydrologically effective rainfall (HER) under permanent grass, winter wheat, miscanthus and willow SRC are given. These show that HER is similar under grass and wheat, and would be reduced by 100-120 mm per year if replaced by miscanthus and by 140-180 mm per year if replaced by SRC. The difference between miscanthus and SRC relates to the shorter canopy duration and shallower rooting of miscanthus.

The effects of these changes will be more serious in the drier areas of the country where the reduction in HER may lead to no deep percolation beneath the energy crops in up to 8 out of 10 years. However, the amount of energy crops planted within a catchment to fuel a biomass power station is unlikely to cause any noticeable change in base flows at a catchment scale. At sub-catchment scales, a substantial plantation of several hundred hectares of energy crops could cause noticeable local effects. The effects at sub-catchment scale will depend on local soil and water table characteristics and therefore need careful consideration.

***Key issues*** ↪ ***Establishment and growing: effects on inland and coastal waters***

*Erosion rates and nutrient leaching should be lower than for arable crops.*
*Large-scale planting may effect stream flows and ground water charging rates.*
*Sewage sludge application may lead to increased nutrient leaching.*

### 7.1.6 Use of natural resources

The main areas of resource use during the establishment and growing phase are:

- fossil fuels in machinery – fuel use is quantified in 7.1.7, climate change;
- agrochemicals (herbicides, pesticides, fertilisers) – as already stated, use of agrochemicals should be lower than for arable crops.

Fertiliser use can be minimised by recycling nutrients in the ash produced by the biomass power plant. Applications of sewage sludge will also minimise use of conventional fertilisers. Pesticide use can be minimised through adoption of integrated pest management techniques (→ 4.2).

***Key issues*** ↪ ***Establishment and growing: use of natural resources***

*No major issues*

### 7.1.7 Climate change

Sources of $CO_2$ during the establishment and growing phase of energy crops include:

- fuel combustion in vehicles and other machinery;
- production of agrochemicals;
- production of other materials such as those used in fencing.

Planting and growing of energy crops can also affect the amount of carbon stored in the soil. This can be a positive or negative effect depending on the land use being replaced.

Some $N_2O$ can also be released from soil as a result of applying nitrogen-containing fertiliser. The amount will depend on the volume of fertiliser added, on the form in which nitrogen is applied ($NO_3$ or $NH_4$, mineral or organic) and on soil conditions, such as density, humidity and temperature. It has been suggested that 1 to 2% of the nitrogen in the fertiliser can be released as $N_2O$. Although the amounts released are not very high, it has to be kept in mind that the greenhouse potential of $N_2O$ is 150 times that of $CO_2$.

In their research, Jørgensen and Jørgensen (1996) found that the total annual emission of $N_2O$ from a soil (sandy loam) cropped with miscanthus was about 1.09 kg $N_2O$-N/ha. If converted to $CO_2$-equivalents this means that the total $CO_2$ displacement from replacing fossil fuel for energy production with miscanthus is reduced by approximately 6%. They concluded that, whilst these $N_2O$ emissions were significant in terms of the total net emission from biomass power production, biomass power production still has a significant net reduction in green house gas emissions when compared to fossil fuel use.

Deep peatlands form a major part of Britain's terrestrial carbon sink. Although in general, woodlands are carbon sinks, there is some evidence that afforestation can change deep peat from a carbon sink to a carbon source, thus contributing to global warming. Until future research is done, a **cautious approach to planting on deep peat sites is appropriate** (Patterson and Anderson 2000).

***Short rotation coppice***

Establishment and growing of SRC contributes just over 20% of the net greenhouse gas emissions from the use of this fuel in power production. For SRC the most important source of $CO_2$ during site preparation and planting is the fence construction (includes emissions associated with manufacture of steel fence etc.). Emissions from cultivation, spraying for weed control and planting and regeneration are significantly lower (DTI 2000a).

| |
|---|
| *Example* |
| *A 10MW$_e$ SRC power plant would typically result in total net $CO_2$ emissions of about 5300 t/y (equivalent to 115 kg/odt fuel) of which 1200 t/y (equivalent to 26 kg/odt fuel) would be from establishment and growing (derived from DTI 2000a).* |

In Britain, arable soils usually contain fairly low amounts of carbon, 5 to 60 t C/ha, depending on the soil type and management, while for forestland the value is estimated to be between 50 and 350 t C/ha. For soils in short rotation coppice cultivation the amount of carbon in soil is somewhere between those for arable soils and forestland, e.g. from 40 to 200 t C/ha. Thus, **as a result of planting arable land with coppice, the soil carbon storage is expected to increase while when forest or grassland is replaced a reduction could be observed** (Matthews 2001).

The full carbon balance for the use of SRC in power production is given in 9.2.4.

***Miscanthus***

The $CO_2$ emissions from establishment and growing of miscanthus have been estimated to be about 46 kg $CO_2$/odt (Lewandowski *et al* 1995). This is about 50% of their estimated total net emissions from the use of miscanthus as fuel. Fertiliser production accounted for about 50% of the establishment and growing emissions so use of ash or sewage sludge may reduce this.

Lewandowski *et al* (1995) also estimated that about 20 kg $CO_2$/odt equivalent of $N_2O$ would be released from soil (there is considerable uncertainty over the levels of $N_2O$ releases) as a result of miscanthus cultivation. Further, they noted that an increase in $CO_2$ emissions from soil has been observed after irrigation of miscanthus plantations but it is difficult to estimate the released amount. Irrigation may not be required under UK conditions.

***Key issues*** ↪ ***Establishment and growing: climate change***

*Use of biomass as a fuel has potential to significantly reduce greenhouse gas emissions associated with energy use*

### 7.1.8 Flood risk

A 'Review of energy crops on hydrology' (Stephens *et al* 2001) states that the general conclusion is that there is little relationship between land use and flood flows. Increased interception from forest (and similarly SRC or miscanthus), which has a marked effect on the runoff from small storms, has a relatively small effect during big storm events.

The high water use of energy crops can lead to reduced hydrologically effective rainfall (HER) compared to other land cover. In areas prone to flooding, this could mean that soil under energy crops starts the winter with substantially higher soil water storage capacity. This in turn means that more rainfall could be stored in the soil before deep percolation and runoff occur, thus reducing flooding. This would be a local rather than large scale effect, and would have no effect on floods arising from heavy rainfall elsewhere in the catchment.

***Key issues*** ↪ ***Establishment and growing: flood risk***

*Large areas of SRC may affect flood risk*

## 7.2 Harvesting and Collection

### 7.2.1 Effects on quality of life

***Visual impact***

*Short rotation coppice*

On SRC plantations the removal of the stand will be clearly noticeable. Large, clear-cut areas can be considered especially unattractive (Sadler 1993). The visual impact of harvesting can be reduced by growing coppice of different ages on one plantation, so that only parts of the plantation will be harvested at any one time.

Also bundles of stems may remain on the site for couple of months and machinery tracks will be apparent (ERL 1987a).

*Forest residues*

All the guidelines recommend that fellings should be planned carefully keeping in mind the resulting visual impact. With proper design, the fellings can be used to increase the variety of woodland scenery by creating batches of forest of different age (and height). Thinnings can be used to create a smooth change from forest to open land. The timing and manner of clear felling operations is unlikely to be influenced by the intention to remove the brash for fuel. However tree thinning may be carried out specifically to produce fuel wood, especially in deciduous forests.

**Figure 7.6 Piling timber and brash separately will ease the collection of forest residues**

**The removal of brash to produce wood fuel usually makes the forest visually more attractive** (Border Biofuels 1996, ETSU 1997). This is partly a result of the forest looking 'cleaner' but also because field layer can develop and the emerging plants and flowers help to create diversity (texture, colour etc).

*Miscanthus and other grasses*

Fields of recently harvested grasses will look similar to fields that contained conventional arable crops. In the case of miscanthus the contrast before and after harvesting may be considered greater as miscanthus grows to a greater height than conventional arable crops.

***Noise***

If the site was previously in rough grazing, the noise from harvesting of energy crops could be considered significant by people living near the plantation. However, **the duration of the disturbance is short and will be comparable to that associated with arable farming**. (ERL 1987). Change of land use from other uses to energy crops is not a planning issue. However, there is guidance about issues that should be considered (British Biogen 1999) and if support is requested under the DEFRA Energy Crops Scheme each planting request is subject to an assessment that will cover a range of issues including the effects of any land use change.

If an SRC plantation replaces agricultural land, the noise pollution will lessen since coppice is harvested less frequently than arable crops. As SRC harvesting takes place during the winter, people may be less affected by the noise than they would be in the summer as they tend to be outdoors less and have windows closed (Allen *et al* 1996). Noise from brash collection is similar to other forestry and agricultural operations. Since straw is often baled anyway, its use as a fuel does not cause additional noise in the harvesting phase.

If the farmer owns the machinery, harvesting can take place during a longer time period and the noise pollution may occur for short periods during a day. If contractors or jointly owned machinery is used, the noise effect will occur only during couple of days on any one site (Allen *et al* 1996). The noise effect may lessen in the future as machinery is further developed (ERL 1987, Allen *et al* 1996). Some noise level ranges for machinery (mainly harvesting and chipping) can be found in literature. Noise levels from different stages compared with background level and distances over which nuisance is experienced are presented in Appendix 1.

***Odour***

Any odours should be typical of normal arable farming or forestry harvesting operations. There should be no significant odour problems associated with the harvesting of energy crops.

***Amenity***

For undermanaged woodland, the removal of thinnings can improve the amenity value by opening up the woods more for leisure activities. Removal of brash for fuel after felling operations in commercial forests can also improve public access where this is allowed.

| | |
|---|---|
| ***Key issues*** | ***Harvesting and collection: visual impact*** |
| ↪ | *Can be significant contrast in landscape before and after harvesting* |
| | ***Harvesting and collection: noise*** |
| ↪ | *Noise levels similar to other farming or forestry operations* |
| | ***Harvesting and collection: odour*** |
| ↪ | *No major issues* |
| | ***Harvesting and collection: amenity*** |
| ↪ | *Woodland amenity may be improved by brash removal* |

### 7.2.2 Effects on wildlife

***Energy crops***

Harvesting of any energy crops will have an immediate impact on flora and fauna. The habitat will be drastically changed, albeit temporarily. This impact can be minimised if the whole area is not harvested a single year.

***Forest residues***

Wood fuel can be obtained from semi-natural and natural woodland through thinning and cleaning operations. **Thinning can encourage the development of ground flora that is often dependent on availability of light** (British BioGen 1999a). On the other hand, **the lack of shading can lead to increased weed growth** and hence additional weeding may be required (Border Biofuels 1996, Nisbet *et al* 1997). Rapid growth of unwanted species could also smother some of the existing vegetation for long times (Rodwell and Patterson 1994). The removal of forest residues can also affect the early survival and growth of the new tree crop partly because they will be competing for the nutrients with other emerging vegetation (Border Biofuels 1996).

The type of flora that will emerge after clearance of residues depends on soil type and location. Species encouraged by presence of brash include heathers and foxglove, while some other species will benefit from the removal of the brash (Border Biofuels 1996). At least partial removal of brash will encourage the plant diversity that would otherwise be smothered by the grassy field layer that usually develops after fellings (Rodwell and Patterson 1994). Besides being removed, some of the brash can be chipped and blown back to surround the stands. A thin layer of chipping may be beneficial as it controls rank grasses and allows more sensitive species to emerge (Ferris and Carter 2000).

**Although harvesting can cause dramatic changes in ground fauna, studies indicate that the population levels will return to previous ones within two or three years**. It is suggested that residue harvesting does not decrease habitats, but that whole-tree harvesting might have an effect if all standing trees are removed. Besides being potentially harmful to some fungi and invertebrates, the removal of residues will also affect the wildlife that feeds on them. However, as the amount of insects and fungi associated with for example Sitka spruce residue is small, the effects are not expected to be significant. Brash does provide suitable environment for certain beetles and spiders, for some birds (wren, robin) and for rabbits and muntjac deer so the removal of brash might have some effect on them. The amount of certain species, like bank vole, might decrease as a result of reduced shelter. On the other hand, there are also species that prefer open areas with bare ground in which to forage or nest (nightjar, woodlark) and whose nesting prospects are improved by clearing of the residues (Border Biofuels 1996, British BioGen 1999a). Sometimes brash accumulation can cause problems for example by encouraging rabbit population or bramble growth (Ferris and Carter 2000).

***Key issues*** ***Harvesting and collection: effects on wildlife***

↪ *Although harvesting can cause dramatic changes in ground fauna, studies indicate that the population levels will return to previous ones within two or three years.*

### 7.2.3 Effects on air

Emissions to air from harvesting will result from:

- combustion of fossil fuels in machinery;
- dust created by harvesting operations.

**Emissions from fossil fuel associated with harvesting of straw or forest residues are lower than for energy crops** because some of the emissions can be attributed to harvesting the primary product, i.e. timber or wheat (ETSU 1997).

Table 7.1 lists the main emissions from collecting and baling of straw (ETSU 1997). Figures are based on diesel fuel consumed by tractors used in baling operations combined with typical low speed emissions from use of diesel.

**Table 7.1 Emissions from collecting and baling of straw[5]**

| Emissions | g/tonne of straw | g/kWh |
|---|---|---|
| **$CO_2$** | 3790-9983 | 3.2-8.3 |
| **CO** | 17.2-45.4 | 0.0014-0.038 |
| **VOC** | 13.4-35.2 | 0.011-0.029 |
| **$NO_x$** | 60.2-158.6 | 0.050-0.132 |
| **$SO_2$** | 1.3-13.6 | 0.001-0.011 |
| **Particulates** | 3.98-10.5 | 0.003-0.009 |

Forest residues can be collected either as a part of an integrated harvesting system or as a second pass operation (→ 4.7). In both cases comminution (chipping) is required and is

[5] Assumptions: Diesel fuel sulphur content 0.05-0.2%. Straw will produce 1,200 kWh/t with combustion efficiency of 30%. The lower figures in the range are based on Hesston bales as these would be most likely used by power stations, the higher figures are for standard bales.

usually carried out the forest site. Emissions from forestry residue chipping are presented in Table 7.2 (ETSU 1997).

**Table 7.2 Emissions from chipping forestry residues**[6]

| Emissions | g/tonne residues | g/kWh |
|---|---|---|
| $CO_2$ | 22,596 | 20.6 |
| CO | 103 | 0.09 |
| VOC | 80 | 0.07 |
| $NO_x$ | 359 | 0.33 |
| $SO_2$ | 7.7-30.8 | 0.007-0.028 |
| Particulates | 23.7 | 0.022 |

Removing forest residues may offset burning and hence the emissions associated with this uncontrolled combustion.

***Key issues*** ***Harvesting and collection: effects on air***

↪ *No major issues*

### 7.2.4 Effects on soil

***Energy crops***

**Use of heavy machinery in coppice harvesting can cause compaction especially on wet clay or silty soils. This can increase surface flow and (wind) erosion**. The increased flow can also transfer nutrients, pesticides and other potential pollutants to surface waters (MAFF 1993). Removal of organic matter can also increase vulnerability to structural damage (ERL 1987a). Compacted soil can restrict root growth, and it also reduces the amount of water that can filtrate into the soil. The decreased amount of air getting into the soil effects the biological activity thus reducing the fertility of the soil and the availability of plant nutrients (MAFF 1993).

***Forest residues***

As the residues act as a mat on top of which the machinery can operate, the removal of forest residues **can cause soil compaction that can cause increased surface runoff, soil erosion, and reduced root growth**. Compaction damage is most likely to occur on wet soils (Nisbet *et al* 1997, British BioGen 1999a). With second pass harvesting (→ 4.7), increased ground damage on thinner brash mats is more likely to be a problem with the forwarder than with the harvester. With whole-tree harvesting (→ 4.7) on peaty gley and surface water gley soils[7], maximum support and thus minimum damage occur when felling is done across the rows as

[6] Assumptions: Diesel fuel sulphur content 0.05-0.2%. Processing speed 5 odt/h of wood chips with a fuel use of 0.25/l/hp, power take-off of 85%. Energy output of 1,100 kWh/t wood, plant efficiency 30%.

[7] A gley soil is one that is permanently or periodically water logged and therefore anaerobic, characterised by its blue-grey colours, often mottled with orange-red (ferric iron).

stumps and root systems then provide support for the machinery. At roadside, the area is crossed many times and some key routes might start breaking up and thatching may be required (Border Biofuels 1996).

When forest residues are cleared from forests, the sites are less likely to develop disease problems. On the other hand, this also means **removing a potential source of nutrients, which could lead to additional use of nitrogen fertilisers** (Border Biofuels 1996, ETSU 1997). Although brash (tops and branches with needles) includes only around 20 to 25% of the biomass in a (lumberable Swedish) forest, it contains more than 70% of the nutrients (N, P, K, Ca and Mg). The removal of brash means that soil will lose the corresponding amount of nutrients (Hovsenius 1999). The losses of nitrogen and phosphate with whole-tree harvesting or with removal of residues in second-pass harvesting are estimated to be an average of two or three times greater than with conventional harvesting. Values for potassium, magnesium and sodium are slightly lower (Nisbet *et al* 1997). The nutrient most affected (reduced) by whole-tree harvesting (as opposite to traditional harvesting) is expected to be calcium.

Especially in areas with acid (increased nutrient leaching) and weatherproof soils (low replenishment through mineral weathering) nutrient loss can be very important for the long-term mineral balance of the soil (Hovsenius 1999). It has been suggested that it could be beneficial to leave the residues uncollected where soil is poorer and collect them only from more fertile forests where the effects are likely to be fairly insignificant (Border Biofuels 1996). Furthermore, it has been suggested that, in most cases, inputs from the atmosphere can provide compensation for at least some of the loss. **Some of the nutrient loss can be mitigated by returning the ash from the combustion** process to the forest. This however needs to be considered carefully as it involves an additional transport phase and also because the nitrogen and organic matter content in the ash are low (ETSU 1997).

**Clearance of the residues can increase surface runoff**, which can lead to soil erosion. As removing residues causes a loss of organic material, the buffering effect it has on the soil can also be reduced. This decreases the acid neutralising potential of the site, potentially leading to **acidification** of soil and stream water, although the role of factors reducing acidity are not well understood (Nisbet *et al* 1997, Border Biofuels 1996). It should be noted, that the removal of residues is never complete (even with whole tree harvesting) and usually the residues left behind can offset most of the potential burdens (ETSU 1997). It has also been suggested that in areas affected by acidification the removal of some of the residues can in fact be beneficial (Bauen 2001).

If second pass harvesting is applied the brash mat can help to reduce the soil damage caused by extraction of the stems in the first phase (Forestry Commission 1990). **The second pass harvesting is also beneficial from the nutritional point of view (compared with whole tree harvesting)** as, depending on for how long the residues are left to dry before collection, a significant amount of needles (with high nutrient concentration) will fall prior to removal resulting in significant amount of nutrients being left on site (Border Biofuels 1996). The UK Forestry Standard expects evidence that harvesting methods are chosen to minimise soil damage (Forestry Commission and Department of Agriculture for Northern Ireland, 1998).

***Key issues*** ***Harvesting and collection: effects on soils***

↪ *Use of heavy machinery can cause compaction with certain soils under certain conditions.*

*Fertiliser applications may be required to maintain soil fertility.*

### 7.2.5 Effects on water

***Energy crops***

For SRC and rhizomatous grasses, established root system will likely take up the nutrients released following harvesting and thus leaching losses will be low (ERL 1987).

***Forest residues***

The removal of the vegetation canopy by harvesting will reduce evaporation and transpiration. As a result, more water will leave the soil as drainage. The pathway of the water to the catchment outlet will have an effect on its quality as well as the volume and timing of the water reaching the aquatic zone.

In some soils, **removal of residues can initialise higher and quicker water flows that can in turn lead to increased erosion and sedimentation**. Increased sedimentation can also cause serious disruption for water treatment plants and water supplies (Nisbet *et al* 1997, Forestry Commission 2000). The amount of **nutrients leaching to drainage waters is reduced with the removal of residues**, especially with whole-tree harvesting.

It has also been suggested that removal of the shade provided by the residues can lead to soil water deficit (Border Biofuels 1996).

More information on the effects of forests in general can be found in the. Forests and Water Guidelines published by Forestry Commission. These are not dealt with here since they are not directly related to use of forest residues for fuel. The UK Forestry Standard (Forestry Commission and Department of Agriculture for Northern Ireland, 1998) requires that all operations are planned and are carried out to minimise disturbance to watercourses and to avoid pollution and siltation.

***Key issues*** ***Harvesting and collection: effects on inland and coastal waters***

↪ *For energy crops nutrient leaching is expected to be low.*

*Removal of forest residues can reduce nutrient leaching but may increase run-off and associated sedimentation.*

### 7.2.6 Climate change

***Short rotation coppice***

According to DTI (2000a), $CO_2$ emissions from coppice harvesting and chipping are 707 t/y (equivalent to 15 kg/odt fuel) over the expected life-time of the 10 $MW_e$ power plant. This represents about 13% of the net emissions from the use of SRC as a fuel in power production.

***Forest residues***

For forest residues emissions from harvesting and chipping trees to improve forest quality is 399 t/y (equivalent to 9 kg/odt fuel) while the corresponding figure for harvesting and chipping branch wood is 693 t/y (equivalent to 15 kg/odt fuel). These emissions represent about 23% of the net emissions from the use of forest residues as a fuel in power production.

***Miscanthus***

Depending on the harvesting method, the $CO_2$ emissions from harvesting of miscanthus are estimated to be between 6 and 23 kg $CO_2$/odt (Lewandowski *et al* 1995). Lowest emissions are related to two-step cutting and pressing, the highest for pelleting.

***Key issues*** ***Harvesting and collection: effects on climate change***

↪ *Improved chipping efficiency has the potential to further increase the climate change benefits associated with biomass fuels.*

### 7.2.7 Flood risk

In some cases, the removal of forest residues can lead to increased water flows (or quicker routes) that could result in increased peak flows. Likewise rates of run-off from land with recently harvested energy crops may be increased. Increased run-off is only likely to be significant where a large proportion of a catchment is under plantation and is harvested at one time.

***Key issues*** ***Harvesting and collection: effects on flood risk***

↪ *Harvesting over large areas on sensitive catchments may have an effect on flood risk.*

## 7.3 Storage

### 7.3.1 Effects on quality of life

*Visual impact*

SRC could be stored in field as bundles of sticks or as chips. These could be open piles or could be under cover. Energy grasses could be stored as bales in a similar manner to straw. The visual impact of these activities would be similar to that of in-field storage of straw.

Forest residues could be stored in heaps or as bales in the forest or at the roadside.

**Figure 7.7 Covering a forest residue storage pile**

*Spores*

If biomass is damp when stored there is a risk of spore production (from reproduction of microfungi), which can cause disease. The numbers and types of fungi are determined by storage conditions, mainly the availability of water and the maximum temperature reached due to spontaneous heating. The growth rate of the fungi has been observed to be highest during the first two weeks. The rate stays high for the first month or two, after that the number of fungi decreases somewhat (Scholz and Idler 2001). **In a confined place spores can represent a health hazard in form of a range of respiratory diseases**. The health risk can be reduced by adequate ventilation and, if required, by using breathing apparatus and protective clothing (ETSU 1996, ETSU 1997, Hudson and Hudson 1997). The microbial activity can be controlled by restricting essential water and nutrient supplies. Reduced initial moisture content of the material as well as storage of uncomminuted material with intact cells can also help to reduce microbial activity (Hudson and Hudson 1997). Scholz and Idler (2001), on the other hand, did not find any correlation between microbial activity and the moisture content or the size of the material.

***Key issues*** ***Storage: effects on quality of life***

↪ *Spores associated with biomass storage will require consideration.*

### 7.3.2 Effects on air

As a result of aerobic microbial activity, carbon dioxide, water and heat are produced. Raised temperatures and water further accelerate chemical reactions (oxidation) thus increasing the temperatures even more. Eventually this can lead to **spontaneous ignition** and fire (Hudson and Hudson 1997). If baled damp, heating may also be a problem with storage of straw (ETSU 1996).

The pile temperature during storage depends on which form the wood is stored. In their experiments Scholz and Idler (2001) found that for fine chips the temperature rises rapidly at the beginning of the storage and then begins to drop after six to ten weeks. Highest temperatures were observed in the upper parts of the storage pile. The permeability of the floor to air also has an effect on the pile temperature. A stable situation, where the temperature of the stored material is that of ambient air, is achieved after five to eight months. For coarse chips the temperature levels reached were lower and the peak did not last as long as for finer chips. For wood chunks and whole trees no rise in temperature was observed; instead the temperature approximately followed that of ambient air.

Covered stores will reduce the moisture content gained from precipitation. Temperature can be controlled by storing uncompacted material allowing cooling by air flow. One option could also be storage of baled residues on an in-forest site prior to transportation (Hudson and Hudson 1997). The storage of wood chips and maintenance of good quality is considered to be costly and difficult. It can also lead to reduction of calorific value due to decomposition (as opposed to storage of uncomminuted material). Therefore, **comminution at a central facility** is considered to be a better option (Border Biofuels 1996).

Since the dry matter content of miscanthus and reed canary grass can be as high as 80% when harvested, no additional drying phase is required (Lewandowski *et al* 1995, Paulrud and Nilsson 2001).

***Key issues*** ***Storage: effects on air***

↪ *Spontaneous combustion is a risk with storage of wood chips.*

### 7.3.3 Effects on water

Some potentially polluting leachate can occur from the biomass stores leading to fungal growth and deoxygenation in local streams as well as spoiling water supplies (Nisbet *et al* 1997). Runoff from stores can also have a high particulate loading. Problems can be avoided through careful choice of sites for stores.

***Key issues*** ***Storage: effects on inland and coastal waters***

↪ *Potential for leachate and run-off problems*

### 7.3.4 Climate change

There can be some emissions of greenhouse gases associated with the decomposition of stored biomass. As this also means loss of fuel there is an incentive to store biomass in appropriate conditions to minimise decomposition.

***Key issues*** ***Storage: effects on climate change***

↪ *Biomass should be stored in conditions to minimise decomposition.*

### 7.3.5 Dry matter loss

It is likely that there will be dry matter loss during storage, mainly due to degradation of the biomass. This will depend on the nature of the biomass and the way in which it is stored and dried. Dry matter losses can vary between 3 and 25%. The method of drying will be determined by the facilities available, the value of any dry matter loss and the cost of drying (Silsoe Research Institute 1997).

For straw dry matter loss has been estimated to be around 10-20% (Newman 2001). Straw stored in the open in piles of bails in fields is susceptible to damage from rainwater and the outer bails in the stack may be lost through rain damage (Band 2002).

## 7.4 Transport

Since road transport is the most likely option for transporting the biomass to storage or power plant, other options are not looked at in this section. The benefits of road transport in comparison to other modes include lower cost (strongly dependent on journey distance and on quantity of the fuel transported), greater flexibility (e.g. scheduling) and reliability (Allen *et al* 1996). Whilst transport by rail or water is often impractical due to lack of appropriate infrastructure and the need to double handle material, etc., it can offer important potential environmental benefits and can reduce impacts on people associated with the presence of road vehicles. Hence use of rail or water transport should be given careful consideration. Some wood and wood chips are currently transported to mills by rail and the possibilities for biomass fuel require further investigation.

**Figure 7.8 Transporting forest residue bales**


**Figure 7.9 Straw delivery at Ely power station fuel barn (EPRL)**

It is difficult to compare the potential impacts of road transport of biomass fuels with the impacts of transport of conventional fuels such as coal. Much coal transport is by rail, sometimes over long distances. In addition the UK now imports substantial quantities of coal. Further work is needed to understand the full impact of transport in the biomass-energy chain and to compare it to transport of other fuels.

### 7.4.1 Effects on quality of life

Road transport can have a number of negative effects on people's quality of life. These include:

- noise;

- road congestion;
- accidents;
- community severance.

These effects are outlined in more detail in Section 9.1.3, which also quantifies the levels of transport associated with typical biomass power plants.

**Traffic levels associated with short rotation coppice plantations are usually highest in winter** and thus may reduce the amount of summer traffic on rural roads, where it replaces cereals or grass silage (Boyd *et al* 2000). When transporting biomass, some of it may escape from the load at least in the starting stages of the journey. Local authorities can demand that all loads are covered, and thus littering of the roads by falling fuel can be minimised (Allen *et al* 1996).

Studies of planning applications Allen *et al* (1996) suggest that the increase in traffic due to new biomass power plant and thus the environmental effects (noise, emissions etc) related to it, will usually not be considered significant (→ 9.1.3). However in some cases traffic movements are raised as an issue of concern (Howes *et al* 2001).

***Key issues*** ↪ ***Transport: effects on quality of life***

*Increased vehicle movements can be considered to reduce quality of life, especially on minor roads.*

### 7.4.2 Effects on air

Fuel use and emissions from transport of energy crops, straw and forest residues (ETSU 1997) are presented in Table 7.. A 100 km round trip carrying wet wood is assumed. Fuel use and emissions are based on factors for HGVs. The figures in Table 7. are related to the amount of electricity output (kWh) from the power station using the fuel. Minimising emissions means minimising transport distances, minimising the number of vehicles being used and using modern efficient vehicles.

The effect of gaseous emissions from transport on air quality is unlikely to be significant in rural areas. However, in areas where there are already air quality problems associated with road traffic, additional vehicles can only make the problem worse on a local level.

**Table 7.3 Fuel use and emissions from transport of energy crops, straw and forestry residue**

| Emissions (g/kWh) | Energy crops | Straw | Forestry residue |
|---|---|---|---|
| $CO_2$ | 5.3 | 5.5 | 6.0 |
| $SO_2$ | 0.07 | 0.002-0.008 | 0.002-0.008 |
| $NO_x$ | 0.067 | 0.07 | 0.077 |
| Particulates | 0.04 | 0.005 | 0.005 |
| CO | 0.022 | 0.023 | 0.025 |
| VOCs | 0.008 | 0.009 | 0.009 |

***Key issues*** ***Transport: effects on air***

↪ *Only likely to be an issue where local air quality problems already exist.*

### 7.4.3 Use of natural resources

Use of natural resources associated with transport includes all the normal consumables such as diesel, lubricating oils, tyres. Minimising traffic requirements in general can help minimise resource use as can use of rail or water transport.

***Key issues*** ***Transport: effects on use of natural resources***

↪ *No major issues*

### 7.4.4 Climate change

According to DTI (2000a), $CO_2$ emissions from transport of forest residues and SRC to power station are 1,344 t/y (29 kg/odt fuel) and 1,071 t/y (23 kg/odt fuel) respectively. This assumes an average distance of 65 km from forest to the plant and 48 km from coppice plantation to the plant. These figures correspond to emissions of 18 g/kWh and 14.4 g/kWh, respectively (assuming plant availability of 85%). These figures also mean that transports accounts for 28% of the total net emissions from the use of forest residues, and 20% from SRC, as a fuel in power production.

In his studies on bioenergy transportation chains Forsberg (2001) found that operating the necessary machines and transport carriers typically consumes 7 to 9% of the electrical energy delivered from the bioenergy system.

The amount of $CO_2$ released (per mass unit of biomass) during the transport will depend on the bulk density of the biomass, which in turn depends on the harvesting method. Some of the more $CO_2$–intensive harvesting methods produce higher bulk density of biomass and thus (at least some of) the increased $CO_2$ emissions during harvesting can be compensated by lower emissions during transport (Lewandowski *et al* 1995).

***Key issues*** ***Transport: effects on climate change***

↪ *Transport gives rise to a significant proportion of the net greenhouse gas emissions from biomass power production (noting that overall emissions from biomass are significantly lower than those from fossil fuel based power production).*

## 7.5 Fuel Processing

### 7.5.1 Effects on quality of life

***Noise***

**Some comminution machines produce fairly high noise levels** (e.g. hammer mills and large-scale drum chippers 100 dB(A) at 1 m). Although the noise attenuates quickly, it could cause noise nuisance in built up areas. An acoustic building for the machine might need to be constructed and employees working in the nearby area could be required to wear ear protection. As comminution machinery is likely to be located at power station sites, effects on the public will be strongly dependent on the site location. Usually the effect on general public will be quite small. Also, the noisiest machines are not the best candidates for centralised comminution and thus the noise pollution from centralised chipping at the power plant site should not be too significant (Border Biofuels 1996). Restrictions concerning working hours could also be placed for chipping in order to reduce the noise pollution (Allen *et al* 1996).

***Dust***

Chipping operations can produce airborne dust that can deposit in areas adjacent to the site. If chipping takes place under cover this risk should be minimised.

***Key issues*** ↪ ***Fuel processing: effects on quality of life***

*Noise from chipping processes*

### 7.5.2 Effects on air

As biomass has a high moisture content drying is often required prior to combustion. Drying is usually realised by using either steam or flue gas. The emissions from biomass drying can be either existing constituents of the fuel or they can be formed by thermal degradation. The emissions from high temperature drying contain more compounds formed by thermal degradation, such as acetic acid, aldehydes and carbohydrates, while with lower temperature drying the emissions are mostly lipophilic compounds like monoterpenes and fatty acids. Of these, monoterpenes, aldehydes and acids can cause blue haze, malodorous odours and ozone formation. The emissions depend on the dryer type and drying conditions as well as the fuel and can be reduced by using lower drying temperatures and shorter drying times. The use of steam drying or burning of the outlet gases can also reduce the emissions (Fagernäs and Sipilä 1996).

With regard to emissions of dust and volatile hydrocarbons from drying some precautions are needed (Bauen 2001). If the gas from the drying process is condensed, effluent water will be released. Water vapour in the exhaust gases from biomass dryers can also produce a visible plume.

As already mentioned in Section 7.5.1, dust can be produced from biomass comminution. Dust produced can be controlled by placing machinery in enclosures and using suitable filters.

***Key issues*** ***Fuel processing: effects on air***

↪ *Volatile emissions from biomass drying*
*Vapour plume from biomass dryers*
*Dust from comminution*

### 7.5.3 Effects on water

The emissions from drying can also produce organic load and toxicity in wastewater from condensing gases (Fagernäs and Sipilä 1996). Hence consideration will need to be given to disposal of such waste water.

***Key issues*** ***Fuel processing: effects on water***

↪ *No major issues*

### 7.5.4 Climate change

Greenhouse gas emissions from chipping wood fuel have been considered in Section 7.2.6. In general **emissions from fuel processing depend on the fuel quality required by the conversion technology used**. For example, coarser material can be used in stokers than in fluidised beds and thus less preparation is needed (Lewandowski *et al* 1995). However any saving resulting from a lower fuel processing requirement should be balanced against the efficiency of the associated power generation technology.

***Key issues*** ***Fuel processing: effects on climate change***

↪ *Improved chipping efficiency has the potential to further increase the climate change benefits associated with biomass fuels.*

## 7.6 Conversion Process

This section gives information on the environmental impacts of power plants using biomass fuel. Data for this section has been gathered from existing plants. Appendix 5 gives some background details on these power plants.

### 7.6.1 Effects on quality of life

***Visual impact***

**The most intrusive aspect of the combustion plant is usually the stack**. By carefully considering the siting, e.g. placing the power plant on industrial or trading areas, the impact can be minimised, although not entirely eliminated (Allen *et al* 1996, ETSU 1997). Apart from the effect of the buildings, the effects of grid connections also need to be considered.

For example at the Elean power plant the stack height is 43.5 m. The visual impact of the plant has been reduced by building the plant 8 m below ground level. In the Thetford poultry litter plant, bunds have been built and trees planted to provide screening. The site base is also lowered by 3 m. The stack height on this plant is 100 m.

**Figure 7.10 Ely power station behind a miscanthus plot**

**Figure 7.11 Thetford poultry litter plant**

Depending on the moisture content of the fuel and temperature of the exhaust gases leaving the stack, **a visible vapour plume can occasionally be seen above the stack**. On exiting the stack, the plume is usually compact and white. However, it will soon dissipate. The plume length will vary depending on for example wind speed and direction, cloud cover, mist or fog and ambient air temperature. For example, in the ARBRE plant a visible plume from the stack is estimated to appear for 30% of the day-time hours. In certain weather conditions, a visible plume can also be emitted from the cooling plant. With careful design of the plant, this visual effect can be minimised. In the ARBRE SRC fired power plant, the cooling plant is designed so that no visible plume will appear at ambient temperatures above 5°C and below 95% relative humidity. These conditions are estimated to occur for 95% of the day-time hours. In some plants, a plume could also result from the fuel drying (if it is not connected to the cooling plant) (ARBRE Energy Ltd 1996).

***Noise***

Conditions for noise emission levels are likely to appear in planning permission, so a background survey could be useful in the planning phase. As an example the limits set for one power plant are given Table 7.. The most likely sources of noise are engines/turbines, chippers and other fuel preparation activities. Engines or turbines are typically constructed within an acoustic enclosure to minimise noise. Acoustic fencing and earth mounding could be used to reduce the noise emissions if required.

**Table 7.4 Noise emission limits for Värnamo power plant in Sweden**

| Time of day | Time | Equivalent dB(A) | Instantaneous |
|---:|:---:|:---:|:---:|
| Daytime, weekdays | 07-18 | 50 | - |
| Daytime, Sundays and holidays | 07-18 | 45 | - |
| Evening | 18-22 | 45 | - |
| Night | 22-07 | 40 | 55 |

Värnamo demonstration programme 2000

Section 9.1.1 puts noise levels into context and identifies levels that are normally considered acceptable.

***Odour***

Odour can also result from transport, handling and open-air storage of the fuel (Allen *et al* 1996). Typical arrangement in the power plant is that boiler combustion air fans draw air from the fuel storage and mixing buildings. Thus a negative pressure to the fuel storage is created and odorous gases are drawn into the furnace instead of being released to the environment.

***Others***

Light pollution could be caused e.g. by all-night lighting. More information can be found on Guidance Notes for Reduction of Light Pollution by The Institution of Lighting Engineers.

Dust is not likely to cause problems outside the plant site. In the Elean plant the straw is stored bunded and the movement of straw outside the barns is permitted only if the straw is sheeted. All lime and ash movement is to be done in an enclosed system and all systems shall have appropriate abatement to minimise dust emissions. Covering the vehicles (transporting fuel, ash etc.) and paving the roads on the power plant site will help reduce the dust emissions.

| ***Key issues*** | ***Conversion process: visual impact*** |
|---|---|
| ↪ | *Stack height* |
| ↪ | ***Conversion process: noise***<br>*Engines/turbines and chippers have highest noise potential* |
| ↪ | ***Conversion process: odour***<br>*No major issues* |

### 7.6.2 Effects on wildlife

Biomass power plants can have direct impacts on wildlife through change of land use. Plants should be located to avoid sites that are habitats for important species. This will be an issue covered in the planning process.

Biomass power plants can also affect wildlife through pollution of air, land or water. Issues are covered in Sections 7.6.3, 7.6.4 and 7.6.5. In most cases, pollution from biomass power plant are unlikely to have significant effects. Exceptions will be where existing environmental quality is close to maximum tolerance thresholds or where species are particularly sensitive to changes in pollution levels.

| ***Key issues*** | ***Conversion process: effects on wildlife*** |
|---|---|
| ↪ | *Plants should be located to avoid sites that are habitats for important species.* |

### 7.6.3 Effects on air

***Combustion***

Table 7. gives examples of emissions from some biomass power plants using different combustion technologies. This Table includes notes on the emissions abatement used at the plant. In Appendix 3, more detailed information is given on typical emissions with different loads at one specific plant.

Biomass plant are commonly fitted with electrostatic precipitators and bag filters to collect particulates; SCR or SNCR and/or flue gas recirculation may be used to abate $NO_x$ emissions. Some plant are also fitted with acid control systems. Emissions are difficult to compare because different countries require the emissions to be reported in different units. However, further analysis of air emissions from biomass plant is given in section 9.2.1. This indicates that the most significant emissions for biomass plant are $NO_x$ and VOCs. Particulates and cadmium might be “significant” (according to H1) for straw and poultry plant as can HCl for straw plant. $SO_2$ emissions are lowest for wood-fired plant but for all biomass plant they are clearly lower than for fossil fuel plant. The sulphur content of straw can vary and this will affect the $SO_2$ emissions. The PAH emissions from large-scale plants are clearly lower (orders of magnitude) than from household stoves or fireplaces. Further information on the types of emission abatement is given in section 8.2.

Further work needs to be done to draw conclusions from the emission levels achieved with different combinations of pollution control equipment. Altering combustion characteristics such as temperature and excess air can result in increased $NO_2$ and decreased NO and increases in both respectively. The chemistry is complex as heterogeneous reactions are taking place. Work with coal-fired stations has shown the following and it is likely that similar effects will be observed in biomass-fired plant:

- Lower excess air decreases thermal-NO and fuel-NO, but increases unburnt carbon;
- Less preheated air will decrease thermal-NO, but the efficiency decreases;
- Fuel gas recirculation decreases thermal-NO, but the efficiency decreases;
- Low-$NO_x$ burners result in lower fuel and thermal-NO, but increased CO and unburnt material in the ash and more corrosion and fouling;
- Air staging has similar results to low $NO_x$ burners;
- Fuel staging will reduce the NO already formed, but with the same negative effects as above;
- SNCR ($NH_3$ or urea) will reduce NO already formed, but the CO will increase. There may also be some increase in emissions of ammonia due to slippage.

This indicates that emissions abatement often results in trade offs between emissions. It is likely that each plant will need to be considered on an individual basis. The system used will depend on the fuel, the type of combustion plant and may also depend on specific local conditions (→ 9.2.1).

**Typically for wood the $N_2O$ emissions from fluidised bed combustion are ~10% of those for coal.** Emission from BFB is usually a bit lower than for CFB. **For NO, for younger fuels (e.g. wood) the NO emission depends strongly on nitrogen content of the fuel (N up, NO up),** but this is not always a case for coal. For grate combustion the conversion of (wood) fuel-bound N to NO increases with decreasing N content of the fuel (this is to do with how the production rate depends on concentrations of different compounds) (Kilpinen 1995).

Although the SNCR process appears to be simple, there are a number of challenges with the implementation. These challenges are mainly due to the relatively narrow temperature "window" (870-1205°C) over which the chemicals selectively react with $NO_x$. **If temperature is too high, ammonia can burn and $NO_x$ levels can increase, but if temperature is too low ammonia will slip unreacted, resulting to $NH_3$ emissions. In smaller boilers the residence times are shorter, thus there is less time for $NH_3$ to react, and the slip is higher.** The $NO_x$ reductions with SNCR are in the range of 30-60%, depending on the specific application. Since no catalysts are used, equipment costs are relatively low compared to other post-combustion $NO_x$ control technologies. However, the SNCR process has also several disadvantages. One is the relatively narrow temperature window mentioned above. Another is the possible emission of e.g. $NH_3$, CO, or $N_2O$, at least under some operating conditions. For co-firing, reactions between $SO_3$ (in boilers utilising high sulphur coal) and $NH_3$ can result in air preheater deposition. Due to the complexity of the interaction of the SNCR process and several basic boiler design features (e.g. flue gas path, temperature-time history, available residence times and gas velocities), it might be impossible to assess these issues in advance (EPRI 2000).

## Table 7.5 Emissions from some biomass-fired power plants

| | Fuel | $NO_2$ ($mg/m^3$) | $SO_2$ ($mg/m^3$) | Particulates ($mg/m^3$) | CO ($mg/m^3$) | HCl ($mg/m^3$) | $N_2O$ (mg/MJ) | Comments on emissions control systems |
|---|---|---|---|---|---|---|---|---|
| **Brista** | FR | 19 mg/MJ | | 4-6 | | | 7-8 | CFB. Flue gas cleaned with ESP. Ash returned to forest[3] |
| **Cuijk** | W | | | | | | | BFB. SNCR reduces $NO_x$ from 240 to 140 $mg/m^3$ and SCR further to 140 to 100 $mg/m^3$, but the main purpose of the system is to keep $NH_3$ slip to flue gas low. Ash from the flue gas is collected by ESP[4]. |
| **Enköping** | W | 42 mg/MJ | 18 mg/MJ | 15 | | | 1 | |
| **Elean** | S | 170 | 40 | 10 | 80 | 12 | | Lime injection (for $SO_2$), bag filter (for particulates). |
| **Ensted** | S | 220 | 130 | 2 | 70 | 50 | | SNCR (efficient with loads up to 70-80%, above which the furnace temp is too high for efficient $NO_x$ reduction.) Values quoted are typical for emission tests with 100% boiler load, oxygen controlled at 6%. High variations occur in $SO_2$ and HCl from hour to hour[5]. Max daily mean $SO_2$ and HCl = 300mg/$Nm^3$, max hourly mean = 400mg/$Nm^3$. Peaks in CO occur after grate vibration. Six hourly mean for PAH 1.8 $\mu g/m^3$ and for PCDD/DF 2.2-2.9 pg I-TEQ/$m^3$. Results in trace analysis ($\mu g/m^3$): AS 0.4, Be<0.05, Cd 0.6, Cr 2.1, Cu 4.5, Hg 0.4, Ni 2.6, Pb 3.1, SE <0.3 and Zn 59[6]. |
| **Eye** | PL | 140 | 210 | 70 | 120 | 120 | | Flue gas cleaned with 3-stage ESP |
| **Falun** | W | 59 mg/MJ | 30 mg/MJ | 15-20 | | | | |
| **Glanford** | PL | 200 | 20 | 6 | 240 | 3 | | Flue gas cleaned with 3-stage ESP. Heavy metal concentrations ($mg/m^3$): As 0.009, Cd <0.004, Cr 0.006, Cu 0.013, Hg 0.011, Mn 0.032, Ni 0.048, Pb 0.013, dioxins ($ng/m^3$ TEQ) 0.017 and VOCs (as C) 21 $mg/m^3$[3, 7]. |
| **Karlstad** | W | 48 mg/MJ | 8 mg/MJ | 3 | | | 5 | |
| **Kristiansand** | W | 70 mg/MJ | | <5 mg/MJ | | | | |
| **Skellefteå** | W | 50 mg/MJ | 20 mg/MJ | 35 | | | | |
| **Thetford** | PL | 240 | 80 | 4 | 110 | 28 | | Dry Scrubber to control acid gas and bag filter for particulates |
| **Växjö** | FR | 20 mg/MJ<br>44 mg/MJ[1] | <br>1 | 4-6<br>0.3 | 90 mg/MJ | | 15<br>10 | |

**Table 7.5 cont**

| | Fuel | $NO_2$ (mg/m$^3$) | $SO_2$ (mg/m$^3$) | Particulates (mg/m$^3$) | CO (mg/m$^3$) | HCl (mg/m$^3$) | $N_2O$ (mg/MJ) | Comments on emissions control systems |
|---|---|---|---|---|---|---|---|---|
| **Westfield**[2] | PL | 50 | 20 | 5 | | 25 | | Bag filter to clean flue gas and flue gas recirculation to control $NO_x$. |
| **Germany** | WW | 66-144 | 2-25 | <0.3 | 2-11 | <0.1 | | SNCR. Flue gas cleaning with quasi-dry process. Flue gas recirculation. Limits/measured values for plant (mg/m$^3$): HF 1/<0.1, Hg 0.05/0.003-0.013, dioxins and furans (ng/m$^3$) 0.1/0.0074-0.0503 and Cd+Tl 0.05/<0.001[8] |

Notes: FR = Forest residues. W=wood. S=Straw. PL= Poultry litter. WW=Waste wood. CFB= Circulating fluidised bed. BFB = bubbling fluidised bed ESP = Electrostatic precipitator.

[1] data from two references [2] Estimated values for normal operation. The values currently in mg/MJ will be converted to mg/m$^3$ if possible

[3] Rydehell 1998, Wahlund *et al* 2001 [4] Remmers 2001

[5] Ramsgaard-Nielson *et al* 2001 [6] Sander *et al* 2001

[7] EA 2001a [8] Graf & Feldmann 2001

*Gasification*

Table 7. gives typical emissions from energy crops gasification. The second table gives emissions on one particular plant when different wood fuels are used.

**Table 7.6 Emissions [g/kWh] from gasification technology using wood fuel (energy crops)**

| | |
|---|---|
| $CO_2$ | 971 |
| $SO_2$ | 0.03 |
| $NO_x$ | 0.24-0.26 |
| Particulate | 0.045 |
| VOC | 0.013 |
| CO | 0.007-0.008 |

ETSU 1994

**Table 7.7 Emission levels measured in the Värnamo gasification plant (fuel gas used in a gas turbine)**

| | $NO_x$ mg/MJ | $SO_2$ mg/MJ | CO ppm (dry gas) | Turbine load MW |
|---|---|---|---|---|
| **Typical** | 260-270 | 30 | 100-170 | 3.5-3.7 |
| **Wood chips** | 90-100 | 10 | 40-60 | 3.7-3.9 |
| **Sawdust** | 70 | 10 | 60-80 | 3.7 |
| **Bark** | 280-310 | 30 | 70-90 | 4.1-4.2 |
| **Willow** | 370-410 | 50 | 150-220 | 3.0 |
| **Straw** | 420-440 | 90 | 300-450 | 2.9765 |

Higher conversion efficiency (compared to combustion) means lower emission of $CO_2$ per kWh. Relatively low reactor temperature means heavier pollutants will be retained in the ash. The gas can be treated before combustion to remove volatile compounds, HCl and $SO_2$, thus the amount of gas treated is much lower than from conventional conversion.

*Pyrolysis*

A pyrolysis process has three potential sources of emissions to air:

- The exhaust gas from the power generation device;
- The exhaust gas from the auxiliary heater providing process heat, and;
- Flaring of process gas during start-up and upset.

Very few data are reported because there are no installations operating on a continuous basis for energy production.

Some indications are given of gas turbine performance in the test work reported by Dynamotive (2002). These show that the emissions from a gas turbine fuelled by pyrolysis oil would be broadly comparable with those from diesel but with a higher CO and lower $NO_x$. Sulphur would be negligible.

Pyrolysis oils can be successfully fired in reciprocating engines if pilot ignition is provided by diesel. CO emissions are very high however. Some tests are reported below in Table 7. and Table 7..

**Table 7.8 Engine emissions data as published – pyrolysis oil**

| Pilot diesel by wt | $O_2$ % | $NO_x$ ppm | NO ppm | $NO_2$ ppm | CO ppm | $CO_2$ % | $SO_2$ ppm |
|---|---|---|---|---|---|---|---|
| 17% | 15 | 384 | 313 | 76.5 | 2057 | 4.55 | 32.5 |
| 7% | 15 | 286 | 240 | 40.5 | 3475 | 4.36 | 0 |

Data for this table taken from an ETSU report soon to be published

**Table 7.9 Engine emissions data for pyrolysis oil, converted to common units ($mg/m^3$ at 11% $O_2$)**

| Pilot diesel by wt | $O_2$ % | $NO_x$ | CO | $SO_2$ |
|---|---|---|---|---|
| 17% | 11 | 1,180 | 5,520 | 140 |
| 7% | 11 | 820 | 6,490 | 0 |

Conversion of $NO_X$ figures assumes original data expressed as $NO_2$

There is no reported data for flares or auxiliary heaters in this context but these should not be different to process heaters and flares in the petrochemicals industry.

***Co-firing***

There is little co-firing experience in the UK. More work has been done in the USA and the Nordic countries. In addition the EU funded the APAS programme (Bemtgen *et al* 1994) to look at co-firing. This work indicates that co-firing is feasible technically, providing the process is managed properly. Section 5.3 discusses the methods of co-firing and technical issues.

There is evidence that some emissions are decreased as a result of co-firing biomass with coal. Tillman (2000) reviewed experience of co-firing and concluded that environmental benefits from co-firing coal with biomass compared to coal-only include reduced $NO_x$, $SO_2$, fossil $CO_2$ and trace metals e.g. mercury. For example, at 10% co-firing there is a 5-20% decrease in $NO_x$. However the composition of the biomass fuel is important. Baxter (2002) reports increases in $NO_x$ when firing switchgrass. He indicates that operating conditions in the boiler are important in influencing $NO_x$ emissions.

Experience in European plant indicates[8]:

[8] Appendix 5 contains details on the operation of these plant.

- Grenå (straw co-fired with coal). Limestone is added to the boiler. Emissions for 50:50 fuel mix are: $NO_x$ < 150 mg/MJ, $SO_2$ < 100 mg/MJ and CO < 200 mg/MJ (Alakangas and Veijonen 1998).
- Kymijärvi (co-firing fuel gas from gasification) uses flue gas recirculation and staged combustion as primary measures for emission control. No sulphur removal is required as low-S coal is used (Alakangas and Veijonen 1998). Measurements indicate reductions in $NO_x$, $SO_2$ and particulates. No changes were observed in CO, dioxins, furans, PAH, benzenes or phenols. However, there was an increase in HCl emission as well as a slight increase in some heavy metals but the base level for these was low[9].
- Västhamsverket (wood pellets co-fired with coal). Clear reductions on $SO_x$ and $NO_x$ emissions have been measured when co-firing with biomass instead of using just coal (Rörgren and Olsson 2001).

Work on trials for co-firing up to 20% straw with coal at ELSAM indicated:

- $NO_x$ emissions varied, depending on the nitrogen content in straw (this was dependent on the use of fertiliser);
- HCl emissions increased compared to the firing of coal alone;
- potassium was captured by aluminium and silicium as potassium aluminium silicates; some potassium reacted to form $K_2SO_4$;
- the coal type dominated the behaviour of potassium and chlorine;
- $SO_2$ emissions were lower, due to the formation of potassium sulphate (see below).
- dust may increase (depending on the conditions);
- there was also a high deactivation of SCR, which was put down to the levels of dust deposition on the catalyst and to a minor extent blocking of the active site by potassium.

In general success in reducing fossil $CO_2$, $SO_2$ and trace metals is thought to result largely from substitution of biomass for coal, substitution of low sulphur fuel for coal and the low heavy metal content of some biomass (Rösch 2001, Unterberger *et al* 2001, Tillman 2000).

However, in some cases there are increased heavy metal emissions (Rösch 2001).

Biomass fuels containing high levels of alkali, e.g. straw or switchgrass can cause problems with slagging and fouling deposits during co-firing. In pf co-firing the alkali in the biomass can be released and react with sulphur in the coal in a complex series of reactions. In highly alkali material the consequence can be a series of potassium or sodium reactions with chlorine, followed by substitution with sulphur (from the coal) for chlorine in the alkali chlorine deposits. Under select conditions the result can be potassium sulphate or analogous compounds in the slagging or fouling deposits in the boiler (Tillman 2000).

There are a number of unresolved issues that need careful evaluation, in particular:

- the impact of biomass co-firing on the ash reuse;
- the impact on SCR catalysts.

[9] www.westbioenergy.org/lessons/les19.htm

*Ash reuse.* This causes a problem in definition. There are standards for the production of cement, concrete (EU standard EN450) and other building materials that state what materials may be used in production. These standards do not include co-fired ash and some work is needed to demonstrate that the ash is suitable before these standards can be altered. There may be problems with unburnt carbon in the fly and bottom ash (due to insufficient residence times for the biomass fuels). However, tests by Wieck-Hansen *et al* (2000) indicated that ash from co-firing of 20% straw did not have problems with strength, deformation or permeability. However, leaching tests resulted in increases in K, Cl, S and Na due to their higher concentration in straw (Cd, Hg and Pb were below detection limits).

*SCR catalysts*. There is some evidence that co-firing biomass fuels (particularly straws and other herbaceous materials) with high ash contents and highly reactive alkali contents can deactivate the catalysts installed in SCR systems. This needs to be evaluated (Tillman 2000, Wieck-Hansen *et al* 2000, Baxter 2002).

Pyrolysis gas from biomass has been found suitable to be used as a reburn fuel to reduce $NO_x$ emissions in coal-fired boilers (Unterberger *et al* 2001).

***Key issues*** ↪ ***Conversion process: effects on air***

*Emissions include NO, $NO_2$ and VOCs. $SO_2$, particulates and cadmium may be significant for straw.*

*Emissions abatement often results in trade-offs. Further work is needed to provide data on emissions and to understand the influence of design and fuel composition on emissions.*

*Co-firing with coal can be beneficial in decreasing $NO_x$, $SO_2$ and fossil $CO_2$ emissions. However, further work on ash composition and the effect of co-firing of ash on reuse is needed. There may also be problems with deactivation of the catalysts in SCR.*

### 7.6.4 Effects on soil

Deposition of air pollutants from biomass schemes to soil is discussed in 9.2.2.

Data on the composition of ash is given in Appendix 4. Further information on the use of ash is given in 7.6.6.

Ash from biomass plant can be applied to soil as a fertiliser. In the UK ash from both poultry litter and straw fired plant is used for this purpose. This use and its impact are discussed in Section 9.4. Prior to application, ash can be stabilised to reduce solubility. One reason for stabilisation is that rapid increase on the humus layer pH has been witnessed when “unstabilised” ash has been applied. This causes the transformation of organic nitrogen to nitrate, and nitrogen is lost to ground and surface waters.

Increased nitrate concentration on the soil can also alter the flora. According to Swedish authorities, the amount of ash applied should not exceed 300 kg per 1,000 $m^2$. Special attention should be paid to redistribution of heavy metals, especially if ash results from combustion of mixed biomass or co-firing with other fuels (Hovsenius 1999). Application of sewage sludge to energy crops may increase the heavy metal content of the crop and thus the content in the ash (→ 9.4).

Work by Piskorz and Radlein (1999) has shown that pyrolysis liquids are biodegradable in both soil and aquatic environments. The pattern of degradation is similar to that of #2 diesel fuel but substantially faster. Biodegradation in the soil environment does not seem to need neutralisation or nutrients (→ 5.5).

***Key issues*** ↪ ***Conversion process: effects on soil***

*The effects of ash application to soil need further investigation.*

*Attention should be paid to build up of heavy metals in soils.*

### 7.6.5 Effects on water

There are three primary criteria that need to be considered when the effects of water are estimated:

- the existing water quality and use;
- the nature of the organisms and habitats that may be affected by the development;
- the existing quality, level and utilisation of groundwater resources associated with the site.

Specific criteria can also include the River Quality Objectives (RQO) based on river quality classification criteria, and water quality standards from the EU Directives (ARBRE Energy Ltd 1996).

Release to water is likely to consist of surface water run-off (e.g. suspended particles or dissolved chemicals from stored wood, dust from chipping, oil spills), plant process wastewater (likely to require treatment) and sewage. Emissions that could affect surface water or groundwater will be regulated by EA or SEPA and discharges to sewage system by the sewage system operator (British BioGen 1999a).

The table below gives examples of typical release to water from the Thetford plant based on the release data reported to the Environment Agency every month. The recorded flow to water was 21 $m^3$/d. The releases to water are comprised of treated boiler blowdown, drainings and condensate, effluent from the water treatment process and surface water runoff.

**Table 7.10 Typical releases to water from a poultry litter –fired power plant**

| | Result | Limit |
|---|---|---|
| **Ammonia (mg/l)** | 0.25 | 5.0 |
| **Cadmium (mg/l)** | <0.002 | 0.05 |
| **Chloride (mg/l)** | 1,500 | 2,000 |
| **Mercury (mg/l)** | <0.001 | 0.02 |
| **Sulphate (mg/l)** | 16 | 1,000 |
| **Suspended solids (mg/l)** | 20 | 60.0 |
| **BOD (mg/l)** | 4.4 | 30.0 |
| **Temperature (ºC)** | 18 | 30.0 |
| **pH** | 7 | 6.0-9.0 |
| **Oil/grease (mg/l)** | 3.6 | 5.0 |

In the ARBRE plant boiler blowdown, water treatment plant effluent and domestic wastewater generated on site will be treated in a small waste water treatment plant. The effluent from the biogas scrubber is first treated in a separation tank. From there, the condensate is filtrated by activated carbon and sand, and flocculated. Surface runoff water will go through a settlement tank and oil-water separator before it is passed to the drain (ARBRE Energy Ltd 1996).

Work by Piskorz and Radlein (1999) has shown that pyrolysis liquids are biodegradable in both soil and aquatic environments. The pattern of degradation is similar to that of #2 diesel fuel but substantially faster. The process is accelerated in aquatic environments by neutralisation with lime or other alkali agents (→ 5.5).

***Key issues*** ***Conversion process: effects on water***

↪ *With attention to effluent and water treatment on site, releases to water should not be an issue.*

### 7.6.6 Use of natural resources

***Ash***

Krotscheck *et al* (2000) have estimated the amount of ash from short rotation coppice conversion to be 9.73 g/kWh for fast pyrolysis, 7.66 g/kWh for atmospheric gasification, 5.69 g/kWh for IGCC and 10.4 g/kWh for combustion and steam cycle. Appendix 4 gives information on ash properties.

Ash handling is regulated under the Environmental Protection Act.

In the Ensted straw-fired power plant the bottom ash is used as a fertiliser and spread directly on the field. Although the fly ash from the plant would be attractive as a fertiliser due to its high potassium content, under Danish legislation it has to be landfilled due to its high cadmium content (Ramsgaard-Nielsen *et al* 2001). The ash from Elean (straw-fired) power plant is rich in potassium and phosphate salts and is used as the basis of an organic fertiliser. The ash from poultry litter combustion is usually rich in phosphate and potash and can be used as a fertiliser. For example the ash from Westfield plant contains 20% and 17% of phosphate and potash, respectively.

In their experiments using different residual biomass fuels in CFB gasification facility van der Drift *et al* (2001) found that the leaching rates of bromine and molybdenum in particular are too high for the ash to be considered inert by the Dutch legislation. It has to be noted that the performance of the gasification unit will largely affect the ash concentration and thus its "classification" as inert, hazardous etc. For example, if the amounts of bed material and carbon in ash are high, concentrations of other components are diluted. Experience at the Värnamo gasification plant indicates that most of the heavy metals in the fuel will end up in the ash and very little will be emitted with the flue gas.

There is some concern that the **fly ash from co-firing** might not meet the existing standards for concrete mixtures. This would decrease the value of fly ash as a usable product and could lead to its disposal by other (maybe less sustainable) means (Rösch 2001). According to Unterberger *et al* (2001) there is no impending EU legislation to permit the use of mixed ashes in the building industry.

***Key issues*** ***Conversion process: effects on use of natural resources***

↪ *Ash from biomass plant may be used as a fertiliser, providing heavy metal concentrations are under limits for application to soil.*

*Co-firing may prevent the use of coal ash in the building industry.*

### 7.6.7 Climate change

Carbon dioxide emissions from the conversion of biomass to energy can be considered as carbon neutral as any emissions from the plant are balanced with $CO_2$ taken up from the atmosphere during the growth of the biomass. Therefore the only net emissions from this stage are those from any fossil fuels used as support fuel. Emissions from activities in the fuel supply chain have been dealt with in previous sections and Section 9.2.4 gives the overall lifecycle net emissions.

A study by Lewandowski *et al* (1995) estimates that 90% of $CO_2$ emissions can be saved if miscanthus is used to replace hard coal. For coal emissions from mining, and for miscanthus plant propagation, plant transportation, planting as well as use of fertilisers (and other crop management) were included in this analysis. The total primary energy required to produce and process miscanthus fuel is estimated to be only 6.7% (based on energy content of the fuel).

In the DTI leaflet (2000a) the $CO_2$ emission from a 10 MW power plant is estimated to be 1,140 g/kWh when using forest residues or short rotation coppice. However, when climate change issues for the use of biomass fuels are contemplated, it is important to look at the whole fuel chain for a picture of the overall effects.

It is interesting to note that biomass-energy is not always perceived to be "green" by the public. A recent survey by the Royal Society for the Protection for Birds (RSPB 2002) found that only 32% of those interviewed were in favour of biomass energy, compared to over 50%

for wave, tidal and solar. The survey revealed that many believed biomass power stations contributed to climate change.

| | |
|---|---|
| ***Key issues*** ↪ | ***Conversion process: effects on climate change***<br>*The major GHG emissions from biomass are frequently due to the production stage and transport. Improved efficiency in these stages will decrease GHG emissions.*<br>*Net emissions are far lower than those from fossil fuel power generation.* |

**Flood risk**

Flood risk from biomass plant is the same for any power scheme. Plant should not be built in areas prone to flooding. If they are, precautions against flooding will need to be taken.

| | |
|---|---|
| ***Key issues*** ↪ | ***Conversion process: effects on flood risk***<br>*No major issues* |

# 8 TECHNIQUES FOR POLLUTION PREVENTION

Many of the techniques that will be used for pollution prevention on biomass power plants are common to those used on conventional power plants. As such techniques are comprehensively covered in various Environment Agency documents they will not be covered here.

## 8.1 Fuel Production and Supply

With regard to the production and delivery of biomass fuels a key issue for minimising pollution will be the choice of site. This will mean consideration of:

- local soil types - their susceptibility to compaction and nutrient status;
- local hydrology – impact of planting on watercourses and flood risk;
- proximity to plant that will use the fuel – minimise transport distances.

Fuel processing may require standard techniques for dust and noise suppression.

**Local soil types** are important because they influence the composition of the biomass. This is particularly true for soils containing heavy metals. Ash compositions for straw and other herbaceous crops have been shown to be a function of harvest time and agricultural regime (Tillman 2000) and the N content of straw varies with fertiliser. Forest residues can also vary as a function of harvesting practice and pick up of extraneous material (e.g. dirt from the forest floor). In addition a paper by Williamson (2002) describes different composition for ash from wood biomass depending on the location (e.g. lime from 32-63% or $K_2O$ from 10% to 21% in willow ash).

The importance of **local hydrogeology** is discussed in sections 7.1.5, 7.1.8 and 7.2.5.

The importance of **proximity to the plant** is down to the low bulk densities of biomass and the issues involved in transporting large volumes over long distances.

In addition the harvesting and comminution processes need to be related to the plant requirements. This is particularly true for moisture content, but it can also apply to particle size and storage conditions.

***Acid gases, sulphur and chlorine***

For straw, the levels of Cl and S vary according to the soil conditions in which it is grown, fertiliser application, straw type and degree of weathering after harvest. For example Cl levels are higher near the sea, and S levels higher in industrial areas. Typical values and likely maximum values for variants including rape and barley straw are:

| | Typical average | Maximum likely |
|---|---|---|
| S (%) | 0.2 | 0.7 |
| Cl (%) | 0.4 | 0.8 |

Recent measured values of S and Cl for energy grasses are

| | Miscanthus | Switchgrass | Reed canary grass |
|---|---|---|---|
| S (%) | 0.04 | 0.04 | 0.05 |
| Cl (%) | 0.4 | 0.07 | 0.07 |

It is not known how the S and Cl content of the energy grasses will vary with soil conditions, but it is anticipated that values will vary in a similar way to those of straw (Christian and Riche 1999).

Values from the Phyllis database (www.ecn.nl/phyllis) for willow clones are Sulphur 0.06% and chlorine 0.01%. The values for willow for both S and Cl are therefore lower than for any of the energy grasses or for straw. Research shows, however, that the values for content of a range of inorganic components in willow and poplar ash vary with location, by a factor of about two (Williamson 2002).

***NPK***

A variety of studies have been undertaken on the application of fertilisers to energy crops. However, these have generally been designed to investigate the effect of fertilisers on yield, and the nitrate run off from the crop rather than the NPK composition of the biomass.

Small-scale work on miscanthus (Christian 2001) shows that the concentration of nitrogen in the biomass increases with increasing amounts of N fertiliser applied. The amount of K also increases with the amount of N fertiliser applied.

However, another important factor in the nutrient content of the biomass is the harvesting time. For the perennial grasses and the willow there is translocation of nutrients from the leaves and stems to the storage organs in winter. Delaying harvest until winter can therefore reduce the nutrient content of the harvestable stems considerably, thus both reducing fertiliser requirements and improving the quality of the biofuel (Yates and Christian 2001, Lewandowski *et al* 2001).

Improvements in quality of annual crops such as straw can also be achieved by allowing the nutrients to wash out by leaving on the field after harvest. However, this is impractical in the UK where straw must be cleared quickly for the following crop. It is also a trade off between the removal of nutrients from the straw and achieving a dry crop to bale.

## 8.2 Conversion Process

Standard techniques for the control of emissions resulting from the products of combustion will apply. Table 8.1 provides a summary of abatement techniques that are commonly employed to abate emissions from across a wide range of sectors including power generation and incineration activities. These techniques may be applied to gasification and pyrolysis processes as well as grate-fired combustion processes. The precise choice of abatement equipment, or combination of equipment, will be determined by an assessment of best available techniques (BAT) on an installation-by-installation basis. This assessment will include consideration of site specific issues, including the nature of the emissions/fuels used, the size of the site, the location of the plant and the environmental cost and benefits associated with the planned abatement.

In addition to these techniques there are other factors that may influence abatement of emissions from biomass combustion:

- It has been generally found that co-firing wood fuels with coal will decrease emissions of $NO_x$, $SO_2$ and fossil $CO_2$ compared to coal-only (→7.6.3). There are synergistic reactions between components of the coal and biomass that result in some of this decrease, but it is also true that some of the increase results from the fact that biomass fuels tend to be low in sulphur and nitrogen. Part of the decrease in $SO_2$ is due to the reaction of sulphur in the coal with sodium or potassium in the biomass (particularly for straw). This can result in deposition of alkali salts in the system and may cause slagging and fouling and also an increase in potassium sulphate in the fly ash (Wieck-Hansen *et al* 2000). In addition there is also evidence that ash can deactivate SCR catalysts (Tillman 2000), but this needs clarification.
- It has been shown to be beneficial to leave straw on field for around a month after harvesting as rainfall decreases the water-soluble alkali content of the straw. This decreases the alkali and chlorine in the straw. The downside of this is that it may result in a high moisture fuel and there will be issues with drying the straw. It is possible to design the drying to use heat from the steam generated at the power station. On the other hand too much rain can make storage and handling of the straw very difficult and can result in very high dry matter loss (up to 17.5% loss was reported by Bond 2002).
- Pyrolysis and gasification systems generally operate better with a homogenous fuel, although there are some gasifiers that require minimal preparation (these tend to be lower efficiency and are usually used for heat only or steam)[10]. Increasing fuel homogeneity will result in more constant and hence more manageable emissions. However, the need to present homogeneous fuel will increase fuel preparation (and hence noise and dust).
- Gasification and pyrolysis systems work better with dry fuel. Most gasifiers will work with higher moisture contents but it will have an impact on efficiency (just as with combustion). The smaller systems will loose too much heat out of the reaction zone and stop working if the fuel is too moist. Using low-grade waste heat from the back of the process to dry fuel at the front end is thermodynamically good and maximises the heating value of the product gas. Fluctuating moisture contents will also cause variations in the heating value of the fuel gas produced, which makes steady operation of the following gas turbine difficult. Flash pyrolysis needs dry material because the operating principle depends on a fast heating rate for the particles of biomass. Moisture slows this down and reduces the yield of liquid products.

[10] Waste Gas Technology, Compact Power, Bioflow, TPS and Lahti all require fuel preparation.

**Table 8.1 Commonly employed abatement techniques that may be applied to treat emissions from biomass to energy facilities**

| Pollutant | Abatement type | Abatement Efficiency | Comments |
|---|---|---|---|
| Oxide of nitrogen ($NO_x$) ($NO + NO_2$) | Selective non-catalytic reduction (SNCR) | 30 – 50% | Involves the injection of reagents (usually ammonia or urea) into the flue gas stream. Some ammonia escapes (“slips”) in the emitted flue gases (7.6.3). |
| | Selective catalytic reduction (SCR) | 80-95% | Involves the injection of reagents (usually ammonia or urea) into the flue gas stream prior to a catalyst. Can only be employed in relatively clean gas streams e.g. after particle abatement, as otherwise the catalyst may become fouled and poisoned. Catalysts can be selected that can operate at a range of flue gas temperatures but can become coated and hence deactivated with ammonium salts such as chloride or sulphate if flue temperatures are sustained below around 180°C. $NO_x$ conversion efficiency increases with increasing catalyst operating temperature. |
| Note on $N_2O$ | | | Systems are available to oxidise $N_2O$ to $NO_2$ or NO. However, primary measures are often employed. For example maintaining FB combustion temperature above 950°C ensures almost complete oxidation of $N_2O$ to $NO_x$ (but general the higher the temperature, the more NOx is produced). |
| Sulphur dioxide ($SO_2$) and hydrogen chloride (HCl) | Wet scrubbers | >90% | Involves the injection of an alkaline reagent, usually aqueous sodium hydroxide into a reaction vessel where the reagents are mixed with flue gases to neutralise sulphur dioxide and/or hydrogen chloride. An aqueous effluent is produced however closed loop systems are available that enable precipitation of chlorides and sulphate as solid residues for recovery or disposal. Some waste water is released in order to maintain metal and chloride levels in the “loop” at a manageable level i.e. to prevent corrosion or fouling problems due to precipitation of pollutants in the system. |
| | Dry or semi-dry scrubbers | >80% | Involves the injection of an alkaline reagent, usually calcium oxide powder (dry) or as a slurry (semi-dry) into a reaction vessel where the reagents are mixed with flue gases to neutralise sulphur dioxide. A solid residue is produced. These scrubbers are usually installed upstream of fabric filters. A layer of largely unreacted lime builds upon the surface of the fabric filters and much of the neutralisation of acid gases occurs here. |

**Table 8.1 cont.**

| Pollutant | Abatement type | Abatement Efficiency | Comments |
|---|---|---|---|
| Particulate matter | Fabric Filters | >99.9% (PM10 and above) | Used across a wide range of industrial processes. Performance characteristics vary with the specification of the filter material. In general, the higher the flue gas temperature the higher the cost and specification of the fabric filters required. Can be used in conjunction with dry or semi dry scrubbing and carbon injection. |
| | Wet scrubbers | 90-98% | Venturi scrubbers can be almost as efficient as fabric filters and can also be used together with reagents to remove acid gases and metals. An aqueous effluent is produced which requires treatment and/or disposal. |
| | Electrostatic precipitators | >99% | ESPs have a high efficiency for particle removal even for smaller particles although for sub-micron particles they are not as efficient as fabric filters. In general ESPs are cheaper to operate than fabric filter devices but have a higher capital cost and are only cost effective for larger installations. ESPs do not work well on particles with very high electrical resistivity e.g. carbonaceous particles such as char and therefore cannot be used together with carbon injection techniques for heavy metals or dioxin removal. |
| VOCs | Catalytic oxidation | >90% | One catalyst may be used for reduction of $NO_x$ and destruction of dioxins and VOCs. Need a relatively clean gas stream, usually after particulate removal. No residues are produced. |
| | Thermal oxidation | >90% | Usually a gas-fired burner is installed to combust/further combust flue gases. Requires fuel input and results in further emission of $NO_x$ and $CO_2$. |
| Dioxins and furans | Activated carbon injection | >90% | Activated carbon commonly employed in many combustion processes and injected together with acid gas scrubbing reagents. A secondary benefit is removal of relatively volatile metals such as mercury from the flue gas stream. Needs to be used together with particulate abatement equipment and a hazardous solid residue is produced. |
| | Catalytic oxidation | >90% | Destruction efficiency increases with operating temperature which is generally required to be in excess of 100$^o$C. The catalyst can also destroy PAH & VOCs and the substrate can be doped to provide simultaneous $NO_x$ reduction. Restrictions on its use are per those given for SCR. No residues produced. |
| Heavy metals | Fabric filters | >99% solid phase | Some catalyst systems may be used for reduction of $NO_x$ and destruction of dioxins. Need a relatively clean gas stream, usually after particulate removal. Can be effective in flue gas streams at temperatures from 120$^o$C. Solid residues are produced. |

**Table 8.1 cont.**

| Pollutant | Abatement type | Abatement Efficiency | Comments |
|---|---|---|---|
| | Dry/semi dry scrubbers and fabric filters | >99% solid phase<br><br>35-80% Hg | Usually a secondary benefit from systems installed for acid gas scrubbing. The efficiency of abatement of the more volatile species (e.g. mercury) can be further enhanced by activated carbon injection upstream of the fabric filter. A solid residue is produced. |
| | Wet scrubbers | 90-98% particulate phase<br>30-50% Hg | Comments as provided for particulate matter abatement. Removal of vapour phase species can be enhanced through the use of two stage scrubbers e.g. one alkaline and one acidic or through the use of additives e.g. sodium hypochlorite for mercury removal. |
| Releases to water | | | |
| Principal sources:<br><br>Wet scrubber effluents<br><br>Ash removal (quench tanks)<br><br>Boiler condensate<br>Demineralisation &<br>Discharge of water steam cycle | See comments for wet scrubbers above<br><br>Settling tank to remove solids with aqueous discharge to sewer<br><br>Discharge to sewer but can be reused as quench water before discharge.<br><br>Sedimentation<br><br>Chemical treatment/precipitation<br><br>Filtration<br><br>Ion exchange | | |

# 9 IMPACT OF SITING

This chapter examines the significance of the environmental impacts associated with biomass plants, and explores the influence that siting of the plant and of upstream fuel cultivation and fuel processing activities may have on impacts. As previously the environmental impacts are examined using the framework of key indicators which the Agency has identified as allowing it to measure its performance in improving and protecting the environment.

In assessing the impacts from the power plant itself, a hypothetical 20 $MW_e$ straw, poultry litter and forestry plant, with typical plant characteristics have been considered. Emissions to air and water for these plant are based on data obtained from monitoring of plant in the UK where possible, and from other European plant, where no UK plant exist. These emissions have been assessed using the Agency's (draft) Horizontal Guidance Note, IPPC H1, Environmental Assessment and Appraisal of BAT (Best Available Techniques) (EA 2001*a*). This provides a methodology for 'screening' emissions from plant, and assessing whether they may be of significance.

The main environmental impacts identified potential mitigation options and implications for siting are summarised Table 9.1 and Table 9.2.

## 9.1 Effects on Quality of Life

### 9.1.1 Noise

A general discussion of noise issues associated with the establishment and harvesting of energy crops is given in Sections 7.1.1, 7.2.1 and 7.5.1. The Agency's horizontal guidance note H3 on noise (EA 2001b) gives guidance on how to establish the acceptability of noise, by comparing noise levels with benchmark values. These are calculated in accordance with BS4142, the Mixed Industrial Noise standard, which addresses the generation of additional noise by comparison with existing background levels. In effective terms, a 10 db(A) increase in noise over background levels is likely to draw complaint, while for a 5 db(A) noise increase the situation is more marginal.

Information on noise levels from cultivation and harvesting of forestry residues and SRC is given in Appendix 1. The noisiest operations are the harvesting and chipping operations, where, depending on the crop and harvesting technique used, noise levels at the stand edge could be between 70 and 107 dB(A) (under a worst case scenario). Noise levels associated with Short Rotation Coppice are generally lower than those associated with single stem or modified conventional forestry. For comparative purposes, Table 9.3 lists the noise levels produced by a range of common daily tasks and situations.

Table 9.4 summarises the distances over which the noise from machinery used in cultivation and harvesting activities could be considered to be an annoyance. As suggested above, this is taken as 10 dB(A) over background for rural areas, with a more stringent criteria of 5dB(A) over background taken for isolated areas where the background level is lower. In isolated areas, (occasional small farms, roads and tracks) the noise from harvesting and chipping could be considered an annoyance over a considerable distance.

**Table 9.1 Summary of potential environmental impacts and siting issues - cultivation and harvesting**

| Category | Ref | Source/cause | Significance of Impact and Mitigation Options | Siting Issues |
|---|---|---|---|---|
| Noise | 9.1.1 | Harvesting of SRC and forestry residues | May cause a disturbance over a limited local area (<1km at maximum) for short periods of time | Most intrusive in isolated rural areas with low background noise levels. |
| Odour | 9.1.2 | Sludge spreading on SRC | Minimise impact by following good practice guidelines for application of sludge to agricultural land | |
| Traffic | 9.1.3 | Establishment and harvesting of energy crops | Impact likely to be low- comparable to traffic movements from traditional farming | |
| Visual impact | 9.1.4 & 7.1.1 | SRC stands | Stands of SRC may be intrusive in some landscapes. Good practice guidelines available. Mitigation possible by use of screening, and introducing variation by use of different species, and having adjoining stands of different ages | SRC usually relates well to existing features in lowland areas. Particular care needed in open, upland areas. |
| Water quality | 9.3 & 7.2.5 | Harvesting of SRC<br><br>Harvesting of forest residues<br><br>Storage of biomass | Leaching losses low as root mass remains<br><br>Reduced nutrient leaching but increased run-off and increased sedimentation; minimise increased flood risk by ensuring large areas not all harvested at same time<br><br>Potentially polluting leachate from run-off | Possible increase in potential flood risk in sensitive catchment areas<br><br>Careful choice of storage sites necessary to avoid run-off to local streams |
| Soil quality | 9.4 | Fertilisation of SRC with sewage sludge | Potentially high levels of heavy metals in sewage sludge; mitigate by applying suitable guidelines, such as the limits given in the Sludge (Use in Agriculture) Regulations 1989 | |

**Table 9.2 Summary of potential environmental impacts and siting issues - power plant**

| Category | Ref | Source/cause | Impact and Mitigation Options | Siting Issues |
|---|---|---|---|---|
| Noise | 9.1.1 | Generation plant | Unlikely to cause disturbance if appropriate measures in place e.g. acoustic enclosures and louvres (see report for more details) | Noise likely to be of similar level to other operations if sited in light industrial area. Noise may cause more of a disturbance in rural areas depending on proximity of residential areas, but should not e at unacceptable levels If mitigation options in place. |
| Odour | 9.1.2 | Unloading at poultry litter plant<br><br>Use of drier (e.g. rotating drum) at SRC/forestry plant | Avoid odour problems by good management including sheeting lorries and using contained unloading area under negative pressure.<br>Use of heat recovery unit for exit gases can condense VOCs and prevent odour | Site downwind of any nearby residential areas to avoid potential problems<br><br>Site upwind of any nearby residential areas to avoid potential problems |
| Traffic | 9.1.3 | Delivery of fuel to plant | Increases in noise, vibration and congestion will be important issue at local level; other impacts include increase in emissions of local and global air pollutants.<br>On minor roads increase in HGV movements can be significant (about 30-80% depending on fuel type). Impacts can be minimised by requiring delivery vehicles to use main roads and limiting delivery hours | Siting near good road access and transport links will minimise impacts.<br><br>Energy used in transporting fuel is small (~5%) compared to energy (electricity) produced, but ratio will improve further if plant can be sited so that heat produced can also be used. |
| Visual Impacts | 9.14 | Plant buildings and stack<br><br>Plume if wood drier used at SRC plant | Mitigate visual impact by using screening, sinking buildings into ground to reduce height, and painting buildings appropriate colour | Additional care needed to mitigate impacts in rural areas; impacts likely to less in light industrial area.<br>Impact of plume may be significant in rural/picturesque areas |
| Emissions to air | 9.2.1 | Stack emissions from generation plant | ***Air quality*** – emission of $NO_x$ and VOC (all biomass plant), $SO_2$, particulates and Cd from straw and poultry plant, HCl and mercury, (straw plant) and lead (poultry plant) are potentially significant[11]<br><br>***Deposition to soil***: emissions of Cd and Hg (straw plant) are potentially significant[11]<br>***Climate change:*** $CO_2$ emissions from biomass combustion are regarded as short cycle carbon and do not contribute to climate change; emissions of other greenhouse gases and of | $NO_x$ (and possibly other pollutants listed) need to be investigated on a site specific basis, e.g. using dispersion modelling, particularly if background pollutant levels are already close to air quality standard limits (urban or semi-urban environments), or site is particularly close to sensitive ecosystems.<br>Increased transport distances (e.g. due to re-siting to mitigate other impacts) will increase greenhouse gas emission but these will still be significantly lower than emissions from a modern gas fired generation |

[11] Typical emissions from plant were assessed using the methodology in the Agency's Environmental Assessment and Appraisal of BAT in Horizontal Guidance Note H1 (Environment Agency, 2001a) emissions which are > 1% of the appropriate environmental benchmark are assessed as potentially significant and warrant further investigation

| | | | | |
|---|---|---|---|---|
| | | | $CO_2$ from other stages of the fuel chain are significantly (over an order of magnitude) lower than emissions from a modern gas fired generation plant | plant |
| Water Quality | 9.3<br>7.6.5 | Releases from plant | Main source of pollutants in releases is boiler blow down and water treatment. | Emissions should be prevented or treated prior to release. Receiving water bodies should be of size and flow adequate to disperse and dilute discharge, i.e. discharge to small rivers and streams should be avoided |
| Waste disposal | 9.4 | Ash | Ash reused as fertiliser can contain heavy metals as well as valuable nutrients; no current legislation prescribes limits for heavy metals content, but existing and proposed legislation on sewage sludge application could be used as a guide | Appropriate limits should be set for heavy metal concentrations in any ash used as fertiliser. |

**Table 9.3 Typical sound levels in everyday situations**

| Situation/ Noise Source | Sound level (dB(A)) | Average subjective description |
|---|---|---|
| 30 m from a military jet aircraft take off | 140 | Painful, intolerable |
| Pop concert | 105 | |
| Passing heavy goods vehicle at 7 m | 90 | Very noisy |
| Ringing alarm clock at 1 m | 80 | |
| Domestic vacuum cleaner at 3 m | 70 | Noisy |
| Business office | 60 | |
| Normal conversation at 1 m | 55 | |
| The reading room of the British Library | 35 | |
| Bedroom in a quiet area with the window shut | 30 | Very quiet |
| Remote country location without any identifiable sound | 20 | |
| Theoretical threshold of hearing | 0 | Uncanny silence |

EA 2001b.

**Table 9.4 Noise from energy forestry**

| **Type of Energy Forestry** | **Activity** | **Distance over which annoyance is experienced** |
|---|---|---|
| Coppice (rural area) | Site preparation, planting, maintenance<br>Harvesting and chipping | 40-80 m<br>180 m |
| Single Stem (isolated area) | Site preparation, planting, maintenance<br>Harvesting and chipping | 180-320 m<br>1km+ |
| Single Stem (rural area) | Site preparation, planting, maintenance<br>Harvesting and chipping | 60 m<br>180-650 m |
| Modified conventional forestry (isolated area) | Site preparation and maintenance<br>Harvesting and chipping | 120-170 m<br>1km+ |

Derived from ERL 1987a

No data was available on noise emissions from existing biomass power plants in the UK, although some anecdotal evidence is available from Local Authority Environmental Health Officers in the vicinities of the plant, and this is discussed below. Noise emission limits set for the Värnamo power plant in Sweden are available, and in lieu of other data are taken as typical of noise levels from biomass plant:

- daylight hours (weekdays 0700-1800) - 50 dB(A),
- evenings (1800-2200) and daylight hours (Sundays and public holidays) - 45 dB(A)
- remainder of the night - 40 dB(A).

The limit for daylight levels fall below the World Health Organisation (WHO) threshold for outdoor noise of 55 dB LAeq, a level below which few people are seriously aggravated by the magnitude of noise produced (WHO 1999). It should be noted that over half the homes in England and Wales are exposed to noise levels exceeding this level. The WHO has also recommended that for negative effects on sleep to be avoided, noise exposure should not exceed 30 dB LAeq. The permitted night-time limits for the Swedish plant is greater than this (at 40 dB(A)).

Specific measures that can be used to reduced noise from the generation plant include acoustic enclosures, acoustic louvres, noise barriers, internal acoustic panelling and lagging, vibration and impact deadening, attenuators, steam and air diffusers and inertia bases (EA 2001*b*).

Discussions with environmental health officers from local authorities responsible for overseeing the operation of two UK poultry litter biomass plants revealed that very few complaints had been received concerning noise at either of the plants. The location of the plants on light-industrial estates was identified as a major factor for this, with operational noise of the plant being seen to 'fit in' with the general noise from the estates as a whole. It was also remarked that on the few occasions when noise complaints had been received for one site, it had been impossible to ascribe the noise as having been due to solely the operation of the plant. In the case of the Ely straw burning plant, several complaints were received concerning the operational noise of a stack-fan designed to propel flue gas up the stack. This has now been housed in an acoustic housing which appears to have largely resolved the problem. Infrequent complaints have also been recorded at Ely concerning the loud report caused by the operation of a steam pressure safety valve. This only operates when an operational failure causes excessive pressure to build up within the system, and so is a rare occurrence.

The establishment and on-going meetings of a local liaison committee were also seen as particularly valuable in resolving problems. Such committees are typically comprised of representatives from local residents, parish, town and district councils, Environment Agency and plant management, and allow discussion of the plant's operations, monitoring of the plant's environmental record, opportunities for information on planned improvements to the plant or changes to operating practices and an opportunities for local residents to raise any issues they would like to see discussed or answered (Howes *et al* 2001, Petts and Leach 2000).

### 9.1.2 Odour

A general discussion of odour issues associated with the establishment and harvesting of energy crops is given in Sections 7.1.1and 7.6.1. Potential areas of concern are:

- poultry litter plant;
- sludge spreading on SRC;
- wood drying.

Odours from poultry litter plant can be controlled by careful management. Measures would include ensuring that lorries are sheeted, that lorries do not tip until doors in the tipping area are closed, having a lightly negative air pressure in the tippings/ storage area and using biofilters. Consultation with local authority environmental health officers confirms that virtually no complaints have been received concerning odour at two UK poultry litter plants, which appear due to both siting and management factors. Although both plants are situated on light industrial estates reasonably close to residential areas (within less than 3 km), the plant sites were selected so that these were not downwind of the usual wind direction. Past complaints concerning odour have only occurred as a result of a mechanical breakdown at the plant (e.g. to an extractor unit) in conjunction with a time when the wind was not in the prevailing direction.

Management factors include on-going compliance with standard good practice techniques such as ensuring heavy goods vehicle loads are covered. Plant design was also identified as important, particularly with respect to a contained unloading zone, with sufficient negative pressure to minimise fugitive odour emissions. The building of additional commercial buildings downwind of the factory on the industrial estate where the (low) odour levels might cause future complaint was also identified as a potential issue.

Odours from sludge spreading on SRC will be similar to other operations where sludge is spread on agricultural land, and similar good practice should be followed.

Various techniques can be used for wood drying. The only one which may potentially lead to odour problems is if a proprietary drier, typically a rotating drum type, is used to dry the wood chips prior to combustion. In such dryers, the wood chips tumble though hot (110 to 150°C) combustion gases or air, and the steam resulting from the water in the chips boiling off exits the dryer with the combustion gases or air. The elevated drying temperature also raises the level of volatile organic materials in the drying gases. Although these are likely to be low and within regulatory limits they can give rise to unacceptable levels of odour. The gases exiting the dryer can be cooled in a heat recovery unit in which case the VOCs are likely to condense into the water, removing the odour problem.

Alternatively the wood chips can be left to dry in windrows or piles. Where these are naturally ventilated, some level of decay may occur, which could lead to some warming of the windrow and release of VOCs but odour from this has not been found to be a problem to date. Forced ventilation can be used to maximise drying and reduce decay. Finally if SRC is not chipped at the time of harvest, the sticks or billets (shorter lengths) can be stacked in windrows at the edge of the field, and left to dry naturally which would not present an odour problem. However, it is often more cost-effective to chip at the time of harvesting.

### 9.1.3 Traffic

***Potential impacts***

General traffic issues associated with the establishment and harvesting of energy crops are discussed in Section 7.4. Establishment of energy crops is likely to use conventional farm equipment, and traffic movements are likely to be similar to those associated with arable farming. Harvesting can be done using modified conventional farm machinery or, in the future as crop areas increase may be done using something like a modified cane cropper, which would be larger than existing farm machinery. The use of the latter may be more noticeable to the general public, but even so given the dispersed nature of SRC sites, and the limited period over which harvesting occurs should not lead to increases in traffic which are likely to be considered a nuisance.

The impacts from traffic movements associated with delivery of fuels to a biomass plant are however more significant. Table 9. shows the additional traffic movements associated with delivery of fuels to deliveries to a 20 $MW_e$ biomass plant are compared to average HGV movements on different types of roads in. For plants in rural locations, where delivery to the plant itself is likely to be on B (or even more minor) roads, this could lead to significant increases in HGV movements, particularly for forestry and poultry plant. Even greater increases could be expected from larger plant.

**Table 9.5 Estimated increases in HGV movements due to biomass fuel deliveries**

| | Plant type | | |
|---|---|---|---|
| | **Straw** | **Forestry** | **Poultry** |
| Deliveries/day/$MW_e$ | 1 | 2 | 3 |
| HGV deliveries per hour for a 20 $MW_e$ plant (based on deliveries over 8 hours) | 2.5 | 5 | 7.5 |
| Increase in HGV movements[A] | | | |
| Motorway | 2% | 5% | 7% |
| Trunk road | 4% | 8% | 12% |
| A road | 9% | 18% | 27% |
| B road | 28% | 55% | 83% |

[A] Based on existing estimated average movements/hour:

| | |
|---|---|
| motorways | 208 |
| trunk roads | 125 |
| A roads | 56 |
| B roads | 18 |

One delivery = 2 HGV movements; 1 delivery and 1 return journey

The additional vehicle movements lead to other effects. These include:

- *Increased noise levels*. The calculation of background noise levels, and additional noise sources, is an involved process. Noise emissions from traffic flows depend on the road surface, the traffic volume, the traffic composition (and especially the proportion of heavy goods vehicles), the speed, and other factors associated with the physical dispersion of noise. The calculation of the additional noise impact from heavy goods vehicles is complex. As there is a logarithmic relationship between traffic volume and noise, halving or doubling the amount of traffic will change the noise level by 3 dB, irrespective of the existing flow. However, in this case, the % increase estimated only applies to heavy goods vehicles, and therefore different increases will arise.
- *Increased vibration*. The vibration caused by vehicles falls into two regimes. There is ‘feelable’ ground borne vibration, which occurs at frequencies between around 1 to 80 Hz, and audible ground borne noise or “rumble”, caused by the vibration from vehicles leading to the fabric of a building vibrating at resonances and radiating sound to its interior, at around 25 to 250 Hz. The mass of the vehicle is very important in determining the vibration level – hence it is heavy goods vehicles that are primarily associated with vibration effects. Ground characteristics then determine the way in which the vibration propagates to roadside properties, but these characteristics are often very difficult to determine as ground is rarely homogeneous, can vary significantly from one site to another adjacent to it, and can vary from one occasion to another depending on water content, settlement etc.

- Increased emissions of transport related pollutants and potential impact on air quality.
- Increased congestion from extra vehicles. The extra number of vehicles will lead to congestion impacts on other road users. The assessment of these congestion effects is complex, being dependent on speed-flow curves for the specific route of the vehicle. It is likely that these effects will be most important for busy roads along the route. If delivery routes are along minor roads, then there may be a risk of bottlenecks, which will lead to increased congestion and risk of accidents.
- *Increased accidents*. The increased vehicle kilometres driven are likely to lead to a greater number of accidents (though the relationships between additional vehicle movements and accident rates are complicated by speed-flow relationships).
- *Community severance and the physical presence of heavy goods vehicles*. Community severance arises when roads bearing high levels of traffic cut through housing areas. The physical presence of the traffic, particularly heavy goods vehicles, as well as the risk of accidents presents a barrier to the community, limiting or disrupting interpersonal networks and reducing social contact.

In summary, the impacts most likely to be of concern at a local level are noise, vibration and congestion.

***Experience from existing plants***

Environmental health officers from local authorities responsible for overseeing the operation of two exiting poultry litter plants in the UK have received no complaints concerning traffic. In both instances this is believed to be due to appropriate siting of the plant. Both are located on light industrial estates on by-passes, and the extra vehicle movements arising from operation of the plant have not been deemed significant by the local community. In the case of the Ely straw-burning plant, comment at the local liaison committee about the extra HGV movements observed after commissioning of the plant led to the plant management requiring transport operators to travel along main roads avoiding small villages. In conjunction with the use of limited delivery hours, this appears to have effectively resolved the problem. Netting on straw loads was also introduced after problems with straw residues escaping during transport and littering roads around the plant. Again, this seems to have largely solved the problem.

***Energy use during transport***

Concerns are sometimes raised that the energy used to transport biomass fuels can be significant compared to the electricity generated by the plant. However estimates for typical plant and transport distances (30 miles) show, for example that the primary energy used to transport SRC is about 5% of electricity generated (derived from Matthews and Mortimer 2000). This percentage would be reduced if the biomass plant is sited somewhere where use can be made of the heat produced.

***Mitigation options***

The potentially large increase in HGV movements if minor roads are used for fuel deliveries (Table 9.) and the experience at existing UK plant, highlights the importance of siting the plant somewhere with good road access and transport links, if traffic impacts are to be minimised. Requiring delivery vehicles to use main roads where possible and limiting delivery hours may also alleviate impacts.

Use of rail for delivery of biomass is being examined, but there are several issues that need to be resolved. Of these the two most important are:

- a single biomass plant typically receives fuel form several dispersed sources; transport of the biomass will therefore require double handling; i.e. fuel must be transported by road to the rail depot, before transfer to rail for delivery to the generation plant.
- new infrastructure for handling of some of the biomass fuels would need to be developed.

### 9.1.4 Visual impact

Potential visual impacts from short rotation coppice were discussed in detail in Section 7.1.1 above. In summary, the visual impact of short rotation coppicing can be minimised by choosing the site carefully and by following good practice guidelines. For example, planting coppice of different ages in nearby field systems, so that large areas are not clear-harvested in any one season. The visual impacts of harvesting can also be minimised through the establishment of a permanent vegetation boundary either surrounding or screening certain areas of the harvesting site. Several rows of fast-growing pine or poplar species can be used for this purpose, or in the case of short-rotation coppicing, the coppicing itself can be used to create a boundary screen. Particular care may need to be taken in upland, open areas, where areas of coppice may be visible for longer distances and may make more of an impact on the landscape.

The visual impacts from the combustion plant would include those associated with any small-scale power plant, i.e. there may be visual intrusion from the stack (which is typically 30 to 50 m) and of surrounding buildings (typically 10 to 20 m maximum height). The impact of the stack and buildings is likely to be more significant in rural areas than in a light industrial setting e.g. in an industrial park on the edge of town it is unlikely to be deemed significant. For SRC plant, if a wood drier is used then steam entrained with gases leaving the dryer may cause a vapour plume in some atmospheric conditions; the significance of which will again depend upon the siting of the plant. In a rural area, particularly if the landscape is important for tourism, visible condensing plumes and plume grounding may be a serious issue.

Existing biomass plants have often been designed to minimise their visual impacts. For example, the Thetford poultry-litter plant is situated in a forested area, but the plant was designed to have a low visual impact on the surrounding area, being screened by trees on all sides. The boilerhouse was sunk into the ground to ensure that it does not exceed the height of the trees and the buildings have been painted dark brown to match the forest background. The poultry litter plant at Eye consists of a low-key steel structure with a curved roof, partially sunk into the ground and surrounded by landscaped embankments to reduce its visual impact. The height of the building does not exceed typical heights of parish churches in the neighbourhood.

## 9.2 Emissions to Air

### 9.2.1 Air quality

Emissions release data for a straw, poultry and forestry residue fired plant were collected, and from these, typical data for a 20 $MW_e$ plant of each type were estimated (Table 9.). Data are based on:

- straw - the Ensted (Denmark) power plant which is equipped with an electrostatic precipitator;
- poultry-litter - the Glanford (UK) power plant which is equipped with a bag filter and sodium bicarbonate abatement for acid gases;
- forestry residues - the Växjö (Sweden) power plant which is equipped with an electrostatic precipitator, flue gas condenser and a combination of SNCR & SCR for $NO_x$ control.

Monitoring data on biomass plant is still relatively limited and only one complete set of data was available for each type of plant. Only single values (rather than a typical range of values) can therefore be shown in Table 9. and subsequent tables. Actual emissions for any one plant will depend on feedstock characteristics (e.g. heavy metal content which in turn may depend on heavy metal concentrations of fertilisers such as ahs or sewage sludge applied to crops), characteristics of the combustion plant and pollution abatement equipment used. No published monitoring data was available for pyrolysis or gasification plant.

**Table 9.6 Estimated release rates (g/s) used in calculating air and deposition to land emissions for a 20 $MW_e$ straw, poultry and forestry residue plant**

| Pollutant | Straw plant | Poultry plant | Forestry plant |
|---|---|---|---|
| $NO_2$ | 0.196 | 0.303 | 0.111 |
| NO | 3.73 | 5.76 | 2.11 |
| $SO_2$ | 2.32 | 0.607 | 0.050 |
| Particulate matter | 0.036 | 0.183 | 0.015 |
| CO | 1.25 | 7.29 | 10.31 |
| VOCs | 0.550 | 0.637 | 0.207 |
| $N_2O$ | n.a. | n.a. | 1.43 |
| HCl | 0.892 | 0.091 | n.a. |
| Dioxins and furans | 4.46E-08 | 5.17E-10 | n.a. |
| PAHs | 3.21E-04 | n.a. | n.a. |
| As | 7.13E-06 | 2.06E-04 | n.a. |
| Cd | 1.07E-02 | 2.00E-03 | n.a. |
| Cr | 3.74E-05 | 1.38E-04 | n.a. |
| Cu | 8.02E-05 | 2.98E-04 | n.a. |
| Hg | 7.13E-03 | 3.34E-04 | n.a. |
| Mn | n.a. | 7.33E-04 | n.a. |
| Ni | 4.64E-05 | 1.10E-03 | n.a. |
| Pb | 5.53E-05 | 2.98E-04 | n.a. |
| Se | 2.67E-06 | n.a. | n.a. |

n.a.: not available

The potential impacts of these emissions was assessed using the BAT assessment methodology in the Agency's horizontal guidance note H1 (EA 2001*a*). The methodology is described in the Box below, but briefly it involves first assessing the 'process contribution' of emissions to concentrations of pollutant and then comparing it to an agreed environmental benchmark. Process contributions that are greater than 1% are assessed as warranting further investigation[12].

**Box 9.1 Environmental Assessment Levels (EALs) and Environmental Quality Standards (EQSs) in quantifying environmental impacts**

*'EQSs and EALs are benchmarks of environmental impact or harm. In assessing the impact of an installation against these benchmarks, consideration of the background contribution from other pollution sources should be taken into account. If a release from an IPPC installation constitutes a major proportion of an EAL, or makes a major contribution to a breach of an EAL then this may not be judged to be acceptable.'*

The Environment Agency guidance note suggests the process by which emissions should be compared to EALs or EQSs using screening correlations supplied. Predicted concentrations of emitted substances to air and water which are equal to, or exceed 1% of the relevant environmental benchmark are noted and for these emissions a decision whether further detailed modelling is required is based on the Predicted Environmental Concentration (PEC: Predicted concentration of emission + background concentration) using the following guidelines:

- *if the short-term PEC is above 100% of the relevant environmental benchmark (EQS or EAL) modelling of short-term emissions may be needed*
- *if the long-term PEC is above 70% of the relevant environmental benchmark (EQS or EAL) modelling of long-term emissions may be needed*
- *if there are any local receptors which are sensitive to any of the emissions identified then modelling of long-term and short-term emissions may be needed.*

The final step after detailed emission modelling is the identification of releases where the contribution from an installation would result in the EAL or EQS being breached. Such options are unlikely to be considered acceptable and should normally be ruled out of further consideration.

*EA 2001a*

Process contributions for emissions to air were calculated from the release rate of substances (where these were available) (Table 9.) and the supplied constants for long- and short-term unit mass emission rates. The calculations for air emissions assumed a stack height of 50 m for the plants and that this stack height was greater than 2.5 times the height of the nearest building within 5 horizontal stack heights. Table 9. shows that a number of pollutants: $NO_2$, NO and VOCs from all biomass plant, $SO_2$, particulates and cadmium for straw and poultry

[12] The screening calculations in H1 are conservative. The results provided here are guidelines only. The actual decision about whether more detailed modelling is required should be made on a case-by-case basis referring directly to H1.

plant, and HCl and mercury for straw plant, and lead for poultry are >1% of the environmental benchmark), particularly in the short term and thus warrant further investigation.

A further assessment was therefore carried out for these pollutants, by calculating the predicted environmental concentration (PEC) for each of them through the addition of the process concentration to the background concentration. This is then compared again to the benchmark value, and in this assessment resulting concentrations that are greater than the short-term benchmark value or 70% of the long-term benchmark value are noted.

Background concentration data was selected from the UK National Air Quality Information Archive for a rural site (Harwell[13]) and a semi-urban/light-industrial site (Brent), reflecting two possible contrasting plant locations. Where concentration data for specific pollutants at these sites was not available, typical values from comparable sites were selected either from the archive or from the Directory of Air Quality Data for the United Kingdom in the 1990s (Department of the Environment contract report PECD 7/12/182).

The only emissions which were notable in a semi-urban environment for the second stage of screening were the long-term releases of $NO_2$ (for all three plant types) and of cadmium from a straw plant. No emissions were above benchmark levels for plants situated in a rural environment. The percentage increases that the respective emissions would make to the background air concentration were also calculated and displayed in the summary table. While emissions of $NO_2$ were picked up by the second stage screening process, they caused an average increase in background concentrations of less than 5%.

In contrast, although not exceeding the benchmark threshold, the emission of HCl and VOCs from the straw-fired plant was nevertheless predicted to cause a relatively high percentage increase in the background air concentration at a typical rural site (increases of 54% and 30%, respectively). The percentage increase in HCl was similarly predicted to cause a 30% increase in HCl concentrations for a plant located at a semi-industrial site. The increases in cadmium and HCl emissions for a straw plant compared to the other plant technologies investigated is largely due to the relatively high cadmium and chloride contents of the raw fuel. Both these elements are physiologically taken up in relatively high amounts by wheat and barley crops, from which the straw is subsequently obtained. The examples described above show the reliance of the secondary screening process on the existing background air quality levels and how, in certain situations, emissions that do not cause benchmark levels to be exceeded can still cause a large percentage increase to occur with respect to existing air concentrations.

The screening suggests that $NO_x$ emissions from biomass plant would need to be investigated in a more detailed site-specific way, e.g. using dispersion modelling.

[13] While Harwell is closer to urban areas and other pollutant sources than some other rural monitoring sites, it was chosen for this exercise as a comprehensive data set on micropollutants is available, which is not the case for other more rural sites.

**Table 9.7 Summary of air emission assessment for straw (S), poultry (P) and forestry (F) plants for long- and short-term emissions**

| Pollutant | Initial screening: Process contribution (PC) as % of benchmark value | | | | | | Further screening: predicted environmental concentration (PEC) compared to benchmark value | | | | | | % increase in background concentration due to long-term emissions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long-term | | | Short-term | | | Long-term >70% | | | Short-term >100% | | | Rural site | | | Semi-industrial site | | |
| | S | P | F | S | P | F | S | P | F | S | P | F | S | P | F | S | P | F |
| **$NO_2$*** | 1.3 | 2.1 | <1 | 27 | 41 | 15 | $76^{+}$ | $77^{+}$ | $76^{+}$ | | | | 4.4 | 6.8 | 2.5 | 1.8 | 2.7 | 1.0 |
| **NO*** | <1 | <1 | <1 | <1 | 1.2 | <1 | | | | | | | 5.5 | 8.5 | 3.1 | 2.0 | 3.1 | 1.1 |
| **$SO_2$** | <1 | <1 | <1 | 18 | 4.7 | <1 | | | | | | | 21 | 5.5 | <1 | 16 | 4.1 | <1 |
| **Particulate matter** | <1 | <1 | <1 | 1.9 | 9.9 | <1 | | | | | | | <1 | <1 | <1 | <1 | <1 | <1 |
| **CO** | <1 | <1 | <1 | <1 | <1 | <1 | | | | | | | <1 | <1 | 1.4 | <1 | <1 | <1 |
| **VOCs** | 1.5 | 1.7 | <1 | 15 | 17 | 5.6 | | | | | | | 30 | 34 | 11 | 3 | 3.4 | 1.1 |
| **HCl** | 3.4 | <1 | n.a. | 3.4 | <1 | n.a. | | | n.a. | | | n.a. | 54 | 5.5 | n.a. | 30 | 3.1 | n.a. |
| **Dioxins and furans** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | <1 | <1 | n.a. | <1 | <1 | n.a. |
| **As** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | <1 | 2.1 | n.a. | <1 | <1 | n.a. |
| **Cd** | 58 | 11 | n.a. | 19 | 3.6 | n.a. | $77^{+}$ | | n.a. | | | n.a. | 608 | 114 | n.a. | 301 | 56 | n.a. |
| **Cr** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | <1 | 1.7 | n.a. | <1 | <1 | n.a. |
| **Cu** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | <1 | <1 | n.a. | <1 | <1 | n.a. |
| **Hg** | <1 | <1 | n.a. | 1.3 | <1 | n.a. | | | n.a. | | | n.a. | 1.3 | <1 | n.a. | <1 | <1 | n.a. |
| **Mn** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | n.a. | 3.9 | n.a. | n.a. | 2.0 | n.a. |
| **Ni** | <1 | <1 | n.a. | <1 | <1 | n.a. | | | n.a. | | | n.a. | <1 | 7.8 | n.a. | <1 | 5.9 | n.a. |
| **Pb** | <1 | <1 | n.a. | <1 | 1.6 | n.a. | | | n.a. | | | n.a. | <1 | <1 | n.a. | <1 | <1 | n.a. |
| **Se** | <1 | n.a. | n.a. | <1 | n.a. | n.a. | | n.a. | n.a. | | n.a. | n.a. | <1 | n.a. | n.a. | <1 | n.a. | n.a. |

Key: Significant; S - straw plant; P - poultry litter plant; F - forestry residue/SRC plant;
n.a.: data not available; + for a semi-urban/industrial site. A stack height of 50 m was assumed.
*Individual release rates for NO and $NO_2$ were not available, and so were derived from an available total $NO_x$ release rate. While at the point of combustion, NO typically comprise 5% of the emitted $NO_x$, NO is quite rapidly converted to $NO_x$. For this assessment it is assumed that by the time the plume reaches the position of maximum concentration, 50% of the $NO_x$ by mass is released is $NO_2$.

**Table 9.8 Summary of air emission assessment for straw, poultry and forestry plants for long- and short-term emissions in a pristine rural site (Narberth, Wales)**

| Pollutant* | Initial screening: Predicted concentration (PC) as % of benchmark value | | | | | | Further screening: predicted environmental concentration (PEC) compared to benchmark value | | | | | | % increase in background concentration due to long-term emissions | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Long-term | | | Short-term | | | Long-term >70% | | | Short-term >100% | | | Narberth site | | |
| | S | P | F | S | P | F | S | P | F | S | P | F | S | P | F |
| $NO_x$[a] | 3.5 | 5.5 | 2.0 | 53 | 82 | 30 | | | | | | | 11 | 17 | 6.0 |
| $NO_2$[b] | 1.3 | 2.1 | <1 | 27 | 41 | 15 | | | | | | | 8.8 | 14 | 5.0 |
| $SO_2$[a] | 3.1 | <1 | <1 | 18 | 4.7 | <1 | | | | | | | 13 | 3.3 | <1 |

Key: Significant; S - straw plant; P - poultry litter plant; F - forestry residue/SRC plant;
n.a.: data not available; a stack height of 50 m was assumed.

*Individual release rates for NO and $NO_2$ were not available, and so were derived from an available total $NO_x$ release rate. While at the point of combustion, NO typically comprise 5% of the emitted $NO_x$, NO is quite rapidly converted to $NO_x$. For this assessment it is assumed that by the time the plume reaches the position of maximum concentration, 50% of the $NO_x$ released is $NO_2$.

[a] $NO_x$ and $SO_2$ emissions were compared to the national air quality strategy objective for the Protection of Vegetation and Ecosystems.
[b] $NO_2$ emissions were compared to the national air quality strategy environmental benchmark for the Protection of Human Health

*Impact of siting*

The impact of siting a plant in a very rural area with high air quality is examined further in Table 9. for $NO_x$ and $SO_2$. Background concentrations for Narbeth in Pembrokeshire were used, and emissions of $NO_x$ compared to both the National Air Quality Strategy environmental benchmark and the more stringent objective for the protection of vegetation and ecosystems. Again, while the initial screening of emissions shows that $NO_x$, $NO_2$ (for all plant) and $SO_2$ (for straw and poultry plant) need to be assessed further, estimation of calculation of the predicted environmental concentration shows them to be below the values of concern.

*Effect of stack height on emission assessment*

The air emissions were calculated for all three plant types using an assumed stack height of 30 m to assess the effect a reduction in stack height would have on the predicted environmental concentrations described above that were based on a 50 m stack. In addition to the pollutants previously identified (Table 9.), the reduction in stack height caused the predicted concentration of several additional pollutants to exceed the initial emission screening criteria (>1% of the environmental benchmark) as shown in Table 9..

Of these additional pollutants, none proved to be above benchmark levels at the secondary emission screening stage (i.e. for all pollutants the predicted environmental concentration was less than 70% of the respective environmental benchmark for long-term emissions and less than 100% of the respective EAL benchmark for short-term emissions). However, the reduction in stack height did cause short-term $NO_2$ emissions for the poultry plant (originally identified as being above benchmark levels at the initial screening: Table 9.) to also be greater than benchmark levels at the secondary emission screening stage for both the semi-urban/industrial and rural locations.

**Table 9.9 Additional pollutants for which initial emission screening criteria were exceeded if the stack height was 30 m rather than 50 m**

| Plant type | Emissions | Pollutants exceeding initial screening criteria (% of relevant environmental benchmark) |
|---|---|---|
| **Straw** | long term | $SO_2$ (1.7) |
| | short term | NO (2.3) |
| **Poultry** | long term | CO (1.2); HCl (1.2) |
| | short term | CO (1.8); HCl (1.1); Ni (1.5) |
| **Forestry** | long term | $NO_2$ (2.5); CO (1.7); VOCs (1.9) |
| | short term | NO (1.3); $SO_2$ (1.2); particulates (2.4); CO (2.5) |

*Effect of conversion of NO to $NO_2$*

As discussed earlier, for combustion related $NO_x$ emissions at the point of release, 95% is typically NO and 5% is $NO_2$, but atmospheric chemical processes can mean that the emitted NO can be rapidly converted to $NO_2$. Under particular conditions all NO could be converted to $NO_2$ by the time the plume hits the ground, leading to higher $NO_2$ concentrations than assumed in the assessment for Table 9.. Assuming that all NO is converted to $NO_2$, then the process contribution from $NO_2$ would be greater than 1% of the environmental benchmark for all three types of plant (Table 9.). Whether these small increases would cause the secondary screening criteria for long-term emissions to subsequently be exceeded (>70% of the environmental benchmark) would be dependent upon the value of the background $NO_2$ concentration relative to the $NO_2$ benchmark value.

**Table 9.10 Long-term predicted concentrations (PC) as % of benchmark value for $NO_2$ assuming 100% conversion of NO to $NO_2$ and a 50 m stack height.**

| Plant type | PC as % of $NO_2$ benchmark value |
|---|---|
| Straw | 2.7 |
| Poultry | 4.1 |
| Forestry | 1.5 |

### 9.2.2 Deposition of air emissions to soils

Deposition of air pollutants to soils was also estimated according the H1 appraisal methodology (Table 9.) for straw and poultry plants and assuming for a 30 and 50 m stack height. No data was available for a forestry residue plant. This shows that there could be cadmium and mercury deposition from straw plants that could be >1% of the environmental benchmark and may need to be investigated further (via, for example, dispersion modelling) for any particular site. Similarly, while predicted ground concentrations of these two metals are lower from poultry plant, they would still potentially warrant more detailed examination. At a 30 m stack height deposition of arsenic, chromium may also require further detailed investigation.

Issues concerning heavy metal inputs to land from sources such as application of sewage sludge to SRC and of ash to land are discussed below in Section 9.4.

**Table 9.11 Summary of air to ground deposition assessment for straw (S) and poultry (P) plants**

| Pollutant | Predicted ground concentration as a % of the environmental benchmark value assuming a 50 m stack | | Predicted ground concentration as a % of the environmental benchmark value assuming a 30 m stack | |
|---|---|---|---|---|
| | Straw | Poultry | Straw | Poultry |
| As | <1 | <1 | <1 | 2.4 |
| Cd | 83 | 16 | 277 | 52 |
| Cr | <1 | <1 | <1 | <1 |
| Cu | <1 | <1 | <1 | <1 |
| Hg | 125 | 5.8 | 416 | 19 |
| Mn | <1 | <1 | <1 | 2.3 |
| Ni | <1 | <1 | <1 | <1 |
| Pb | <1 | <1 | <1 | <1 |
| Se | <1 | <1 | <1 | <1 |
| Zn | <1 | <1 | <1 | <1 |
| PAHs | <1 | n.a. | <1 | n.a. |

Key: Significant; n.a.: data not available.

### 9.2.3 Photochemical ozone creation potential

Photochemical ozone is a secondary air pollutant. The atmospheric processes causing the formation of ozone are highly complex and can involve a number of chemical species, with $NO_{x,}$ VOCs and CO being the principle players (see discussion box below). The actual contribution of process emissions to ozone formation is thus highly dependent on the location of the emissions, the background concentrations of the main pollutants involved in ozone formation and destruction at that location, and the time of year, and can only be determined accurately through detailed modelling. A rough estimate of the relative total photochemical ozone creation potential (POCP) of primary air pollutants such as $NO_x$, VOCs and $SO_2$ can however be calculated using the 'photochemical ozone creation potential' for each pollutant, to express their ozone creating potential in terms of g of ethylene equivalent. This is the approach taken in the H1 assessment methodology and is used here.

The photochemical ozone creation potential of each of the 20 $MW_e$ biomass plants over their lifetime (i.e. including emissions from fuel cultivation, processing and transport as well as combustion) were calculated (Table 9.) and are compared to emissions from a conventional gas fired CCGT plant on a g/kWh basis, and on an annual basis assuming an output of 160 GWh. All of the biomass plant have a significantly lower POCP than a gas fired CCGT plant due to higher $NO_x$ emissions. In urban areas, an increase in $NO_x$ emissions can lead to a lowering of ozone concentrations (as in these circumstances ozone concentrations are governed by VOCs), but it should be remember that $NO_x$ is a pollutant in its own right.

***Ozone Formation***

*Ozone is formed in the troposphere and the polluted boundary layer which extends from the ground to a height ranging between 100 and 3,000 m. The pollutant forms by the oxidation of VOCs and CO in the presence of $NO_x$ and sunlight. In the polluted boundary layer, the more reactive VOCs act as the main 'fuel' in this process whereas in remote areas the process is predominantly driven by $CH_4$ and CO oxidation. Ozone formation is usually limited by the availability of the catalyst NO.*

*The processes that result in these various patterns of ozone concentration are highly complex. In polluted urban environments for example, freshly emitted NO can immediately combine with ozone and reduce its concentration. Because of these and other reactions chemical reactions, a decrease in $NO_x$ emissions can lead to an increase in ozone concentrations in cities. In these circumstances ozone concentrations are governed by VOCs and it is these that must be controlled to reduce ozone concentrations. In less polluted areas it is generally $NO_x$ emissions that must be controlled rather than VOCs.*

*EEA (1998)*

**Table 9.12 Photochemical ozone creation potential assessment of biomass and conventional gas fired plant**

| Pollutant | Emission (g/kWh) | | | | POCP (g ethylene equivalent/kWh) | | | |
|---|---|---|---|---|---|---|---|---|
| | S | P | F | CCGT | S | P | F | CCGT |
| **NO***  | 0.279 | 0.387 | 0.264 | 0.105 | -11.93 | -16.53 | -11.27 | -4.5 |
| **$NO_2$*** | 0.429 | 0.593 | 0.405 | 0.162 | 1.2 | 1.66 | 1.13 | 0.45 |
| **$SO_2$** | 0.452 | 0.132 | 0.069 | 0.001 | 2.17 | 0.63 | 0.33 | 0.005 |
| **VOCs**** | 0.124 | 0.163 | 0.117 | 0.135 | 5.74 | 7.55 | 5.43 | 6.26 |
| **Total** | | | | | -2.82 | -6.68 | -4.37 | 2.22 |
| Annual Emission for 20 $MW_e$ plant (kt ethylene eq)+ | | | | | -4.3 | -6.4 | -4.3 | -1.1 |

*Total $NO_x$ by mass was assumed to be 50% NO and 50 % $NO_2$
**Total VOCs (as gC): a speciated breakdown was not available so emissions were assumed to comprise a mixture of representative light hydrocarbon species typical of those formed in combustion processes: ethane (30%), propane (30%), ethylene (15%) formaldehyde (15%) and acetaldehyde (10%). VOCs arising directly from wood during storage, chipping or drying are not included as no estimate of these emissions could be found.
+assuming 8,000 h/a operation

### 9.2.4 Climate change

The relative greenhouse gas emissions and global warming potential (GWP) associated with a kWh of electricity generation from biomass plants is shown in Table 9. together with emissions from a conventional gas fired CCGT plant. These emissions have been assessed on a life cycle basis, i.e. emissions from fuel cultivation, harvesting and fuel processing, transport and combustion are included, and in the case of the gas plant, those associated with natural gas extraction and transport. For each of the greenhouse gases emitted from the plants, an index was constructed that was calculated by establishing the annual release of each gas released from the process to air and multiplying by a factor for the 100-year global warming potential of that gas, as set out in the H1 Guidance note (EA 2001*a*). The GWP of a gas is defined as the cumulative radiative forcing between the present and a future time 'horizon' caused by a unit release relative to a reference gas, in this case $CO_2$ (IPPC 1996). The total climate change impact of emissions from the biomass plants is only 2 to 8% of the gas fired CCGT plant. A breakdown of the emissions from each stage of the fuel cycle for each of the three plants is shown in Table 9..14, Table 9..15 and Table 9..16.

Figure 9.1 shows a comparison of the total emissions from the fuel cycle for each of the three biomass plant types.

**Table 9.13 GHG emissions from biomass and conventional gas-fired plant**

| | Emissions over all fuel stages: g pollutant/ kWh | | | | Emissions over all fuel stages: g $CO_2$ equivalent/ kWh | | | |
|---|---|---|---|---|---|---|---|---|
| | **S** | **P** | **F** | **CCGT** | **S** | **P** | **F** | **CCGT** |
| **$CO_2$** [*] | 12.7 | 9.4 | 29.2 | 390.3 | 12.7 | 9.4 | 29.2 | 390.3 |
| **$CH_4$** | | | | 0.192 | | | | 4.0 |
| **$N_2O$** | | | 0.0003 | 0.001 | | | 0.1 | 0.3 |
| **Total** | | | | | 12.7 | 9.4 | 29.3 | 394.6 |
| Annual Emission for 20 $MW_e$ plant (kt $CO_2$ eq)[+] | | | | | 2.0 | 1.5 | 4.7 | 63.1 |

[*]excluding biomass $CO_2$ (this effectively has a GWP of zero)
[+]assuming 8000 h/yr operation
S= straw, P = poultry litter; F = forestry residues. For straw and forestry residues a 100km round trip is assumed.

**Table 9.14 Emissions associated with the straw to energy fuel cycle**

| | Straw – Emissions (g/kWh) | | | | |
|---|---|---|---|---|---|
| | **Collection** [a] | **Transport** [a] | **Plant manufacture**[a] | **Combustion**[b] | **Total** |
| **Non-biomass $CO_2$** | 4.6 | 5.5 | 2.6 | | 12.7 |
| **$NO_2$**[*] | 0.037 | 0.035 | 0.004 | 0.353 | 0.429 |
| **NO**[*] | 0.024 | 0.023 | 0.003 | 0.230 | 0.280 |
| **$SO_2$** | 0.006 | 0.008 | 0.021 | 0.417 | 0.452 |
| **VOCs** | 0.016 | 0.009 | - | 0.0989 | 0.124 |

[a] ETSU 1997. Values assume a 100km round trip to a combustion plant. Round bales are assumed.
[b] Combustion emissions derived from estimated release rates (Table 9.) assuming a 20 $MW_e$ plant operating for 6500 h/yr.
* The total $NO_x$ release rate available was assumed to comprise 50% NO and 50% $NO_2$.

**Table 9.15 Emissions associated with the poultry litter to energy fuel cycle**

| | Poultry litter – Emissions (g/kWh) | | | |
|---|---|---|---|---|
| | Transport [a] | Plant manufacture[a] | Combustion[b] | Total |
| Non-biomass $CO_2$ | 6.8 | 2.6 | | 9.4 |
| $NO_2$* | 0.04 | 0.004 | 0.546 | 0.59 |
| NO* | 0.028 | 0.003 | 0.356 | 0.387 |
| $SO_2$ | 0.002 | 0.021 | 0.1093 | 0.132 |
| VOCs | | | 0.152 | 0.163 |

[a] ETSU 1997

[b] Combustion emissions derived from estimated release rates (Table 9.) assuming a 20 $MW_e$ plant operating for 6500 h/yr.

* The total $NO_x$ release rate available was assumed to comprise 50% NO and 50% $NO_2$.

**Table 9.16 Emissions associated with the forestry residue to energy fuel cycle**

| | Forestry residue– Emissions (g/kWh) | | | | |
|---|---|---|---|---|---|
| | Chipping[a] | Transport[a] | Plant manufacture[a] | Combustion[b] | Total |
| Non-biomass $CO_2$ | 20.6 | 6.0 | 2.6 | | 29.2 |
| $NO_2$* | 0.165 | 0.036 | 0.004 | 0.200 | 0.405 |
| NO* | 0.108 | 0.023 | 0.003 | 0.130 | 0.264 |
| $SO_2$ | 0.028 | 0.011 | 0.021 | 0.0091 | 0.069 |
| VOCs | 0.07 | 0.009 | - | 0.0373 | 0.117 |

[a] ETSU 1997. Integrated harvesting and 100km round trip to combustion plant are assumed.

[b] Combustion emissions derived from estimated release rates (Table 9.) assuming a 20 $MW_e$ plant operating for 6,500 h/yr.

* The total $NO_x$ release rate available was assumed to comprise 50% NO and 50% $NO_2$.

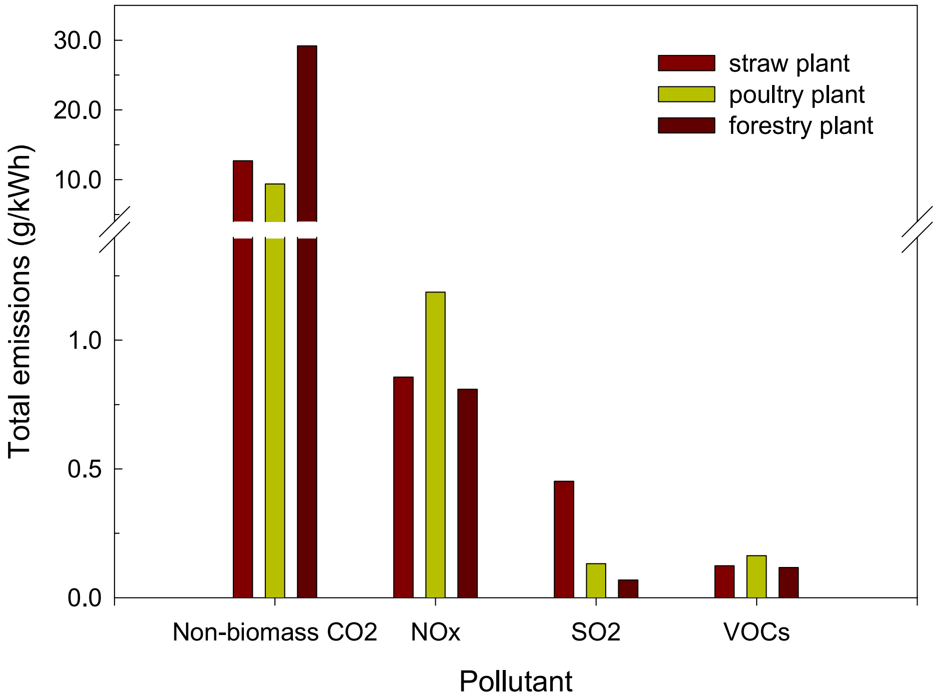


**Figure 9.1 Comparison of total fuel cycle emissions for the three biomass plant types**

***Impact of siting***

The main impact of siting would be to alter the transport distances for the biomass fuels. In Table 9., with an assumed round trip distance of 100 km, transport accounted for 43%, 72.3% and 20.5% of the total greenhouse gas emissions for the straw, poultry litter and forestry residue plants, respectively. The total increased emissions caused by a doubling of the transport distance to 200 km for the respective plant types are shown in Figure 9.2 below. Although the increased transport distance does lead to relatively large percentage increases in emissions, the absolute emissions are still very much smaller (by approximately an order of magnitude) than conventional CCGT emissions.

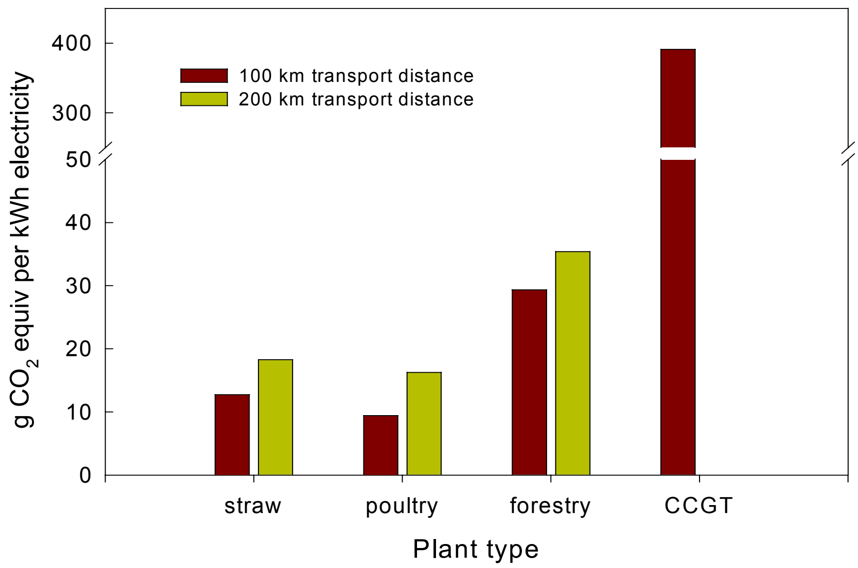


**Figure 9.2 Increase in total g $CO_2$ equivalent per kWh electricity generated caused by a doubling of fuel transport distance from 100 km to 200 km**

## 9.3 Water Quality

General considerations concerning the impact of cultivation, harvesting and storage of biomass on water quality and water resources are described in a number of previous sections of this report (Sections 7.2.5, 7.2.7, 7.3.3, 7.6.5 and 0).

In summary,

- cultivation of SRC and miscanthus should lead to lower erosion rates and nutrient leaching than for arable crops and could therefore lead to an improvement in water quality;
- the high water use levels for SCR and miscanthus mean that large scale planting may effect stream flows and ground water charging rates;
- nutrient leaching after harvesting of SRC and energy grasses will be low as the established root system takes up nutrients;
- in some soils the removal of forest residues can lead to increased erosion and sedimentation, but reduced nutrient leaching;
- harvesting of forest residues and energy crops can lead to increased run-off and in sensitive areas could increase the potential flood risk;
- some potentially polluting leachate can occur from biomass stores.

Further work on the environmental impacts of forest residue removal is currently being carried out for the DTI. The main issues for siting from the fuel cultivation stage are therefore:

- in drier areas, where ground water recharge is important in the catchment area, the impacts of large scale planting of energy crops need to be carefully considered;
- in sensitive catchment areas, consideration should be given to the potential increase in flood risk if a large area of the catchment is under plantation and is harvested at one time. Potential effects could be mitigated by ensuring that for SRC stands in the area are of different ages, and are therefore harvested at different times;

- ensuring that sites for biomass stores are chosen so that leachate cannot pollute local streams.

For the purposes of quantifying specific emissions to water from generation plant, detailed data on releases to water was only available for a poultry litter plant (Thetford) and was based on the monthly release data reported to the Environment Agency. The recorded flow to water was 21 $m^3$/d. The releases to water were comprised of treated boiler blowdown, drainings and condensate, effluent from the water treatment process and surface water runoff. It seems likely that main contribution to the pollutant in the effluent comes from boiler blowdown and water treatment and is unlikely to be significantly different from effluents from any boiler.

There is little data currently available concerning the emissions to water for plants using alternative biomass fuel sources (e.g. straw, forestry residues etc.) or for the impacts on water quality caused by different stages of the process e.g. water run-off from stock-yards or from other conversion processes such as pyrolysis. Future research could address this lack of information.

Assessment of the Thetford data (Table 9.) shows that for rivers of typical water quality, the increase in pollutant concentrations from the discharge is negligible for the pollutants assessed. Where discharge is to very small rivers/streams, or where the dispersion/dilution would be less, impacts could of course be correspondingly greater.

**Table 9.17 Assessment of water releases from poultry plant**

| Pollutant | Release conc. (µg/L) | Predicted concentration (PC) in river (µg/l) | | Benchmark value (µg/l) | PC as % of benchmark | |
|---|---|---|---|---|---|---|
| | | release via sewer and sewage treatment | direct release to river | inland waters (annual mean) | release via sewer | direct release to river |
| **$NH_3$** | 250 | 0.030 | 0.030 | 21 | 0.14 | 0.14 |
| **Cd*** | 1 | 0.000 | 0.000 | 5 | 0.00 | 0.00 |
| **Cl** | 1,500,000 | 180.728 | 180.728 | 400,000 | 0.05 | 0.05 |
| **Hg*** | 0.5 | 0.000 | 0.000 | 1 | 0.00 | 0.01 |
| **$SO_4$** | 16,000 | 1.928 | 1.928 | | | |
| **Suspended solids*** | 20,000 | 1.446 | 2.410 | 25,000 | 0.01 | 0.01 |
| **BOD** | 4,400 | 0.530 | 0.530 | 3,000 | 0.02 | 0.02 |
| **Temp ($^o$C)** | 18 | 0.002 | 0.002 | 21.5 | 0.01 | 0.01 |
| **pH** | 7 | 0.001 | 0.001 | | | |
| **Oil/grease** | 3.6 | 0.000 | 0.000 | | | |

## 9.4 Waste Disposal

The Agency's horizontal guidance note H1 requires an assessment of waste hazard and disposal to be performed. As previously described in this report, the production of ash from the combustion processes will comprise a major portion of the solid waste from biofuel energy generation plants.

Disposal of ash from combustion processes is currently controlled under the Environmental Protection Act (1990). For ash not classified as hazardous material, a number of potential disposal pathways are available. Pulverised fuel ash from coal-fired plants has been used in a number of applications within the construction industry, including aerated concrete block manufacture, concrete products, structural fill, grouting of underground voids and as a partial replacement for cement in concrete. Furnace bottom ash is also used primarily in the manufacture of lightweight blocks. Such use reduces the need for quarrying of aggregates with its associated environmental impacts. The amount of ash that can be sold is governed by the demand from the construction industry, with any remaining unsold being disposed of in landfill sites.

The re-use of ash from biomass plants for construction purposes can be more problematic. This is largely due to the potential variable nature of the ash produced from the different fuel types, unlike the more homogenous nature of ash produced from coal combustion. Even within a single type of biomass fuel crop (e.g. straw, miscanthus), large variations can occur in its chemical constituency (and hence also in its physical material properties) which reflect the underlying differences in soil and growing conditions at different sites.

A number of power companies are conducting research into the re-use of ash from biomass crops, especially with respect to co-firing. Straw ash for example, is quite similar to that derived from coal, and a mixture of straw-coal ash can therefore potentially be used in construction applications. In contrast, wood ash has very different characteristics from coal, but on a mass basis produces relatively less ash. Therefore incorporation of a small fraction of wood (e.g. 5%) in a co-firing plant will produce an ash containing significantly less than 5% wood ash, and which can still be suitable for re-use in industrial applications.

Reference has already been made within this report to the possibilities of using ash as the basis of fertilisers. One of the most successful disposal pathways of ash from biomass plants has been in the application of the waste ash to land, which not only provides both a valuable waste disposal pathway (avoiding landfill) but a good source of major plant and soil nutrients.

The UK Thetford poultry litter plant recovers ash from both the furnace (bottom ash) and from the exhaust flue (via a baghouse filter), which is subsequently packaged and marketed as 'an environmentally friendly fertiliser' Fibrophos, rich in phosphates and potash, but nitrate-free. The UK Ely (straw) plant similarly states that its segregated ash streams are rich in potassium and phosphate salts and are also destined to form the basis of agricultural fertilisers, thus returning their nutrients to the soil.

A significant potential problem with the application of ash to land can be the build-up of heavy metals in the soil, which are persistent, bio-accumulative and toxic to micro-organisms, plants and animals in high doses. High concentrations of heavy metals can occur in ash due to the distillation-like process of combustion, where large amounts of raw materials containing low metal concentrations are reduced in mass by ashing, but the total amount of metal present has remained largely unchanged.

It is important that the concentrations of heavy metals in ash or derived fertilisers are regularly monitored to ensure that any subsequent inputs of heavy metals to soil are minimised. Although the UK Fertilisers Regulations 1991 No. 2197 (and subsequent Amendments) controls the formulation of fertilisers, there is currently no statutory instrument which limits the concentrations of, or sets maximum application rates specifically for the heavy metal contaminants in fertilisers. However, there are strong parallel issues concerned with ash and sludge disposal to land, with both materials containing valuable nutrients for soil and plant fertility, but both also capable of containing high concentrations of persistent and bio accumulative heavy metals.

In terms of soil protection, one possibility is to base guidance for applications to land of waste ash or fertilisers derived from ash products on the relevant UK regulations for sludge application to agricultural land.

General information concerning the application of sludge to land used to produce energy crops is given elsewhere in this report (Sections 4.2, 0 and 7.1.5). The European Commission Council Directive 86/278/EEC regulates sewage sludge applications to agricultural land throughout the EU. The Directive is implemented in the UK by the Sludge (Use in Agriculture) Regulations 1989, which specifies safe limits for metal concentrations in soil, as well as maximum annual addition levels. The regulations are supported by the DOE Code of Practice for Agricultural Use of Sewage Sludge. However, the proposed provisions of the EC draft Working Document on Sludge (EC 2000) set stricter thresholds than the 1986 Directive, for both the allowable maximum concentrations of existing heavy metals in soil to which sludge application is proposed, and for the concentrations and loading rates of heavy metals in the sludge itself (Table 9.18).

These controls are designed to protect soils from becoming too heavily loaded with metals, as has occurred in several instances through the application of contaminated sludges to land both in the UK and other European countries (e.g. Sweden). Crops grown on soil containing high concentrations of heavy metals generally accumulate higher concentrations of heavy metals than crops grown on non-contaminated land. If for agricultural food crops the higher concentrations subsequently exceed relevant food safety limits (e.g. EC Commission Regulation 466/2001 setting maximum levels for certain contaminants in foodstuffs) then the soil contamination will have effectively reduced the productive capacity of the land. A similar situation can occur for industrial biomass crops planted on contaminated sites, where the higher concentrations of heavy metals found in the crop can have subsequent repercussions for the suitability of the resultant ash to be used as a fertiliser.

**Table 9.18 Proposed limit values for concentrations and loading rates of heavy metals in sludge from the proposed EC Working Document on Sludge**

| Element | Limit values for concentrations in sludge (mg/kg dry-matter) | | Limit values for amounts of metals added annually to soil, based on a ten year average (g/ha/y) | |
|---|---|---|---|---|
| | Directive 86/278/EEC | Proposed | Directive 86/278/EEC | Proposed |
| **Cd** | 20–40 | 10 | 150 | 30 |
| **Cr** | - | 1,000 | - | 3,000 |
| **Cu** | 1,000–1,750 | 1,000 | 12,000 | 3,000 |
| **Hg** | 16–25 | 10 | 100 | 30 |
| **Ni** | 300–400 | 300 | 3,000 | 900 |
| **Pb** | 750–1,200 | 750 | 15,000 | 2,250 |
| **Zn** | 2,500–4,000 | 2,500 | 30,000 | 7,500 |

EC 2000

Appendix 4 contains examples of the chemical breakdown of ash from the straw, poultry litter and forestry residues. The variability in ash characteristics is clearly illustrated. Where data from the UK was not available, values for comparative purposes were obtained from other regions (e.g. wood residues from timber grown in the Great Lakes area) which may not be representative of the concentrations that would occur in UK-grown fuels.

Inspection of the available chemical analyses in Appendix 4 shows that in general, most heavy metals in the different ashes fall within the respective limit values for concentrations in sludge proposed in the Working Document on Sludge. However, maximum concentrations of cadmium, lead and zinc observed in wood samples from the Great Lakes region exceeded the respective proposed limits, as did the average cadmium concentration. Although not having a specified concentration limit in the sludge document, arsenic concentrations from the Great Lakes wood samples were also high and would be of concern were the ash to be spread onto land. The high levels of arsenic in the wood ash from these samples were presumably derived from the combustion of wood previously treated with arsenic wood preservatives. The samples from the Great Lakes region may not be representative of ash from UK biomass plant, as it is not known whether it included scrap wood which may be contaminated by paints and preservatives.

The product specification of the Fibrophos fertiliser produced from the UK Fibrowatt group of poultry-litter power plants gives a zinc concentration in the fertiliser of 3,000 ppm, slightly higher than the 2,500 ppm concentration limit value proposed in the Working Document on Sludge. As Fibrophos note, zinc is a valuable and necessary trace element, however, zinc deficient agricultural soils are rare in the UK.

Sludge applications to land are currently controlled in the UK by the Sludge (Use in Agriculture) Regulations 1989, which implements the European Commission Council Directive 86/278/EEC regulating sewage sludge applications to agricultural land throughout the EU. It should be noted that the definition of agriculture in the 1989 Regulation does not include industrial crops, but only commercial food crops.

However, guidelines for the application of sludge to industrial crops have been published (ADAS 2001), although no maximum concentrations of heavy metals in sludge or application loading rates are specified. Crops such as such as willow and poplar grown for coppicing, and miscanthus are permitted to receive applications conventionally and enhanced treated sludges, and untreated sewage sludge (only until 31/12/2005). Demonstrable audit procedures must be followed to provide evidence that no part of an industrial crop enters the food chain (e.g. for crops such as oilseed rape). Similarly, if land to which sludge has been applied is returned to food use, minimum time intervals are specified for the interval between the application of sludge to land and the harvest of any subsequent food crop.

In contrast, application of sewage sludge to plantation crops (short-rotation and plantations for growing energy crops) will be specifically controlled under the proposed provisions of the EC draft Working Document on Sludge (EC 2000). This document sets stricter thresholds than the 1986 Directive for both the allowable maximum concentrations of existing heavy metals in soil to which sludge application is proposed, and for the concentrations and loading rates of heavy metals in the sludge itself (Table 9.18).

# 10 ECONOMICS OF POLLUTION REDUCTION OPTIONS

## 10.1 Background

Biomass plant will be developed within an established electricity generation market. Consequently biomass developers face competition with conventional electricity generation from fossil fuels such as coal and natural gas, which are currently much cheaper fuels. In the heat market they face additional competition from oil and LPG. The basic costs of biomass fuel are higher than the costs of these fuels and the infrastructure for supply and conversion is not as mature. The Government has recognised this, and, in recognition of the role biomass can play in decreasing $CO_2$ emissions, has set up support mechanisms to provide a more even playing field. This chapter examines the economics of biomass use and the influence that requirements for emissions abatement may have on these economics. It also examines the sensitivity of the economics to factors such as load factor and fuel costs.

The analysis undertaken here used a model developed by AEAT specifically to examine the economics of biomass use. The results were used to examine the influence abatement techniques could have on these economics.

This model uses a discounted cash flow method[14] to examine all costs involved in the biomass-energy chain, including production, storage, drying, transport, fuel handling and conversion. Much economic data for biomass schemes is regarded as confidential. Consequently it is not possible to present complete cost breakdown for each type of biomass scheme. Where specific information is not available aggregated costs were used based on discussion with the industry and information from the literature. The model has been used in a number of projects within the UK and the EU and data from these projects has also been used.

In this report results are expressed in terms of the electricity price needed for the scheme to break even rather than in terms of profitability (see footnote below).

[14] Discounted cash flow analysis essentially involves calculation of discounted annual costs and income over the lifetime of the plant, allowing an estimate of the profitability of the plant. Using this approach, examination of the influence of abatement costs on the viability/profitability of the plant is possible. However, this analysis is not straightforward for biomass schemes at present for two important reasons. Firstly, there are few biomass plant in the UK at present (hence little data). More significantly at the moment, it is difficult to estimate annual income for the plant due to uncertainties about the electricity price for biomass under the Renewables Obligation (RO). As an example, the last two NFPA auctions (for non-NFFO renewable electricity) have resulted in prices of 2.61p and 6.52p/kWh respectively, showing how prices vary tremendously at present.

As a result of these uncertainties, the analysis undertaken for this report is based on the approach taken by DTI in the underlying analysis for the RO (DTI, 1999). This approach used typical capital and operational and maintenance costs to estimate the electricity price required to ensure the plant is economic at discount rates of 8% and 15%. The results provide an indication of the electricity price required to break even at these discount rates. This is the electricity price required to ensure that income covers all plant costs. Any price above this level allows a margin for contingency and profit. The analysis itself does not provide an insight into how much profit typical developments might make, as annual income is currently uncertain.

### 10.1.1 Factors influencing electricity price

Most current biomass plant in the UK are contracted under the non fossil fuel obligation (NFFO). These contracts provided for a set electricity price guaranteed for a set period. NFFO contracts allow the biomass plants to operate for the number of hours chosen by the project developer, i.e. the load factor is chosen by the developer. Thus they enabled the plant developers to take a clear view on the annual income for the plant. The most recent contracts provided for an average income of 5.51 p/kWh for a set period of 15 years (1997 prices). Gasification plant contracted under NFFO3 were contracted at an average price of 8.6 p/kWh (1994). The conditions contracted under NFFO for all current plant are given in Table 10.1. The figures in brackets give the prices normalised for 2001 using the retail price index issued by the Office of National Statistics. A number of these schemes in Table 10.1 are still not built (primarily because of problems with planning permission). Schemes contracted under NFFO will continue under NFFO but there will be no more Orders under NFFO.

**Table 10.1 Biomass plant contracted under NFFO**

| NFFO band | No of biomass schemes contracted | Lowest price contracted (p/kWh) | Weighted average price (p/kWh) | Highest price contracted (p/kWh) | Comments |
|---|---|---|---|---|---|
| NFFO 1 | 3 | - | 6 | - | Now out of contract |
| NFFO 2 | 1 | - | 5.9 | - | Not built |
| NFFO3 (1994) gasification | 3 (19 MW dnc) | 8.4 | 8.6 (10.8) | 8.7 | 15 year contracts |
| NFFO3 Non gasification | 6 (103.8 MW dnc) | 4.9 | 5.0 (6.16) | 5.2 | 15 year contracts |
| NFFO4 (1995) Biomass gasification or pyrolysis | 7 (67.33 MW dnc) | 5.49 | 5.51 (6.06) | 5.79 | 15 year contracts |
| NFFO5 (1997) | Biomass not included because a number of NFFO3 and 4 contracts not commissioned. | | | | |

Note: current (2002) electricity prices for coal and natural gas are 1.8 and 2p/kWh. The prices for coal are currently low and may be difficult to sustain.
Figures in brackets are for the electricity price in 2001 prices, calculated using the RPI.
Declared net capacity (dnc) is defined in the Electricity Act 1989 and modifications made in SI 1990 No. 624.

In 2001 new electricity trading arrangements (NETA) were launched. The intention was to increase competition and decrease prices to the consumer (particularly industrial users). Data from the electricity sector suggests there have been substantial reductions in wholesale electricity prices since the launch of NETA (Utilities Journal 2002). However, this has not been good for renewable electricity suppliers, because it has exposed them to considerable risk, particularly the risk of low electricity price for their generation, but the need to buy at peak price should they shortfall on their contracts. Some analysts have stated that NETA has inflicted serious damage to the prospects of renewable generators. Primarily this affects less flexible generators such as wind power, but the biomass industry is hit by low prices and is in a very poor negotiation position (Utilities week 2002).

From April 2002 a new support mechanism for renewable energy technologies has been introduced. This is the Renewables Obligation (RO) (The Renewables Obligation 2002), which is placed on the electricity supply companies. The RO is intended to increase the supply of electricity from renewable energy sources from 3% in 2003 to 10% by 2010. The Government has proposed to retain the RO to 2026.

The RO will oblige licensed electricity suppliers within the UK to supply a specified proportion of their electricity from renewable sources to their customers in the UK. If the supply companies are unable to meet this obligation, they will have to pay a buy out price. For the initial period this will be 3 p/kWh. Under the RO the receipts from the buy out will be recycled to ***supply companies*** in proportion to the quantity of renewable electricity they supply. Biomass schemes are included in the RO (see also section 6). It is not easy to speculate the precise implications for the biomass developer, but it is highly likely that they will obtain a premium price for their electricity under the RO[15].

Initially, while the redistribution of funds from the buy out is high, generators may also be able to negotiate a premium price based not only on the £30/MWh RO but on a share of the redistributed pay back from the buy out funds. There has been much speculation how much this payback will be worth, but if there is a significant shortfall on generation of electricity under the RO it could be important. It must be remembered that the payback goes to suppliers not generators. However, in a market where there is considerable competition to contract renewable electricity, generators are also likely to command some of the payback. How much of payback will come to biomass developers is not certain: it will depend on the negotiations between suppliers and generators and on how much renewable energy is available. This will vary with time, which means that annual incomes could be highly variable. To decrease the effects of such variability biomass developers may be willing to sacrifice some potential short-term income for a longer term contract. However, all of this is speculation and the real outcome will not be certain until the RO has been in operation for some time. What is probable is that developers in a more secure position, such as those that have the backing of big supply companies or those developing co-firing, will be most likely to be in the best position to develop biomass power schemes in the near future; and they will also be the ones who benefit from high redistributed paybacks. As a example, if little renewable electricity is generated, the funds recycled from the buy out could add as much as £15-30/MWh, such that the price received for co-fired electricity by a company that is both generator and supplier could be as much as the baseline price + the RO (£30/MWh) + the recycled payback (in this case £15-30/MWh). This then becomes a very attractive, if short-term option. Generation only companies will not fair so well, but should still have significant incentives. The main risk is that this is a peak price; the market is unpredictable and prices will decrease as more renewable power is generated. Table 10.2 provides an indication of the Government's targets for renewable power generation under the RO.

The climate change levy (CCL) may also bring positive news for biomass developers. The CCL is a "tax" collected by the supply companies for customs and excise. In an effort to

[15] This issue was discussed at a recent seminar on Renewable Energy Finance (run by the Renewable Power Association). This seminar concluded that the demand side of the market is not clear; the value of the ROCs cannot be easily predicted. In addition it is the "big" players that are going to be the ones who can enter the ROC market first. Small players will need to meet the demands of venture capital finance, which will demand a higher return. The electricity market is currently over-capacity, so there is a weak market for green energy.

maintain competitive prices, supply companies are likely to be eager to supply as much electricity as possible from sources that do not attract the CCL. These will include biomass electricity. It is probable that some (not all) of the CCL (currently set at 0.43 p/kWh) could be passed to biomass developers in the price they are paid for their electricity. (Note: some industries have achieved an 80% exemption for the CCL, reducing its potential value to 0.084 p/kWh).

**Table 10.2 Renewables obligation: % total electricity supply from renewable energy***

| Obligation period | % total supplies | TWh/y based on 2000 generation |
|---|---|---|
| 1/4/02 - 31/3/03 | 3 | 9.4 |
| 1/4/03 – 31/3/04 | 4.3 | 13.5 |
| 1/4/04 – 31/3/05 | 4.9 | 15.6 |
| 1/4/05 – 31/3/06 | 5.5 | 17.7 |
| 1/4/06 – 31/3/07 | 6.7 | 21.5 |
| 1/4/07 – 31/3/08 | 7.9 | 25.4 |
| 1/4/08 – 31/3/09 | 9.1 | 29.4 |
| 1/4/09 – 31/3/10 | 9.7 | 31.5 |
| 1/4/10 – 31/3/11 | 10.4 | 33.6 |
| Each subsequent 12 month period, ending on 31/3/27 | 10.4 | |

* As set out in the Renewables Obligation Order, 2002
Note: in reality electricity consumption has steadily increased over the past few years, so generation may increase with time. Generation from renewable energy in 2000 was 8.3 TWh/y.

### 10.1.2 Financing energy from biomass

***Availability of capital***

There are a number of ways of financing a project (DTI 2000b). In the UK for projects involving the generation of energy from biomass, financing is likely to be in one of five ways:

- **Project finance**. Here a loan is given to the project by a bank (or a number of banks). The loan is secured against the suite of contracts associated with the project and future project cash flows. This requires long-term secure contracts for all relevant aspects of the plant's operation e.g. fuel supply, heat or electricity contract, operating and maintenance contracts, etc.
- **On-balance sheet**. Finance is raised against a company's assets. Many energy from biomass schemes will cost several million pounds, so any company will need significant resources to raise finance through this route. Also the lenders ultimately have recourse to the developer's balance sheet should the income be insufficient to cover debt repayments.
- **Venture capital**. This is generally for projects that are perceived to be novel and have higher percentage risks but have high potential returns. This can be a hybrid between debt and equity. The cost of capital is generally higher than for other financing options.
- **Own resources**. Where a company developing a project has a strong balance sheet it can use this to finance the project. Individuals may also invest their own money in projects.
- **Government grants**. There are a number of government grants available in the UK at present. These include capital grants, planting grants for energy crops and support for supplier groups. Capital grants do not cover 100% of the costs. In addition there are

funds available from the EC for capital costs (Europa web site). Again these do not cover 100% of the costs and the project usually has to be novel within the EU context.

***Project finance***

Many banks have specialist units examining the finance of renewable energy projects, as part of their power sector investment portfolio. Although banks may be willing to loan up to 80% of the capital costs of a scheme they are familiar with, if there are higher risks (such as for the more novel advanced technologies) this percentage would decrease. The remaining 20% (or more) would be equity that the developers would provide from their own balance sheet or raise from other sources.

Many banks would be reluctant to consider projects worth less than £10M (although there may be banks with specialist portfolios that are willing to consider smaller projects). Currently there is no shortage of money for the loan for the "right" projects, but there are a number of reasons why biomass projects may not be considered the "right" projects:

- The value of many small-scale projects may be considered too low to be of interest to the banks. In some renewable energy sectors, such as wind, developers are packaging together a number of projects to increase the project value. This may be a solution for biomass schemes.
- Banks consider that the risks associated with relatively unproven technology make the project unattractive. This could well apply to pyrolysis and gasification schemes. It may be possible to use the insurance market (efficacy insurance) to insure plant incomes against under-performance to help satisfy the banks, but the developer will obviously have to pay the premium.
- Manufacturers of novel equipment are often unable to offer normal equipment guarantees in terms of performance (power output, efficiency, etc) or serviceability.

***On balance sheet***

Whilst this is simpler and often cheaper than project finance, it does require a developer with a strong enough balance sheet to cover the cost of the project. This can be practical in the case of small projects, and so may be available to some heat schemes or to small advanced conversion projects. It may also be feasible for co-firing schemes. However, many biomass developers do not have strong enough balance sheets to raise finance through this route. Those that do are only likely to have resources to develop one or two projects at a time.

***Venture capital***

Venture capital may be one of the few practical options for financing projects using some of the advanced conversion technologies.

### *Own resources*

A few companies or individuals will have sufficient resources and the willingness to fund the development of biomass pants themselves. This may be a route into finance itself. Once a plant has been built and has a successful track record technology risks will be reduced making project finance more feasible and the owner will have an asset against which on-balance sheet finance can be raised. It may also be the route chosen for co-firing of biomass.

Overall commercialisation of advanced conversion technologies for biomass is constrained by a lack of availability of capital. In many cases the projects are too small and perceived to be too risky for project finance and the companies and individuals involved in the technologies have limited resources to fund projects.

### *Government grants*

In addition to the RO, the Government has recently announced a bio-energy capital support scheme of £66 million (***see DTI web site***: www.dti.gov.uk). The purpose is to promote the efficient use of biomass for energy and, in particular, the use of energy crops by stimulating the early deployment of biomass fuelled heat and electricity generation projects. This scheme is aimed at delivering:

- a small number (~3-5) of substantially sized (>20 $MW_e$) installations that will convert energy crops and other biomass feedstocks to electricity with a high efficiency, using state of the art technology. Energy crops must make up at least 25% of the input fuel energy by the end of 36 months of commercial operation; by the end of 72 months they must make up at least 50% of the input fuel energy. The balance must be biomass and the electrical output must be eligible for ROCs;
- at least 10 $MW_e$ capacity with a preference for CHP at outputs >1 $MW_e$. Fuel input must be energy crops and/or forestry wood-fuel and/or agricultural by-products with a preference for energy crops;
- one or more commercially scaled demonstrations of advanced conversion technology, that will significantly improve the efficiency of conversion of energy crops to electricity and can look to commercial deployment in the sort to medium term. The fuel inputs must be on the same basis as the first category above;
- several examples of biomass heating/CHP projects or clusters that will create an initial market for equipment and services and stimulate rural economies. Fuel input must be energy crops and/or forestry wood-fuel and/or agricultural by-products with a preference for energy crops;
- a range of projects that will deliver learning benefits that will accelerate deployment in the future.

## 10.2 Methodology for Economic Assessment

The model used in this analysis was developed by AEA Technology specifically to examine the economics of the biomass energy chain. This model uses discounted cash flow to examine the influence of prices/costs on IRR (internal rate of return, the average return on investment in the project over the lifetime of the project). The model has been used in UK and EU projects.

The model allows capital/operating costs and given discount rate to be used to calculate electricity prices. This is similar to the analysis used in the background analysis for the RO. In that analysis discount rates of 8 and 15% were used and for consistency the same discount rates are used here. There is commonly a high financial risk associated with projects of this nature (primarily due to their perceived novelty) which means that discount rates would be expected to be high.

The capacity of projects to withstand increased costs resulting from the introduction of additional pollution prevention measures was considered, along with sensitivity to other factors such as grants/subsidies, reduced load factor and lower prices.

The results show predicted electricity price against percentage change in assumed values for capital costs, fuel price, availability and load factors. This allowed examination of the ability of the plant economics to withstand the additional capital and operating costs that would be associated with abatement costs. It also gives an insight into the influence of lower than expected load factors.

### 10.2.1 Input data for model

Costs for capital equipment, operation and maintenance (O&M), labour and fuel for generic 20 $MW_e$ biomass power plants were estimated from information available in the literature, on the internet and from personal communications (→ Appendix 6). Data from the UK was used, whenever available. This was supplemented with information from other (European) countries. The difficulty in using international data is that the average investment costs in different countries vary significantly depending on the national framework. Differences between countries include:

- national standards for technical design;
- environmental regulations;
- different concepts for load management (e.g. only biomass vs. additional oil boiler for peak loads);
- building design and construction;
- fuel storage (affected by e.g. the efficiency of logistics).

and many other issues, which all have an impact on capital and O&M costs. High capital costs due to investment in technical equipment may lead to lower O&M costs and better plant performance. Thus, in countries with high labour costs, a high degree of automation might be preferred to manual operation. In other regions where the cost of labour is low, automation may be considered unnecessary and the resultant capital cost is low. Raw data from the UK and abroad is presented in Appendix 6.

Capital, O&M, labour and fuel costs used for each generic plant are presented in the Table 10. below. The calorific value of the fuel and the conversion efficiency (to electricity as power production only was assumed) are also included.

**Table 10.3 Input data for the economic analysis for 20 $MW_e$ generic plant, used in this report**

| | biomass comb | poultry comb | straw comb | wood gasific | pyrolysis | co-firing |
|---|---|---|---|---|---|---|
| capital | £20m | £40m | £40m | £30m | £30m | £7m |
| O&M | £400,000 | £2m/y | £1.6m/y | £1.2m/y | £1.2m/y | £140,000 |
| rates and insurance | £320,000 | £560,000 | £560,000 | £440,000 | £440,000 | £160,000 |
| labour | £500,000 | £500,000 | £500,000 | £700,000 | £700,000 | £100,000 |
| fuel (delivered) | £40/odt | £5/odt | £30/odt | £40/odt | £40/odt | £48/odt |
| conversion efficiency | 30% | 25% | 25% | 35% | 35% | 30/35% |
| lifetime | 15 | 15 | 15 | 15 | 15 | 5 |
| operating hours | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 | 4,000 |

Comb= combustion. Gasif = gasification.
Conversion efficiency represents the conversion to electricity only.
Figures for co-firing are based on 20 $MW_e$ generation from biomass, operation until 2006 and a typical load factor of 4000 hours for current coal–fired plant. This load factor may be difficult to achieve over this timescale.
The figures for delivered fuel costs for wood assume that any SRC will receive grants from the energy crops scheme and that the crops are grown on set aside land for which the set aside payment is being received.

All plants are 20 $MW_e$. Where possible the costs have been set using available data on commercial plant (see Appendix 6 for such data). Where these costs are not available, they have been obtained through discussions with manufacturers and developers of similar plant. A view has been taken on the typical conversion factors for the matured technologies, from experience of these plants in the UK and abroad. The same is true for lifetime and operating hours. For biomass plant, lifetimes are not always available because some of the technologies have not been in use for that long. In this case a view was taken from plant operating on more conventional fuels. Fuel costs are in line with those quoted earlier in this report (→ 4.1).

For gasification and pyrolysis, capital cost and conversion efficiency are for matured technology. As there is no data on pyrolysis plants available and this technology will be competing with gasification, similar costs for these two plants were assumed (N Barker, F Dumbleton, Pers. Com). In this context matured technology means that the development phase has reached the stage where initial issues have been overcome and the technology is available “off the shelf”. Clearly, this is not the situation for gasification or pyrolysis, where the techniques are new and far from optimisation and where plant manufacturers are being cautious about guarantees of plant reliability or performance. Significant progress on the costs and performance of pyrolysis and gasification equipment is expected from lessons learned with early installations. To estimate the future costs for such plant a technique used in the petrochemical industry has been used. This uses a cost decay curve to estimate the ratio of the cost of the first to the tenth commercial installations. The future performance of plant is based on expectations of what is realistically achievable from the technology, once developed and optimised.

The figures for co-firing represent the additional costs arising when 20 $MW_e$ of the electricity is generated by co-firing biomass. The higher fuel price for co-firing allows further pre-processing either off-site or on-site, which is an essential requirement for all existing plant in the UK. The conversion efficiency of 30 to 35% should be typical of most co-firing. The lower operating hours are typical of operating conditions at current coal-fired plant and may be difficult to sustain.

The following values were kept constant for all plants:

- discount rate 8 and 15%
- land cost £0
- construction time 1y
- annual insurance cost 1.2% of equipment cost
- plant availability 68.5% (i.e. 6,000 hours), except for co-firing
- plant lifetime 15 years, except for co-firing
- rates £4k/$MW_e$

The plant capacity (t/h) was set so that the plant would generate 20 $MW_e$, under the conditions indicated in Table 10..

### 10.3 Results of Analysis for Generic 20 $MW_e$ Plant

The results indicate that electricity prices above 5.9 p/kWh are required for all biomass plant in order to achieve the IRR required. The exception to this is co-firing, where prices ranging between 5.0 and 5.8 p/kWh achieve the appropriate IRR (Table 10.). The price for electricity from coal was 1.8 p/kWh in 2001 (DTI 2001). If a ROC price of 3 p/kWh is added to this, it can be seen that the price of electricity from most biomass plant exceeds the market price including a ROC of 3p/kWh. However, if there is a substantial payment received from the redistribution of the buy out funds, this situation could be reversed, at least in the short term.

**Table 10.4 Results to economic analysis for generic plant described in Table 10.3**[16]

| | IRR % | Electricity price p/kWh |
|---|---|---|
| **Wood combustion (forest residues or SRC)** | 15<br>8 | 6.9<br>5.9 |
| **Poultry combustion** | 15<br>8 | 9.0<br>6.9 |
| **Straw combustion** | 15<br>8 | 10.8<br>8.8 |
| **Biomass gasification and pyrolysis** | 15<br>8 | 9.0<br>7.4 |
| **Co-firing efficiency 30/35%** | 15<br>8 | 5.8/5.3<br>5.4/5.0 |

[16] The price of electricity generated from coal was 1.8p/kWh in 2001 (DTI 2001)

### 10.3.1 Sensitivity analysis

***Capital cost***

It is difficult to separate abatement costs from the rest of the capital costs typically quoted for biomass schemes and biomass developers are reluctant to release such data. Abatement costs from the literature are often quoted as costs per tonne abated. However, it is rare to find data on the tonnes of emissions prior to abatement. These costs give no indication of the size of the plant and there is no reliable data comparing the costs of different techniques. Taking a view on abatement costs is difficult. In modern plant designed to ensure emissions do not exceed required levels it is easier to design in abatement as part of the combustion process and in back end abatement. In such plant the costs of bolt-on abatement may represent under 10% of the total capital costs. However, the total capital costs may be higher because of the cost of designing the combustion system to decrease emissions. This is a difficult cost to gauge. For plant already in operation the cost of adding on abatement can be much higher, as the plant would not have been designed with this in mind. The economic analysis assumes that the maximum cost of abatement would be 25% of the total capital costs, but in reality the +10% analysis will be more representative as techniques develop. The negative costs are there to represent the costs of designs that incorporate abatement as part of the system and represent a savings in capital cost over conventional plant with bolt-on clean up.

Ultimately the cost of abatement will depend on a number of plant specific factors such as the emissions without abatement, other abatement techniques employed at the plant, the fuel composition, combustion parameters (e.g. temperature, excess air ratio and residence times in particular temperature zones) and the design of the plant. In other words, each plant has to be assessed on a case-by-case basis. Table 10. discusses design approaches to abatement and the relative costs.

**Table 10.5 Relative costs of emissions abatement on biomass plant**

| Design for abatement | Costs (low cost or expensive) | Comments on abatement |
|---|---|---|
| **Conventional thermal conversion** | | |
| Advanced furnace design e.g. Fluidised bed | Low | Assists abatement of $NO_x$, CO, UHC |
| SCR | High | Removal of $NO_x$ (and CO?) |
| SNCR | High | Reduction in $NO_x$; usually plant specific. |
| ESP | Low | Removal of particulates. Relatively untested with biomass fuels. |
| Bag Filter | Low | Removal of particulates |
| Dry Scrubbing | Medium | Removal of sulphur (NB there is a knock on cost in decreased price for ash used for fertiliser)<br>Removal of organic pollutants. |
| Wet Scrubbing | Medium | Removal of HCl and other soluble gases |

## Table 10.5 cont

| Design for abatement | Costs | Comments on abatement |
|---|---|---|
| **Gasification** | | |
| *Particulates*<br>In fluidised bed gasifiers the usual practice is to remove fine ash from the fuel gas using a filter. Low-pressure systems would use fabric filters around 200°C, high-pressure systems will probably use sintered metal at around 500°C. Low-pressure systems will also have a water scrubber/cooler.<br>In fixed bed gasifiers the usual practice is to rely on water scrubbers within the process. | Medium to high | The level of particulate removal necessary to meet the requirement for a clean gas at the inlet to the gas turbine or engine is normally adequate to ensure compliance with stack emission regulations. This may not be the case for very small units below the threshold for EA regulation. |
| *Acid gases*<br>There is little experience in removing sulphur as this is only likely to be a problem with poultry litter and other specialised wastes.<br>HCl can be a present if there is straw or paper in the feedstock or plastic contamination. In fluidised bed units the strategy would be to absorb the acid with limestone that is added to the gasifier and removed with the ash.<br>Fixed bed units would rely on water scrubbers to remove HCl. There is little experience with sulphur removal. | Low | Sulphur is very much an unknown quantity in biomass systems and the view is usually taken the levels are so low as to be negligible.<br><br>High levels of HCl can inhibit the performance of the catalyst used to remove tars from the gasification product. There is relatively little experience with this problem. |
| *Nitrogen Oxides*<br>The main source of NOx emissions is the fuel bound nitrogen that is converted in the gasifier to ammonia. This ammonia in turn is converted to NOx in the combustion chamber of the gas turbine or the cylinder of the engine. In **low pressure** fluidised bed units the strategy is to remove the ammonia in a water scrubber that has been slightly acidified. The resulting salts could be sold as fertiliser if not contaminated.<br>**High-pressure units** do not have water scrubbers and are reluctant to install them because of the loss of efficiency. The optimum strategy has not been found as yet. The options are to use a catalyst bed to decompose the ammonia in the process, develop a new burner in the gas turbine, or fit conventional exhaust clean up.<br>The situation with fixed bed units is unclear at present with little data. | Low<br><br>Uncertain for high pressure units | The low calorific value of the gas reduces the flame temperature and so the generation of NOx from atmospheric air is not a problem.<br><br>The nitrogen content of the fuel is very important in determining the level of NOx. Fuels that contain a high proportion of new growth, such as grasses, coppice and bark will give higher levels of NOx than stem wood. |

## Table 10.5 cont

| Design for abatement | Costs | Comments on abatement |
|---|---|---|
| *CO and Hydrocarbons*<br>Elevated levels of CO and hydrocarbons in the exhaust of gas turbines and engines is a characteristic of using producer gas.<br>For gas turbines the problem can be overcome by a redesign of the combustion system. Reciprocating engines have a generic problem of fuel gas bypassing the valves. The solution is to install an oxidising, or three-way, catalyst on the exhaust if low levels are required. There is however little experience of doing this. | Low for turbines medium for engines. | The problem is not particularly serious for gas turbines and should be eliminated in the next generation of combustor designs.<br><br>Where the unit is operation on contaminated wood there are reports of trace amounts of metals passing through to the exhaust catalyst leading to poisoning.<br><br>Pilot ignition engines have higher levels of unburned hydrocarbons than spark ignition. |
| **Pyrolysis** | | The systems below are those that generate a liquid product that is subsequently fired in an engine, gas turbine or boiler. |
| *Particulates*<br>The first stage of removal is within the process itself. The vapour is cleaned in two or more stages of cyclones and possibly a filter before it is condensed to a liquid.<br>If the processing above or the combustion quality in the gas turbine or engine is inadequate then an exhaust particulate filter may be needed depending upon the standard. | Low to medium | The pyrolysis liquid properties make it extremely difficult to filter other than on a very coarse mesh.<br><br>The vapour cleaning process is designed to reduce the size and quantity of particulates in the final liquid down to levels that are acceptable for the burner and injector designs. |
| *Acid gases*<br>There is no experience with these. | | Some early work on straw showed that chlorine tended to concentrate in the char by-product of the pyrolysis reactor. |
| *Nitrogen Oxides*<br>There is relatively little data published but the indications are that levels will be lower than diesel oil. If reduction is necessary then this would require the addition of SCR or SNCR | | Pyrolysis liquids have a high moisture content and so combustion temperatures are low. This will reduce thermal NOx.<br><br>Some concepts have a char combustion unit to improve the overall efficiency. Char is a high calorific value, low ash fuel that will burn with a high temperature. This will lead to high levels of thermal NOx that may need conventional abatement on the exhaust. |
| *CO and Hydrocarbons*<br>Both engines and gas turbines are reported to have high CO and particulate emissions. There are no accepted measures for abatement although these might be expected to be filters and/or an oxidising catalyst. | | Pyrolysis liquid is a very new and differs in many respects from conventional fuels. It is slow to ignite but then burns well. It has variable flow properties that give difficulties in atomisation. |

**Table 10.6 Sensitivity analysis of increased capital costs**

| | IRR | Capital+25 | Capital+10 | Capital-10 | Capital-25 |
|---|---|---|---|---|---|
| **Wood** | 15 | 7.8 | 7.3 | 6.6 | 6.0 |
| | 8 | 6.5 | 6.1 | 5.6 | 5.2 |
| **Poultry** | 15 | 11.0 | 9.8 | 8.2 | 6.9 |
| | 8 | 8.4 | 7.5 | 6.3 | 5.4 |
| **Straw** | 15 | 12.8 | 11.6 | 10.1 | 8.9 |
| | 8 | 10.2 | 9.4 | 8.2 | 7.3 |
| **Gasification+** | 15 | 10.4 | 9.6 | 8.4 | 7.5 |
| **pyrolysis** | 8 | 8.5 | 7.9 | 7.0 | 6.3 |
| **Co-firing** | 15 | 6.4 | 6.0 | 5.6 | 5.3 |
| **30% eff** | 8 | 5.9 | 5.6 | 5.3 | 5.0 |
| **Co-firing** | 15 | 5.9 | 5.6 | 5.1 | 4.8 |
| **35% eff** | 8 | 5.4 | 5.1 | 4.8 | 4.5 |

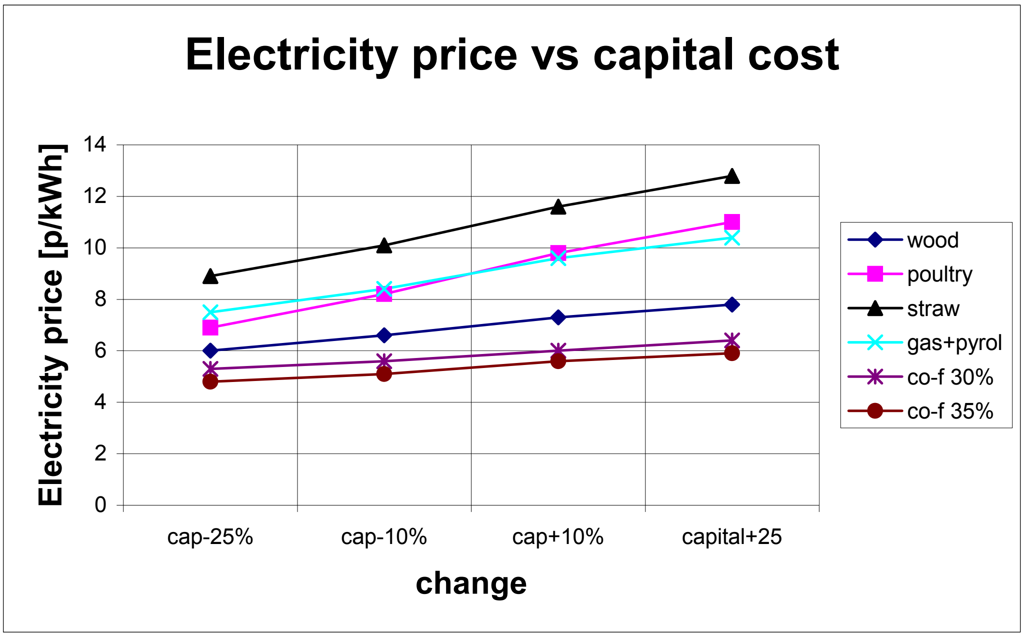


**Figure 10.1 Electricity price vs. capital cost for generic 20 $MW_e$ biomass plant**

The results indicate that co-firing is best placed to withstand the increased capital cost due to abatement at current electricity prices. In the short term power generation from wood also looks resilient. The situation will depend on changes in the RO in the longer term.

In reality examining just capital cost is misleading. For example, it may be impractical to introduce abatement equipment for pre-existing plant, particularly for co-firing where the plant still has to cater for the original fuel. In addition, operators of poultry plant currently sell the ash from the plant for fertiliser and obtain an income from it. Abatement techniques such as lime injection for acid gases result in a high lime content in the ash, which decreases its value as a fertiliser and the price the operator is able to obtain. Thus the cost of abatement technology in this case increases the capital costs in building the plant (through additions of a bag filter for particulates to enable lime addition), increases operating costs (addition of lime) and decreases the income from the plant. The acid gas emissions from the plant are decreased significantly, but for the plant operator the costs go beyond an increase in the initial capital cost.

***Fuel cost***

Changes in the fuel price take into account changes in production methods (e.g. changes required for lower environmental impact, or to increase in quality), increases in harvesting and handling costs and increases in transport costs. In reality it is likely that a plant would be sited to minimise transport cost, by siting the plant closely to the production area or to a good transport link. In addition, as the use of biomass increases and improved equipment for the production of biomass are developed, it is likely that fuel costs will decrease. The prices below assume that energy crops receive support from the Energy Crops Scheme and are grown on land that is receiving set aside payment. No other support, such as capital support grants is included.

For poultry litter fuel prices of £2/t and £10/t were modelled.

**Table 10.7 Sensitivity analysis for increased fuel costs**

| | IRR | Fuel+25 | Fuel+10 | Fuel-10 | Fuel-25 |
|---|---|---|---|---|---|
| **Wood** | 15 | 7.6 | 7.2 | 6.6 | 6.2 |
| | 8 | 6.6 | 6.1 | 5.6 | 5.2 |
| **Poultry** | 15 | *9.4* | *Fuel price £2/t* | | *8.7* |
| | 8 | *7.3* | *and £10/t* | | *6.6* |
| **Straw** | 15 | 11.5 | 11.1 | 10.6 | 10.2 |
| | 8 | 9.4 | 9.0 | 8.5 | 8.2 |
| **Gasification+** | 15 | 9.6 | 9.2 | 8.7 | 8.4 |
| **pyrolysis** | 8 | 8 | 7.7 | 7.2 | 6.8 |
| **Co-firing** | 15 | 6.7 | 6.2 | 5.5 | 5.0 |
| **30% eff** | 8 | 6.3 | 5.8 | 5.1 | 4.6 |
| **Co-firing** | 15 | 6.1 | 5.6 | 5.0 | 4.6 |
| **35% eff** | 8 | 5.7 | 5.3 | 4.6 | 4.2 |

The results indicate that a decrease of 25% in fuel price is still not sufficient to make use of biomass feasible at current electricity prices, except for co-firing.

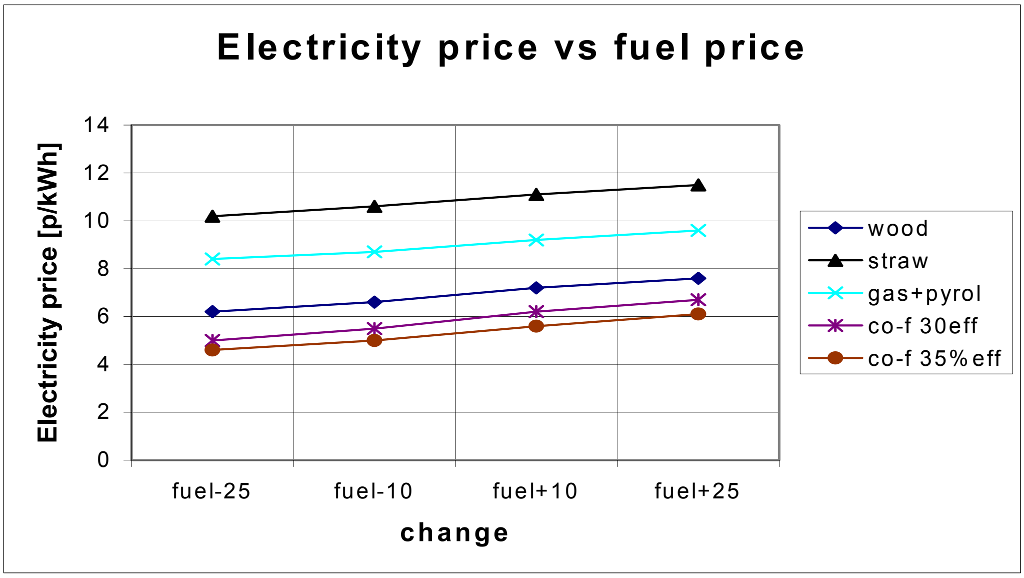


**Figure 10.2 Electricity price vs. fuel price for generic 20 $MW_e$ plant**

***Load Factor***

The effect of varying load factor, while keeping capital cost constant was examined. Operating and maintenance costs were also kept constant, as it was assumed that the number of men employed would be the same unless hours were cut dramatically. It is not strictly true that O&M costs would remain constant, as some costs are bound to decrease and others may increase.

**Table 10.7 Sensitivity of electricity price to load factor**

| Fuel | IRR | Base case | -10% load factor | -25% load factor |
|---|---|---|---|---|
| **Wood** | 15 | 6.9 | 7.4 | 8.3 |
| | 8 | 5.9 | 6.2 | 6.9 |
| **Poultry** | 15 | 9.0 | 10.0 | 11.9 |
| | 8 | 6.9 | 7.7 | 9.1 |
| **Straw** | 15 | 10.8 | 11.8 | 13.7 |
| | 8 | 8.8 | 9.5 | 10.9 |
| **Gasification + pyrolysis** | 15 | 9.0 | 9.7 | 11.1 |
| | 8 | 7.4 | 8.0 | 9.0 |
| **Co-firing 30% eff** | 15 | 5.8 | 6.1 | 6.6 |
| | 8 | 5.3 | 5.7 | 6.1 |
| **Co-firing 35% eff** | 15 | 5.4 | 5.6 | 6.1 |
| | 8 | 5.0 | 5.2 | 5.6 |

-10% load factor is equivalent to generation of 18 rather than 20 $MW_e$
-25% load factor is equivalent to generation of 15 rather than 20 $MW_e$

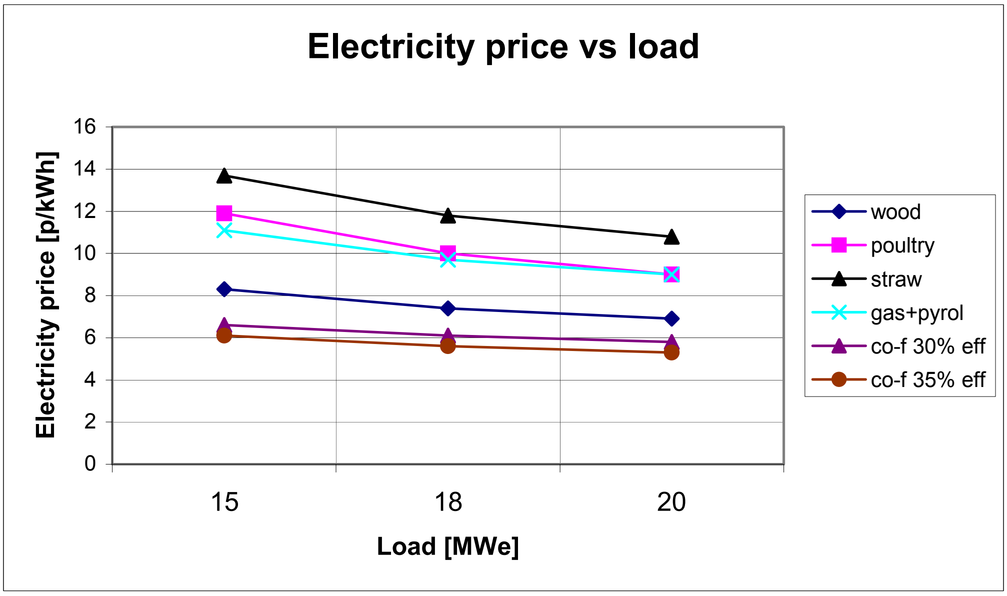


**Figure 10.3 Electricity price vs. load for generic 20 MW$_e$ biomass plant**

It can be seen that decreasing the load factor has a significant impact on the electricity price needed to ensure the plant is economic. For most of the biomass plant the decrease in load factor by 25% results in an increase in electricity price over 20% (35% in the case of poultry litter). This analysis shows how sensitive biomass schemes are to load factor: these impacts are greater than the increases in 25% for capital cost or the increase of 25% in the fuel price. As in the other analysis, co-firing is the most robust option in this case.

***Availability***

For this analysis it was assumed that the plant is either at full load or is not operating at all.

This analysis also shows a highly significant effect. In the case of poultry litter the high availability allows for a decrease of 25% in the electricity price, whereas the availability of 4,000 hours results in the need to increase the price by over 50%.

These results are presented in the graph below.

**Table 10.9 Sensitivity of electricity price to availability**

| | IRR | 8,000h | 7,000h | 6,000h | 5,000h | 4,000h |
|---|---|---|---|---|---|---|
| **Wood** | 15 | 5.9 | 6.3 | *6.9* | 7.7 | 9.0 |
| | 8 | 5.1 | 5.4 | *5.9* | 6.5 | 7.4 |
| **Poultry** | 15 | 6.8 | 7.7 | *9.0* | 10.7 | 13.2 |
| | 8 | 5.3 | 6.0 | *6.9* | 8.2 | 10.1 |
| **Straw** | 15 | 8.8 | 9.7 | *10.8* | 12.5 | 15 |
| | 8 | 7.2 | 7.9 | *8.8* | 10 | 11.9 |
| **Gasification+** | 15 | 7.3 | 8.0 | *9.0* | 10.3 | 12.2 |
| **Pyrolysis** | 8 | 6.2 | 6.7 | *7.4* | 8.4 | 9.9 |
| **Co-firing** | 15 | 4.6 | 4.8 | 5.0 | 5.2 | *5.8* |
| **30% eff** | 8 | 4.4 | 4.6 | 4.8 | 5.0 | *5.4* |
| **Co-firing** | 15 | 4.1 | 4.3 | 4.5 | 4.8 | *5.3* |
| **35% eff** | 8 | 3.9 | 4.1 | 4.3 | 4.6 | *5.0* |

Base case in italics.

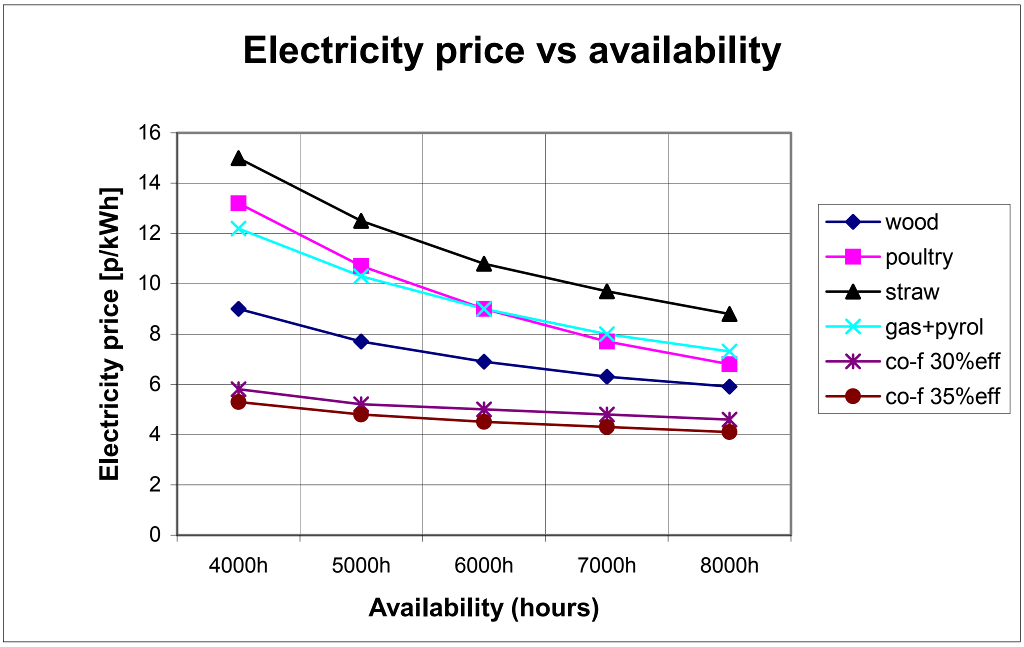


**Figure 10.4 Electricity price vs. availability for generic 20 $MW_e$ biomass plant**

In all cases the higher availability made a significant difference in electricity price, although for most biomass use, it is still not sufficient to provide a competitive price.

***Grants***

The above analysis does not include capital grants and indicates how difficult it is for biomass schemes to compete with conventional fossil fuels, even with the RO. Therefore the effect of grants was examined to see where they are most effective in assisting the economics of biomass schemes.

Current grants available for biomass in the UK relate to the establishment of energy crops, support for producer groups and the capital grants scheme (→10.1.2). In addition there is a possibility that EU funding may be obtained for capital equipment and further schemes are available in Objective 1 areas.

The crops currently supported under the Energy Crops Scheme are willow or poplar short rotation coppice (SRC) and the energy grass, miscanthus.

Support for establishing the crops under the Energy Crops scheme, including ground preparation, fencing, purchase of planting stock, planting, maintenance until first harvest, is available for both SRC and miscanthus. The level of support for SRC is

- £1,600/ha enhanced rate (for land currently used for forage)
- £1,000/ha standard rate (other land which forms part of an agricultural holding)

The level of support for miscanthus is £920/ha (for land forming part of an agricultural holding).

In addition to support for establishing energy crops, support is available for establishing producer groups (for SRC only). Grants for up to 50% of eligible costs are available. Eligible costs will include legal costs, office accommodation, office equipment purchase, IT equipment, recruitment costs, planting and harvesting machinery costs.

The analysis in this report assumes that all energy crops are in the Energy Crops Scheme.

In this analysis the effect of a capital grant of up to 99% was examined. This is above the level of support available under the Capital Grants Scheme. However, using a higher level of grant enables this analysis to examine and comment on the effects of all possible grants. The results (see Table 10.) indicate that something near 90% capital grant is required to ensure that biomass schemes can compete under the RO with conventional fossil fuels. Without the RO the biomass schemes are not competitive with fossil fuel plant, even with a 99% capital grant.

**Table 10.10 Sensitivity of electricity price to capital grants for biomass schemes**

| Fuel | IRR | Grant 50% | Grant 90% | Grant 99% |
|---|---|---|---|---|
| **Wood** | 15 | 5.4 | 4.1 | 3.9 |
| | 8 | 4.9 | 4.0 | 3.9 |
| **Poultry** | 15 | 6.0 | 3.5 | 3.0 |
| | 8 | 4.9 | 3.3 | 3.0 |
| **Straw** | 15 | 7.8 | 5.4 | 4.8 |
| | 8 | 6.8 | 5.2 | 4.8 |
| **Gasification +** | 15 | 6.7 | 4.8 | 4.4 |
| **pyrolysis** | 8 | 5.9 | 4.7 | 4.4 |

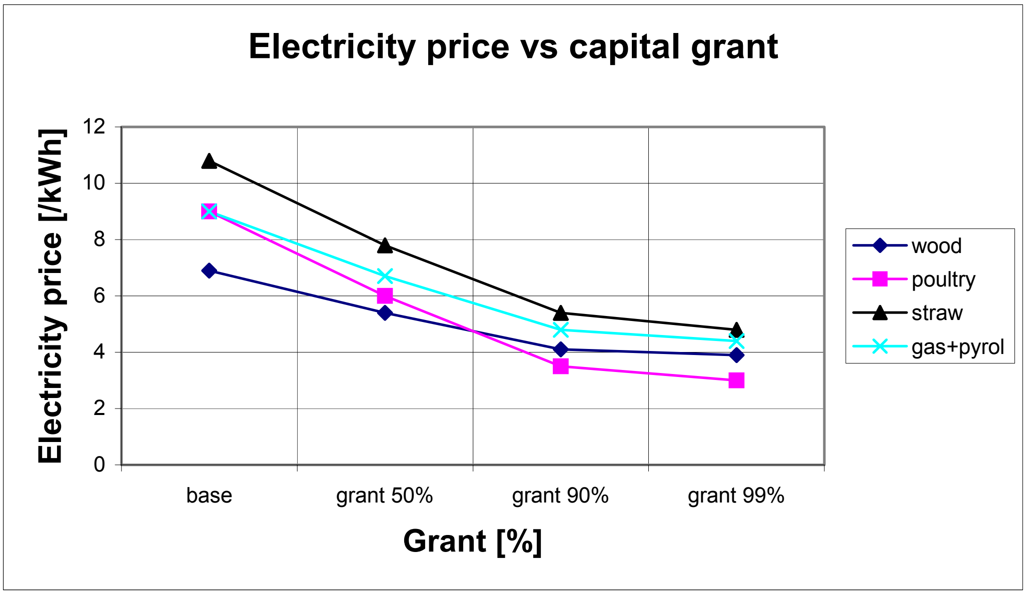


**Figure 10.5 Electricity price vs. capital grant for generic 20 $MW_e$ biomass plant**

### 10.3.2 Discussion

The analysis above indicates that the cost of electricity from biomass to energy schemes is higher that current prices for conventional fuels, unless grant support and the RO is taken into account. In all of above analysis grants for energy crops and set aside are included routinely where relevant. In addition, although the costs estimated above are based on data where it is available, estimates of some costs have had to be made where data is not available. This means that the analysis is theoretical and more basic economic data is required.

The addition of emissions abatement adds not only to the capital cost but can add to operational costs and (in the case of addition of lime, for example) may decrease the income from sales of residues. In addition not all emissions abatement is "bolt on". In some cases it may be necessary to design the plant to take emissions requirements and abatement techniques into account. The effect this has on the economics of biomass use is not clear and more data are required. However, some comments can be made. It is generally true that bolt-on emissions abatement is more expensive than abatement included in the design of the scheme. Thus it is important to the developer to understand potential emissions and necessary abatement at the design stage of the project. More advanced combustion techniques allow greater flexibility and better emissions control but they are more expensive than conventional grate combustion and cannot be retro fitted. Advanced conversion technologies are expensive and there is little experience in this country. Nevertheless they promise greater conversion efficiencies and more flexibility in conversion to energy (i.e. the product gases, chars and liquids can be stored for transport or later use). Emissions abatement should be much improved once these processes are fully developed. This is because individual chemical reactions can be separated and then operated under the optimum conditions for each. It must be understood that at this stage of development unexpected results may be obtained, such as higher than expected generation of ammonia in some gasification reactions, so ongoing development is essential and unavoidable. For this reason it is likely to be some time before the full potential of advanced conversion processes can be realised and this applies to both plant performance and emissions.

The most significant impacts on the competitiveness of biomass were found to be availability and load factor[17]. Results indicated that not only does the capital cost have an important influence on the economics of the plant, but the efficiency of the plant operation is also important and it is important that abatement techniques do not significantly impact on these aspects of operation.

The BEAM project (Mitchell *et al* 1996) indicated similar results:

- the largest effect on the economics of energy generation from SRC is caused by changes to productivity, overall capital, reactor efficiency, engine efficiency and steam cycle efficiency;
- there is a direct relationship between feedstock cost and the cost of electricity generated for each technology.

The BEAM project also examined production costs. Their results indicated that integrated harvesting of conventional forestry resulted in the lowest electricity price; for SRC it was better to harvest as chips and store the chips until required than to harvest whole shoots. In addition BEAM showed that SRC productivity had a significant impact on the final electricity generation cost.

The relationship between production costs (i.e. fuel price) and overall economics is also important. It is likely that production techniques will be lead by costs and that the most efficient and cost-effective techniques will be adopted. Analysis of production costs and techniques indicates that these techniques are likely to include integrated harvesting and chipping of SRC on site. In addition techniques to improve the productivity of energy crops are likely to be adopted and these will have a significant impact on the delivered fuel price.

Grants and other support mechanisms are vital to the success of biomass energy schemes. The analysis above includes the Energy Crops Scheme support and assumes that energy crops are grown on land that has been set aside and for which the set aside payment is being received. This analysis shows that one type of support mechanism on its own is not sufficient to allow energy from biomass to be competitive. There is a need for the RO plus some other form of support (capital grant or establishment grants for example).

Other projects have shown similar results. An EC project (Kaltschmitt 1995) examining heat and power schemes in rural areas indicted that assistance is needed for a combination of establishment grants, capital grants for conversion technology and support the market for the heat and power generated, before biomass can compete with conventional fuels[18]. A number

[17] Increasing availability to 8,000 hours per year had a similar effect to a decrease of 25% in the capital cost. Decreasing load factor by just 10% had a similar effect to increasing capital cost by 10%; decreasing the load factor by 25% had a more significant effect than increasing the capital cost by 25%.

[18] Kaltschmitt's analysis also indicated that economy of scale is important as is load factor; transport costs were not shown to have a significant influence.

of EU countries provide support mechanisms for a number of different parts of the biomass energy chain for just this reason[19].

[19] For example Denmark's electricity prices are artificially high, there is an energy plan that requires generation of a % of electricity from renewable sources; and capital grants have been made available to develop technology in the past.  Innovations in the application of abatement technology are encouraged through capital grants.

# 11 KEY POLICY ISSUES

Although large-scale generation of energy from biomass represents only a small proportion of the heat and power generated in the UK at present, Government policy is likely to accelerate its uptake (→ Chapter 0). There are a number of issues that will need to be addressed if this is happens. These are summarised in the Table below. They are grouped in significance for the Agency (high, medium or other issues) and by Agency key indicator (→ 2.3). The Table is further sub-divided by part of the energy chain (i.e. production and harvesting, storage and supply and conversion). The opinions expressed in Table 11.1 are those of the authors and are not necessarily those of the Agency. In addition they are priorities, all other things being equal, but local circumstances may alter the level of priority.

**Table 11.1 Key priorities for information on the biomass to energy chain**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| SIGNIFICANCE: HIGH | | | |
| **General** | | | |
| Limiting and adapting to climate change<br>Quality of life | Renewables Obligation and related policies<br><br>Biomass has an important role to play in achieving the Government's renewable energy targets at regional and national level. However, there is often local opposition to plant, where immediate impacts of plant are felt.<br><br>Life cycle analysis indicates mitigation of GHG emissions | 2<br><br>9.2.4 | There is a need to balance local impacts with national/global needs and to consult with local communities.<br>Socio-economic benefits need clarification.<br><br>Clear information comparing the generation of heat and power from biomass and conventional fuel sources should be available to local communities. |
| Greener business; wiser, sustainable use of natural resources and climate change | Economic analysis indicates that the cost of electricity from biomass schemes is higher than prices for conventional fuels. However, there is a lack of detailed data on basic issues such as capital, abatement and O&M costs. This makes it hard to assess the relative economic effectiveness of abatement techniques and to provide advice in this area. | 10<br>10.3 | Opportunity should be sought to monitor NFFO schemes or those receiving the RO for relevant economic data to enable good quality advice on BAT to be developed. |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| ***General continued*** | | | |
| Climate Change | **Use of biomass**<br>It is a high priority to maximise the use of biomass and the efficiency of conversion. | 6<br>7.1.7<br>10.3.1 | Improvements in the efficiency and loading of the conversion process will not only cut $CO_2$ emissions further but will improve costs and competitiveness.<br>Applications for the use of heat as well as power should be encouraged. |
| **Production and harvesting** | | | |
| Impact of siting<br><br>Quality of life; visual impact; noise; odour; effects on wildlife | Large energy crop plantations will be required for any significant biomass power generation. This will have visual impacts, but they can be minimised by adhering to guidelines already available. These guidelines cover planting, harvesting and collection of biomass.<br>These guidelines include examples of techniques that can be applied to decrease impacts from biomass fuels including the impact on the environment, wildlife, water courses, climate change, flood risk and general quality of life. | 4<br>7.1.1<br>7.1.2<br>7.1.3<br>7.1.5<br>7.5.1<br>9.1.1<br>9.1.4 | Where there is potential for decreasing emissions from conversion by adopting production, harvesting and collection techniques these should be clarified and included in the guidelines. |
| Effects on air (and soil) | **Fertiliser applications**<br>The nature and composition of fertiliser applied to biomass crops will influence the composition of biomass fuel and in turn the ash from the conversion plant.<br>**Application of sewage sludge as a fertiliser**<br>This has been proposed for energy crops. Accumulation of contaminants from the sludge in the crop and subsequent emissions at the conversion stage need to be considered; accumulation of contaminants in the soil may also need consideration. | 8.2<br><br>0 | The influence of farming/production practices on the composition of ash from biomass power plant needs clarification.<br><br>Attention should be paid to build up of heavy metals in soils.<br>MAFF guidelines on the use of sewage sludge in agriculture should be consulted. |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| **Conversion** | | | |
| Quality of life | **Impact of siting** | | There are guidelines availableon which sites should be avoided when siting a plant (e.g. habitats for important species, SSSIs, sites of archeological interest etc.) In addition there may be other planning restrictions locally. |
| Effects on air | **Abatement of emissions of NO, $NO_2$ and VOCs** | 9.2.1 | Emissions from plant depend on fuel, plant design, abatement techniques, site and stack height. Comparative data are needed to understand the influence plant design (including abatement techniques) has on emissions and how this relates to BAT and plant economics.<br>Emissions of complex aromatics should not be a problem with properly designed and efficient equipment (monitoring should be undertaken to confirm this). More data is needed regarding these emissions from pyrolysis and gasification. |
| | Cd, Hg and $SO_2$ emissions from straw and poultry litter plant.<br><br>Emissions of complex aromatics | 7.6.3<br>8.2<br>9.2.1 | |
| | **Air emissions from co-firing**<br>Co-firing biomass with fossil fuels should reduce some emissions from the fossil fuel plant e.g. $CO_2$, $NO_x$ and $SO_2$), but may increase others. The effect will be dependent on fossil fuel type and configuration of the fossil fuel plant, as well as the composition of the biomass fuel. The DTI is supporting work on co-firing that includes combustion trials, but further work is needed to clarify specific emissions issues, in order to support development of policy in this area. | 7.6.3 | There is currently much interest in co-firing within the power industry and there may be opportunities to support demonstrations and evaluation programmes on emissions from co-firing.<br>Information is required on the implications of co-firing on electrostatic precipitation performance and emissions of trace substances such as heavy metals. |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| ***Conversion continued*** | | | |
| Effects on soils | **Disposal of ash from biomass plant**<br>Ash handling procedures are regulated under the Environmental Protection Act. In some cases ash from biomass power plant may be used as a fertiliser or as a raw material in the building industry. | 8.2<br>9.4 | There is a need to<br>- Monitor ash applied to land for heavy metals and halogenated compounds.<br>- Undertake performance and leaching tests on biomass ash used in the building industry. |
| | **Re-use of ash from co-firing**<br>Ash from coal-fired power stations is commonly used in the building and cement industry. | 8.2 | There is a need to clarify the effect co-firing has on the properties of ash from coal power stations where co-firing is practised, particularly its effect on re-use of the ash (see point above). |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| **PRIORITY: MEDIUM** | | | |
| Production and harvesting | | | |
| Wiser, sustainable use of natural resources | **Arboricultural residues**<br>There is a possible use for arboricultural and other *clean* urban wood wastes (e.g. saw mill waste) as a biomass fuel, although emissions from treated wood could be an issue if it is not easy to separate *clean* and *treated* wood. | 4.7 | Collections and supply logistics are not straightforward. Currently these residues tend to go to landfill.<br>To encourage their use supply chains need to be developed. Develop of a database of the arisings of suitable *clean* fuel would assist potential use and supply logistics. |
| Climate Change | **Cost of biomass fuel**<br>Economic analysis indicates that the cost of biomass fuel can make a significant difference to the economics of the plant. | 10.3 | Techniques that decrease the cost of biomass fuel will improve the economics of biomass use. The trade-off (if any) between needs to maximise yield and minimise cost and environmental impacts requires examination. |
| **Storage and transport** | | | |
| Greener business world.<br>Climate change. | **Supply strategies**. Transport of the biomass will be an important issue at the planning stage. The cost of transport and its efficiency will influence fuel price, plant economics and green house gas emissions. | 7.4.4<br>10.3 | Strategies to improve the logistics and decrease the impact of transport may have a significant influence on the emissions, economics and acceptability of the biomass-energy chain.<br>Emissions are only likely to be an issue where local air quality problems already exist. |
| **Conversion** | | | |
| Effects on air. | **Emissions from pyrolysis and gasification**.<br>These are novel technologies with respect to biomass. Emissions data is frequently not available. | 7.6.3 | Emissions monitoring will be important to providing data on pyrolysis and gasification of biomass. The bio-energy capital grants scheme may provide an opportunity to monitor emissions. |
| Effects on soils | **Deposition of air emissions to soils**<br>This will be a function of fuel type, stack height and design of plant. | 9.2.2 | Work on monitoring the influence of plant design and abatement techniques on air emissions (see above) should also include deposition to soil. |

| | | | |
|---|---|---|---|
| Effects on water | **Disposal of tar, dust and bulky residues from pyrolysis and gasification**<br>Gas conditioning is a crucial issue in the commercialisation of gasification technology for power generation. Gas cleaning is still relatively unproven. For both pyrolysis and gasification exhaust gases from the conversion processes are likely to need cleaning. | 5.4<br>5.5<br>9.3 | There is a need to develop guidelines for the disposal of the residues from the cleaning process. |
| | **Storage of pyrolysis liquids**<br>These liquids contain a variable and complex mix of organic compounds, some of which may be toxic. | 5.5 | Material Safety Data Sheets will be required for these liquids. Procedures for handling and disposal will be required. |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| **PRIORITY: OTHER** | | | |
| **Production and harvesting** | | | |
| Effects on air | **Harvesting and storage of straw**<br>Danish work has shown that leaving straw on the field for a month after harvest increases wash out of trace compounds and decreases harmful emissions. | 4.6 | This results in a fuel with higher moisture content and may necessitate forced drying. |
| Effects on inland and coastal waters | **Effects of production and harvesting of biomass on soils, erosion and nutrient leaching**<br>There is a need to ensure that production and harvesting techniques do not adversely affect water quality, supply or flood risk. Issues highlighted in this report include the effect that substantial plantations of several hundred hectares of energy crops may have on ground water recharge in drier parts of the country. | 7.2.4<br>7.1.5<br>7.1.8<br>7.2.7<br>7.2.5 | These effects depend on soil, climate and crop and need careful consideration. |
| Wiser, sustainable use of natural resources | **Investigation of energy grasses**<br>The energy grass that has received most interest is miscanthus. However, the north of the UK (above a line from Chester to Lincoln) is beyond its normal climate zone. Other energy crops are being considered in these areas. | 4.4 | Crops include switchgrass and reed canary grass |
| **Storage and transport** | | | |
| Climate change | **Dry matter loss during storage**<br>This may be an issue if the biomass is subject to rapid drying, or for biomass stored on the field and repeatedly subjected to rain. | 7.3.3 | This is an important issue for the fuel supplier and conversion plant. There are management techniques to minimise dry matter loss, but there will always be a balance between the costs and benefits for different storage and drying options. |

**Table 11.1 cont**

| Key area | Issue | Section | Comments |
|---|---|---|---|
| **Conversion** | | | |
| Quality of life | **Noise, Odour and Visual impact.**<br>These are all sources of concern for local communities.<br><br>Pressure to minimise the visual impact of biomass plant by decreasing stack height may conflict with a need to decrease the impact of air emissions and deposition of emissions to soil. | 7.5.1<br>7.6.1<br>9.1.1<br>9.1.3<br><br>7.6.1<br>9.2.1 | There are management techniques for all of these. Clear guidance on the sources of noise and odour and the techniques to reduce their impact are important.<br>Restrictions on vehicle movements to decrease noise will mean larger storage capacity for fuel will be required.<br>The trade off between these issues should be clarified to allow clear advice to be drawn up for plant design. Specialist plume modelling can help to establish the appropriate height of the stack, taking the height of nearby buildings and general topography into account. |
| | **Effects of drying**<br>There may be a need to use rapid drying methods for conversion plant requiring large quantities of material or very dry material (e.g. flash pyrolysis). There are two potential impacts: visual impact of dryer plumes and volatile emissions. | 5.4<br>5.5 | Plant location should be carefully considered to minimise visual impact.<br>The need for drying and the methods used should be monitored to provide information on procedures that minimise the impact of volatile emissions. The relationship between efficiency of conversion and the moisture content of the biomass will need to be balanced with the cost (environmental and economic) of rapid drying of the biomass. |

# 12 CONCLUSIONS

This report reviewed biomass plants and their associated energy chains, using the Environment Agency's key indicators to examine potential impact and other issues. There are a number of conclusions that can be drawn from the report:

1. Biomass is generally accepted as a "green" fuel for energy production because $CO_2$ emissions are greatly reduced compared to fossil fuels. This is because the $CO_2$ released on conversion equals the $CO_2$ sequestered as the plant grows. The associated fossil fuel emissions from production and utilisation of the fuel have been assessed on a life cycle basis and found to be 2-8% of those from a gas fired CCGT plant.

2. Currently there are few biomass plants in the UK, but recent Government policy initiatives may change this situation. The Renewables Obligation is likely to encourage co-firing in the near future, and the Government's bio-energy capital grants scheme is also intended to encourage a whole range of biomass heat and power plant in the short to medium term. This scheme aims to encourage demonstration of efficient and advanced conversion options for biomass.

3. The biomass fuels most likely to be used in the UK are: wood from forestry and forestry residues, agricultural residues (including straw and poultry litter), wood waste, energy crops (e.g. short rotation coppice and miscanthus) and other sources of biomass such as arboricultural residues and food processing wastes.

4. Around 1,500 ha of short rotation coppice (SRC) and 350 ha of miscanthus have been established for commercial use. If the Government initiatives discussed in (2) above are taken up they will result in larger plantations of energy crops. Understanding the environmental implications of energy crops and optimising any environmental aspects is one of the most important deployment issues for energy crops. There are guidelines for the siting and planting of large areas of energy crops and as a condition of the Energy Crops Scheme an Environmental Impact Assessment may be required. These guidelines and assessments should minimise impact from energy crops.

5. Removal of forest residues for fuel may have positive and negative effects on forest ecology, run off, leaching of nutrients, soil etc. These issues are being investigated under the DTI Sustainable Energy Programme. The impact of harvesting of forestry residues may also be considered as part of the power plant EIA.

6. The ecology of farming is a major conservation issue: farmland dominates the landscape. As a new crop, the growing of SRC may provide a new exploitable habitat for wildlife in the British countryside. Research, largely by the Game Conservancy Trust, has shown that SRC may provide a good habitat for a wide variety of wildlife including floral communities, birds and insects. However, work to date has mainly been on small trial plots and without direct comparison to the land use it replaces. A study is underway to monitor commercial-scale plantations and compare flora and fauna to adjoining agricultural (arable) land. Preliminary results have showed SRC to have positive effects on flora, songbirds, butterflies and other invertebrates. The size of the field, particularly

with respect to the edge habitats was also shown to be important. Managing these edge habitats will be important in optimising biodiversity. Further work on the environmental impact assessment of miscanthus is being undertaken under the DTI Sustainable Energy Programme.

7. It is recognised that SRC is likely to be a low input crop (with respect to nutrient requirements), although good site preparation is important and further work is needed on low nutrient soils. It has been suggested that sewage sludge can be used as a fertiliser (has been used in ARBRE plantations) and as a source of water for energy crops. However, careful consideration of subsequent land use and the build up of contaminants in the soil is important.

8. SRC willow can have high water demands. Further work on the water use of SRC and its influence on hydrogeology is underway as part of the DTI Sustainable Energy Programme.

9. The composition of biomass crops is very much a result of production conditions (soil and inputs) and these can have a significant effect throughout the biomass-energy chain. There are opportunities to minimise impact later in the energy chain as a result of manipulation of production conditions, such as control of fertiliser inputs. This whole area requires careful consideration and guidance.

10. Equipment for establishment, collection and harvesting of biomass fuel requires further development. Harvesting equipment is being developed for SRC as part of the ARBRE project and under other initiatives. Equipment for the collection of forestry residues is available but requires further testing under UK conditions. Establishment of miscanthus remains an issue.

11. Storage and supply infrastructure is being developed by the biomass industry. The impact of collection and storage techniques on the need for subsequent fuel drying and on emissions from plant are important considerations and should be taken into consideration in development of collection and storage strategies.

12. Siting of conversion plant is likely to be a trade off between the need to site the plant near the fuel resource and the need to minimise impact on the local environment. Issues such as visual impact, noise, odour and traffic movements will be important at the planning stage. Good consultation with local communities and good management techniques should minimise these issues. The environmental impact of emissions should also be an important consideration at the siting/planning in order to minimise impact, optimise design and location. These issues are considered in detail in Chapter 9.

13. Generation of heat and power from biomass fuels by thermal conversion is technically proven, both in the UK and abroad. There are a number of other conversion options open to the biomass developer, including gasification, pyrolysis or co-firing with another fuel. These technologies are at the demonstration stage in the UK, and there are examples abroad. It is an aim of the bio-energy capital grant scheme to encourage advanced conversion. Advanced conversion technologies offer key advantages, such as higher conversion efficiency, improved control of environmental emissions and flexibility of fuel use. These are of key environmental importance.

14. Emissions from biomass plant are generally lower than from fossil fuel plant. Nevertheless there are issues, noticeably with $NO_x$ and VOCs from all biomass plant, particulates and cadmium for straw and poultry litter, HCl and mercury for straw plant and lead for poultry litter. Emissions will depend on the composition of the biomass fuel, which in turn can vary with soil and production and harvesting conditions. These emissions can all be abated using available technology.

15. There are major issues for plant siting, including noise, visual impact and odour. These issues can all be mitigated by careful design and planning. However, they will be important to the local community and community liaison is important to discuss the community's concerns.

16. Stack height is an important factor in deposition of emissions to soil. It is also an important visual impact. Careful design and consultation with the local community is required to resolve these issues.

17. A substantial local impact will be traffic movements. Siting near existing main roads will minimise this impact. Use of alternatives such as rail and water transport require careful investigation, development of infrastructure and handling equipment.

18. Ash disposal is an important issue. Some ash is currently used as a fertiliser, but there must be a market for the product for this to work. In addition there are issues with trace contaminants building up in the soil. Ash from co-firing is a particular issue, because a lot of coal ash is currently re-used in the cement and building industry.

19. Biomass fuel costs range from £1.8-3/GJ or £30-45/odt. For energy crops this includes grants from the Energy Crops Scheme and assumes the crops are grown on land that has been set aside and for which set aside payments are being received. These fuel prices are higher than those for natural gas or coal.

20. Economic analysis indicates that the cost of electricity from biomass to energy schemes is higher than current prices for conventional fuels, unless grant support and the RO are taken into account. (For the RO the sum of the Obligation itself and the redistributed buy out funds is important for biomass). The most significant impacts on the competitiveness of biomass were found to be availability and load factor. Not only does capital cost have an important influence on economics, but the efficiency of plant operation is also important.

19. Economic data for abatement costs is not readily available and is frequently quoted in ways that do not allow ready comparison. Such data is required for advice on plant design for abatement in terms of cost and viability. However, some comments can be made. It is generally true that bolt-on emissions abatement is more expensive than abatement included in the design of the scheme. Thus it is important to the developer to understand potential emissions and necessary abatement at the design stage of the project. More advanced combustion techniques allow greater flexibility and better emissions control but they are more expensive than conventional grate combustion and cannot be retro fitted. Advanced conversion technologies are expensive and there is little experience in this country. Nevertheless they promise greater conversion efficiencies and more flexibility in

conversion to energy (i.e. the product gases, chars and liquids can be stored for transport or later use). This is of key environmental importance for the long term. Emissions abatement should be much improved once these processes are fully developed.  This is because individual chemical reactions can be separated and then operated under optimal conditions for each.  It must be understood that at this stage of development unexpected results may be obtained, such as higher than expected generation of ammonia in some gasification reactions, so ongoing development is essential and unavoidable.  For this reason it is likely to be some time before the full potential of advanced conversion processes can be realised and this applies to both plant performance and emissions.  In the short term this means there is risk in their development, but the long-term gain will be significant improved efficiency.

20. Further work is required in a number of major policy issues.  These are listed in Chapter 11.

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## APPENDIX 1 Noise levels from energy forestry

| | $L_{eq}$ at stand edge dB(A)[1] | Background dB(A) | Criteria for nuisance | Distance over which annoyance is experienced (m) | |
|---|---|---|---|---|---|
| | | | | indoor | outdoor |
| **Coppice** | | | | | |
| Site preparation | 78 | 50[2] | 10 over background | 30 | 80 |
| Planting and post-planting | neg | 50 | 10 over background | 30 | 80 |
| Stool establishment | 78 | 50 | 10 over background | 30 | 80 |
| Post-stool establishment and post-harvest treatment | 78 | 50 | 10 over background | 30 | 80 |
| Harvesting and chipping | 83 | 50 | 10 over background | 60 | 180 |
| Chipping only[2] | 71 | 50 | 10 over background | Neg. | 40 |
| **Single stem[5]** | | | | | |
| Site preparation | 79 | 45 | 5 over background | 90 | 320 |
| Planting and post-planting treatment | 75 | 45 | 5 over background | 60 | 180 |
| Plantation maintenance | 75 | 45 | 5 over background | 60 | 180 |
| Harvesting and chipping | 107 | 45 | 5 over background | 1000 or more | 1000 or more[3] |
| Harvesting only | 83 | 45 | 5 over background | 80 | 180 |
| Chipping only | 107 | 45 | 5 over background | 1000+ | 1000+ |
| Harvesting (combined harvester) | 92 | 45 | 5 over background | 350 | 900 |
| Ground preparation | 75 | 45 | 5 over background | 60 | 180 |
| **Single stem[5]** | | | | | |
| Site preparation | 78 | 50 | 10 over background | 25 | 60 |
| Planting and post-planting treatment | 78 | 50 | 10 over background | 25 | 60 |
| Plantation maintenance | 78 | 50 | 10 over background | 25 | 60 |
| Harvesting and chipping | 99 | 50 | 10 over background | 320 | 650 |
| Harvesting | 83 | 50 | 10 over background | 60 | 180 |

| | | | | | |
|---|---|---|---|---|---|
| Chipping | 99 | 50 | 10 over background | 320 | 650 |
| Harvesting (combined equipment) | 97 | 50 | 10 over background | 300 | 600 |
| Repreparation | 78 | 50 | 10 over background | 25 | 60 |
| **Modified conventional forestry** | | | | | |
| Site preparation | 79 | 45 | 5 over background | 60 | 170 |
| Plantation maintenance | 75 | 45 | 5 over background | 45 | 120 |
| Harvesting and chipping | 107 | 45 | 5 over background | 1000+ | 1000+[4] |
| Harvesting | 103 | 45 | 5 over background | 1000+ | 1000+[4] |
| Chipping | 107 | 45 | 5 over background | 1000+ | 1000+[4] |
| Harvesting (combined equipment) | 92 | 45 | 5 over background | 250 | 600 |
| Final harvest, including chipping | 107 | 45 | 5 over background | 1000+ | 1000+[4] |

Notes: [1]worst case
[2]if chipping is carried out after harvesting
[3]assuming a small capacity chipper is used because of proximity to homes
[4]the likelihood that other noise sources will prevail over long distances must be taken into account
[5]see text below for clarification

In the first single stem case, the area includes occasional small farms, and roads and tracks. The recreational use includes hill-walking (long-distance walking, one or more days, off-road sports like orienteering and cross-country running) and field sports. Roads are local and used by residents.

In the second single stem case, there are hamlets and farms in close proximity, also occasional towns. Recreational areas and public open space, casual walking (rights-of way, frequent use). There major and minor roads in close proximity are used both by local residents and for through traffic.

## APPENDIX 2 Typical compositions of different biomass fuels

The tables below describe the composition of the main biomass fuels considered in this report.

| | Willow | Miscanthus | Straw | Untreated wood | Forest residue |
|---|---|---|---|---|---|
| **Water w-% wet** | 13.6-43.5[1] | 4.4-40[1] | 12.7<br>1.5-88 | 19.8<br>0-71.2 | 29.6[1] |
| **Volatiles** | 81.1-85.9 | 78.6-83.7 | 81<br>72.8-87 | 81.9<br>54.9-94.9 | 76.8 |
| **Ash w-% dry** | 1.1-1.9 | 0.8-4.6[1] | 7.3<br>1.2-24.4 | 2.3<br>0-39.4 | 0.8[1] |
| **HHV MJ/kg daf** | 18.3-19.6 | 18.4-20.0 | 19.3<br>16.3-23.5 | 20.1<br>16.4-26.7 | 18.3 |
| **LHV (calc) MJ/kg daf** | 17.0-18.3 | 17.1-18.8 | 17.9<br>14.8-21.8 | 18.8<br>8.5-25.0 | 17.0 |
| **C** | 48.5-51 | 48.8-50.3 | 48.9<br>40.4-60.0 | 50.8<br>42.4-59.7 | 48.8 |
| **H** | 5.9-6.2 | 5.8-6.4 | 5.97<br>3.2-7.32 | 6.06<br>4.55-8.9 | 6.1 |
| **O** | 42.9-44.9 | 42.5-44.3 | 43.9<br>30.8-54.1 | 42.7<br>33.1-52.5 | 45.1 |
| **N** | 0.1-0.64 | 0.30-061 | 0.82<br>0.01-5.39 | 0.36<br>0.02-3.41 | 0.71 |
| **S** | 0.06 | 0.09-0.12 | 0.15<br>0-0.82 | 0.07<br>0-0.88 | 0.1 |
| **Cl** | 0.01-0.026 | 0.101-0.492 | 0.464<br>0-2.316 | 0.055<br>0-1.189 | 0.101 |

Notes: First number is the mean value, below the range of variation.
Values are in w-% of daf if not indicated otherwise
[1] as received
All values from Phyllis database, www.ecn.nl/phyllis/

Straw has also a high concentration of potassium, typically between 0.5 and 2w-% (in Danish straw) (Jensen *et al*, 1999). Miscanthus has typically 0.06% of phosphorus and 0.65% of potassium (Lewandowski *et al* 1995).

| | Switchgrass | Reed canary grass | Poultry litter |
|---|---|---|---|
| **Water w-% wet** | | 9.5[1] | 39.7 |
| **Ash w-% dry** | 10.1 | 5.7 | 17.5 |
| **HHV MJ/kg daf** | 20.1 | 20.1 | 20.8 |
| **LHV (calc) MJ/kg daf** | 18.7 | 18.8 | 19.1 |
| **C** | 53.2 | 49.3 | 49.9 |
| **H** | 6.4 | 6 | 7.4 |
| **O** | 39 | 44.1 | 34.2 |
| **N** | 1.3 | 0.42 | 7.38 |
| **S** | 0.11 | 0.05 | 0.6 |
| **Cl** | | | 0.302 |

Notes: Units as above
[1] as received
All values from Phyllis database, www.ecn.nl/phyllis/

Compared to wood fuels, spring harvested reed canary grass has higher values for Si, K, Ca and P. All in all, the composition varies significantly with soil type and fertilisation (Paulrud and Nilsson 2001).

## APPENDIX 3 Emissions data from straw-fired power plant

Table below lists emissions from spot checks at Elean straw-fired power plant with different loads (exported electricity). Also shown are typical monthly averages and highest values as well as the range of values between January and June 2001.

| | $NO_2$ | $SO_2$ | Particulates ($mg/m^3$) | CO | HCl |
|---|---|---|---|---|---|
| **23 MW** | 260 | 50 | 7 | 400 | 38 |
| **32 MW** | 250 | 100 | 4 | 400 | 42 |
| **35 MW** | 250 | 40 | 10 | 500 | 23 |
| **Typical average** | 170 | 40 | 0.6 | 80 | 12 |
| **Range** | 145-193 | 28-47 | 0.3-4 | 44-219 | 9-16 |
| **Typical highest** | 230 | 130 | 15 | 145 | 60 |
| **Range** | 191-300 | 61-312 | 0.6-30 | 119-611 | 39-104 |

The results show no correlation between emissions and load. Oxygen concentration in the flue gas is controlled at 4%.

# APPENDIX 4 Ash properties

The Table below gives typical wood ash composition (FEC 1990).

| | Softwood % | Oak % | Birch % |
|---|---|---|---|
| **CaO** | 32.0 | 65.0 | 45.0 |
| **MgO** | 4.4 | 8.3 | 10.8 |
| **$SiO_2$** | 36.3 | 2.3 | 2.8 |
| **$Al_2O_3$** | 4.7 | 0.9 | 1.4 |
| **$Fe_2O_3$** | 1.5 | 0.5 | 0.7 |
| **$Na_2O$** | 2.3 | 0.8 | 1.3 |
| **$K_2O$** | 8.5 | 9.9 | 11.4 |
| **$TiO_2$** | 0.3 | 0.1 | 0.1 |
| **MnO** | 1.8 | 0.9 | 5.6 |
| **$SO_3$** | 1.7 | 2.2 | 2.2 |
| **$P_2O_5$** | 4.8 | 7.5 | 17.0 |
| **Unaccounted** | 1.7 | 1.6 | 1.7 |
| **Soil type** | Coastal sand | Brown earth | Peat |

Table below lists values for the elemental concentrations (mg/kg) for wood ash samples. Data sources were as follows:

1. Data from the Great Lakes Region in North America. Samples represent 45 industrial wood burning sites as well as different burning systems. Fuels include waste wood as well as 'clean' wood. There was also co-firing with waste materials such as tyres in some of the plants. It is not clear whether the data reported is for bottom ash, fly ash or a mixture of the two (McGinnis *et al* 1995).
2. Data from Swedish plant firing a mixture of wood chips and bark. In some cases other fuels such as oil, coal or fibre from paper production were also combusted (Steenari *et al* 1996).
3. Data for ash from the cyclone of the Ebeltoft plant in Denmark (Pedersen *et al* 2000).

| Data source | 1 | | | 2 | 3 |
|---|---|---|---|---|---|
| | Average | Minimum | Maximum | Bottom ash | Fly ash |
| Dry solids % | 93 | 39 | 100 | | |
| pH | 12.6 | 10 | 12.9 | | |
| Aluminium | 8,367 | 1,365 | 51,646 | 34,400 | |
| Arsenic | 112 | 2 | 683 | 1.4 | |
| Boron | 250 | 19 | 1,117 | 155 | |
| Cadmium | 14 | 0.4 | 83 | <0.2 | 28 |
| Calcium | 170,000 | 16,000 | 360,000 | 29,800 | 235,000 |
| Chlorine | 5,586 | 4 | 123,750 | 20 | 4,500 |
| Chromium | 59 | 5 | 267 | 79 | |
| Copper | 146 | 14 | 504 | 100 | |
| Iron | 7,556 | 1,482 | 24,741 | 17,000 | 7,700 |
| Lead | 172 | 7 | 3,155 | 4 | 100 |
| Magnesium | 14,728 | 2,309 | 55,149 | 37,000 | |
| Manganese | 3,322 | 407 | 16,156 | 27,000 | |
| Mercury | 0.084 | 0.05 | 0.454 | 0.02 | |
| Molybdenum | 12 | 1 | 92 | <5 | |
| Nickel | 39 | <0.1 | 233 | 200 | |
| Nitrogen | 679 | 4 | 5,400 | | |
| Phosphorous | 4,392 | 100 | 10,000 | 17,500 | |
| Potassium | 51,000 | 2,000 | 243,000 | 41,000 | 60,400 |
| Silicon | | | | 13,300 | |
| Sodium | 4,439 | 256 | 44,533 | 8,400 | |
| Sulphate | 38,000 | 100 | 259,000 | | |
| Zinc | 1,354 | 32 | 13,000 | 165 | |

The Table below gives typical straw ash composition (FEC 1988).

| | Wheat % | Barley % | Rape % | Average % |
|---|---|---|---|---|
| CaO | 4.0-17.0 | 5.20-14.7 | 26.5-66.0 | 16.9 |
| MgO | 1.2-2.6 | 1.1-2.0 | 1.0-2.5 | 1.6 |
| $SiO_2$ | 42.6-72.5 | 35.4-69.8 | 0.9-30.5 | 46.4 |
| $Al_2O_3$ | 0.1-1.5 | 0.1-2.1 | 0.1-3.8 | 0.6 |
| $Fe_2O_3$ | 0.1-2.2 | 0.1-6.3 | 0.1-2.2 | 0.8 |
| $Na_2O$ | 0.1-0.6 | 0.3-2.3 | 0.8-5.6 | 1.3 |
| $K_2O$ | 16.3-22.0 | 8.8-33.0 | 13.6-30.7 | 20.4 |
| $TiO_2$ | 0.01-0.11 | 0.01-0.17 | 0.01-0.23 | 0.04 |
| $Mn_3O_4$ | 0.01-0.32 | 0.01-0.12 | 0.02-0.05 | 0.06 |
| $SO_3$ | 2.1-6.6 | 2.0-4.8 | 5.4-10.9 | 4.6 |
| $P_2O_5$ | 1.9-7.4 | 2.6-5.0 | 3.0-5.9 | 3.8 |
| $CO_2$ | 0-0.3 | 0-0.4 | 0.9-20.0 | 1.6 |
| Cl | 0 | 0-13.2 | 0-5.3 | 1.5 |

The table below gives details of trace pollutants in ash from straw combustion (Sander & Andrén 1996).

| | **Fly ash (mg/kg)** | **Bottom ash (mg/kg)** |
|---|---|---|
| **Cd** | 9.0 | 0.1 |
| **Pb** | 139.2 | 3.4 |
| **Cr** | 28.6 | 42.5 |
| **Ni** | 16.5 | 17.7 |
| **Cu** | 97.1 | 41.4 |
| **Zn** | 872.3 | 52.7 |

Data averaged from 4 straw types and 7 heating plants in Sweden.

The Table below gives typical poultry litter ash composition (www.ecn.nl/phyllis/).

| | **Poultry litter %** |
|---|---|
| **$CaO$** | 27.3 |
| **$MgO$** | 9.1 |
| **$SiO_2$** | 15.9 |
| **$Al_2O_3$** | 1.5 |
| **$Fe_2O_3$** | 3.3 |
| **$Na_2O$** | 0.7 |
| **$K_2O$** | 23.5 |
| **$TiO_2$** | - |
| **$Mn_3O_4$** | - |
| **$SO_3$** | 2.5 |
| **$P_2O_5$** | 12.1 |
| **$Cl$** | 2.6 |

The table below gives details of trace pollutants in ash from poultry litter combustion (FEC 1995).

| | Fly ash (mg/kg) | Bottom ash (mg/kg) |
|---|---|---|
| **Cd** | 2.1 | <0.1 |
| **Hg** | <0.1 | 1.3 |
| **As** | 7.6 | <0.1 |
| **Pb** | 22.4 | 0.6 |
| **Cr** | 26.7 | 2.3 |
| **Ni** | 32.9 | 4.2 |
| **Cu** | 465 | 77 |
| **Mn** | 690 | 365 |
| **Co** | 13.8 | 0.63 |
| **Sb** | 4.1 | <0.1 |
| **Sn** | 2.9 | 1.6 |
| **Tl** | <0.1 | 0.8 |
| **V** | 17 | 2.8 |
| **Dioxins I-TEQ** | 0.028ng/g | <0.005ng/g |

# APPENDIX 5 Example biomass power plants

*Combustion*

The table below summarises the features of some biomass combustion plants. After the table, brief additional description is given on some of the plants.

**Examples of biomass power plants**

| | fuel[1] | 1000 t/y | tech[2] | capacity $MW_{th}$ | output $MW_e$ | output $MW_{th}$ | steam °C | steam bar | steam kg/s |
|---|---|---|---|---|---|---|---|---|---|
| **Brista** | FR | | CFB | 132.6 | 44 | 85 | 540 | 140 | 50 |
| **Cuijk** | WR | 250 | BFB | 82 | 24.6 | | 525 | 100 | 27.4 |
| **Elean** | S | 200 | G | | 36 | | 540 | 92 | |
| **Enköping** | W | | G | 80 | | | 540 | 100 | 10.2 |
| **Ensted** | S<br>W | 120<br>30 | S/G | | | 41 | 542 | 200 | 33.3 |
| **Eye** | PL | 164 | G | 56 | 12.7 | | 450 | 65 | 13.9 |
| **Falun** | W | | FB | 35 | | | 490 | 63 | 10.2 |
| **Glanford** | PL | 180 | S | 55 | 13.5 | | 453 | 67 | 17.2 |
| **Karlstad** | W | | CFB | 88 | | | 500 | 66.7 | 29 |
| **Kristian-sand** | W | | BFB | 55.5 | | | 510 | 65 | 5.7 |
| **Navarra** | S | 160 | | | | | | | |
| **Skellefteå** | W | 106 | CFB | | 35.6 | 62.9 | 540 | 140 | 37 |
| **Thetford** | PL | 450 | G | | 38.5 | | | | |
| **Växjö** | FR | | CFB | 100 | 38 | 62 | 540 | 142 | 41 |
| **Westfield** | PL | 110 | BFB | | 10 | | 460 | 60 | |
| **Germany** | WW | | G | 8.5 | | | 265 | 28 | |

Notes: [1]FR forest residues, PL poultry litter, S straw, W wood, WR wood residue, WW waste wood
[2]BFB bubbling fluidised bed, CFB circulating fluidised bed, FB fluidised bed, G grate, S stoker

Brista power plant (Sweden) uses chipped forest residues. The moisture content of the fuel is around 55% and no drier is used before combustion. It has been estimated that the plant uses 10% of the annual growth (in energy) of the forests around the plant. The steam turbine has high and low pressure parts (Rydehell 1998, Wahlund *et al* 2001)

The Cuijk plant in the Netherlands uses clean wood residues from pruning and thinning as well as some sawmill waste.

Elean Power Plant (near Ely) is the UK's first straw-fired power station. Fuel consumption (by energy) is 90% straw and 10% natural gas. Moisture content below 25% is required. Straw arrives in big bales and it then fed to the conveyor by unloading cranes. Before being fed to the boiler the bales go through twine cutters and bale shredders. Boiler consists of a two-stage grate (stationary + vibrating) and an economiser. Main emissions (besides flue gas) are dust from straw barn vents, water treatment resin regeneration effluents to sewer together with normal boiler blow-down, turbine drains and periodic cooling water purge (EA Introductory and authorisation notes available from public register).

In Ensted power plant in Denmark straw is used as the main fuel while wood chips are used for superheating. The plant has a Benson type boiler with a screw stoker and a vibrating grate and it is coupled on water/steam side with 660 MW pulverised coal plant (Ramsgaard-Nielsen *et al* 2001). In Denmark, grate combustion is currently used for large-scale thermal conversion (CHP) of straw.

The power plant in Skellefteå (Sweden) uses 80% wood (chips, bark) and 20% peat. The power plant is integrated with a pellet plant and process steam can be used in pellet production (drying) (Tomic 2000, Wahlund *et al* 2001).

The main fuel at the Thetford plant is poultry litter but it also uses some wood waste and straw/horse bedding. The mean moisture content of the fuel is 42.8%. Both Eye and Glanford can take fuel with moisture content between 25 and 50%.

Växjö Energi AB (Sweden) owns a CHP plant built in 1997. The plant uses circulating fluidised bed technology to forest residue chips, bark, sawdust and occasionally peat. The calorific value of the fuel is typically 8.2 MJ/kg and moisture content 50 w-%. Particle size needs to be less than 200 mm. Feed water temperature is 230ºC and flue gas exits at 130ºC. The plant operates 5,000 to 6,000 hours per year (Alakangas and Veijonen 1998)

The Westfield Biomass Plant is the first plant in the world to use fluidised bed technology for poultry litter. It is also the first plant in Scotland that generates electricity using this particular biomass fuel.

The plant in Germany uses waste timber and wooden frames, telegraph poles, wooden poles from vineyards etc. The fuel has a calorific value between 12 and 20 MJ/kg and moisture content up to 30%. The plant has an inclined movable grate (Graf and Feldmann 2001).

***Gasification***

**Examples of biomass gasification plants**

| | **fuel** | **1000 t/y** | **Technology** | **capacity $MW_{th}$** | **output $MW_e$** | **output $MW_{th}$** |
|---|---|---|---|---|---|---|
| **ARBRE** | SRC | 41.5[1] | CFB (atm) | | 8 | |
| **Värnamo** | Forest residue | | CFB (pres 18 bar) | 18 | 6 | 9 |

Notes: [1]in odt

The ARBRE plant in North Yorkshire uses mainly SRC with some chipped forest residues. The incoming fuel is dried with flue gas. The plant includes an atmospheric pressure gasifier, gas turbine, heat recovery steam generator (HRSG) and steam turbine. The total amount of electricity generated is 10 $MW_e$, of which 8 $MW_e$ is exported (ARBRE website http://www.arbre.co.uk/, Pitcher and Weekes 2001).

At the Värnamo demonstration plant in Sweden flue gas drier is also used. The moisture content of the fuel after drying is 5 to 20%. Operating temperature is 950-1000ºC, which is a bit higher than in ARBRE plant, and contrary to ARBRE Värnamo uses pressurised gasification. Fuel gas (LHV 5 MJ/m$^3$n) goes through gas cooler and filter to a gas turbine with an output of 4.2 $MW_e$. After HRSG the steam turbine (40 bar, 455ºC) generates further 1.8 $MW_e$ (Ståhl *et al* 2001, Wahlund *et al* 2001).

***Co-firing***

In different European countries different combustion techniques and biomass fuels are used in co-firing. In Finland, for example, biomass is often used as the main fuel in fairly small (5-20 MW) plants, while in Sweden co-firing smaller portions of biomass with coal is more common. Waste wood is used in co-firing in many European countries while straw is used (co-firing with coal) mainly in Denmark (Rösch 2001).

The table below gives basic information on some existing biomass co-fired power plants in Europe. After the table some additional information is again given.

**Examples of power plants where biomass is co-fired**

| | **fuel** | **1000 t/y** | **tech** | **capacity MW** | **output $MW_e$** | **output $MW_{th}$** | **steam °C** | **steam bar** | **steam kg/s** |
|---|---|---|---|---|---|---|---|---|---|
| **Grenå** | S<br>C | 70<br>38 | CFB | 80 | 17 | 40+20[1] | 500 | 92 | |
| **Midtkraft** | S, C | | | 380 | 150 | | 540 | 143 | 139 |
| **Kymijärvi** | G, C | | | | 167 | 240 | | | |
| **Västhams -verket** | B, C | | | | 65 | 129 | 540 | 110 | 82 |

Notes: B biomass, C coal, G fuel gas from biomass gasification, S straw
[1] process steam and district heat

The Grenå plant (Denmark) started in 1992 and uses straw and coal. The maximum share of straw is 60%.

Midtkraft Power Company plant can use a maximum of 20% straw.

Kymijärvi power plant (Lahti, Finland) has and atmospheric CFB gasifier where wood with high moisture content (50-55%) is gasified. The gasifier load is between 30 and 45 MW. The produced fuel gas is then used in a pulverised coal fired steam boiler. Flue gas recirculation, staged combustion, no sulphur removal (low-S coal). In order to start using fuel gas with coal only small modification were needed for the existing PF-boiler. In this type of arrangement, problems with gasifier do not require the shutdown of the power plant.

Västhamsverket plant uses wood pellets with calorific value typically between 17.8 and 18.2 MJ/kg and moisture from 4.4 to 5%. The plant has a steam boiler with a back pressure turbine. Clear reductions on $SO_x$ and $NO_x$ when co-fired (Rörgren and Olsson 2001).

## Summary of factors important to co-firing of biomass with fossil fuels in the UK

Under the renewables obligation (RO) co-firing of biomass with fossil fuel is eligible for all biomass until 2006. After this date 75% of the biomass used must come from energy crops. Co-firing will cease to be eligible after 2011. No more than 25% of a supplier's Obligation can be met using co-firing.

The immediate issues of importance to co-firing will be price; fuel supply; storage; fuel handling; quality control and composition of the biomass resource; impacts on combustion equipment; impacts on efficiency; impacts on ash use.

**Price.** It is not possible to predict the effect of the RO on the market. The initial buy-out price will be £30/MWh, so this will set the upper limit on the economics of co-firing. At this price it is likely that some co-firing will be attractive. If the required percentage of renewable electricity is not generated, buy-out funds will be re-distributed to suppliers, in proportion to the level of their Obligation that has been met. Under these circumstances it is likely that generators of renewable electricity (including co-firing) will be in a good negotiating position with suppliers and will receive a price that takes these redistributed funds into account.

**Fuel supply.** Initially (up to 2006) all biomass sources will be of interest. After this date, energy crops will dominate the issue. As energy crops take some time to establish there is an immediate need to plan for planting. It is likely initially that all sources of biomass, including some traditionally regarded as wastes may be considered for co-firing. Ofgem will require the supplier to demonstrate that these sources satisfy its eligibility rules (that the source is 98% biomass, with proof that the fossil-derived energy content in the biomass residue used is less than 2%).

**Storage.** As many sources of biomass are seasonal, storage will be an important issue. It is likely that storage will be combined with drying or partial drying of energy crops.

**Fuel handling**. Bulk handling and transport are covered elsewhere in the report. At the power station there will be a number of options open to the generator including: mixing of the biomass with coal in the fuel delivery system; separate handling, metering and comminution of the biomass with injection upstream into the burners; a dedicated handling and firing system; use of the biomass as a reburn fuel. Factors such as the quantity and quality of the biomass and the nature of operation of the power plant will influence the choice of handling at the plant.

**Quality control and composition of the biomass fuel.** It is likely that the generator will establish a quality control system. The operator will wish to test the fuel initially to ensure that there are no unexpected problems with combustion or emissions as a result of its use. In addition such testing will provide information on the composition of the ash from the process.

**Impacts on combustion equipment.** Experience in systems abroad indicates that the most important impacts will be slagging, fouling and corrosion. The extent of these impacts will depend on the composition of the biomass, which in turn is influenced by moisture content, where the biomass is grown and the fertilisers used. Components such as chloride and alkali metals are important in causing corrosion, which is one reason why schemes involving significant amounts of straw usually involve stand-alone systems with combination of the steam in the power station super heaters. There are indications that the way in which the fuel is mixed with coal can have a significant effect in reducing the corrosive gases generated, when the coal has a high sulphur content.

**Impacts on efficiency.** The CV of biomass is generally lower than that of conventional fossil fuels. Thus schemes involving significant amounts of low CV biomass may influence the efficiency of the power station.

**Impacts on ash use.** Ash from conventional coal power stations is used extensively in the cement and aggregates industry. The co-firing of biomass may increase ash deposition; increase the rate of gas-side corrosion; generate a finer ash than coal, with possible impacts on particulate collection equipment; interfere with the operation of $SO_x$ and $NO_x$ abatement equipment; and have impacts on the utilisation and disposal of ash from the station. It is important that ash from the biomass does not interfere with the normal re-use of ash from the station and create a waste that requires disposal. International work indicates that wood based material does not have a deleterious impact, but that the design mix for the concrete has to be altered. This is an area where further work is required in the UK.

## APPENDIX 6 Raw data for economics

Note: The year in brackets indicates the date of the original data. Figures have been converted to present day values using the retail price index, supplied by the Office of National Statistics. If the year has not been mentioned in the reference, the publishing year has been used. For predictions, no correction has been made.

In most cases it is unclear exactly what is included in the figures. Sometimes there is no information on the type and/or size of the plant either. Not all costs are relevant to business calculations and for international data there are differences in national framework (e.g. taxes, labour costs, emissions regulations etc).

### Wood combustion

| | **Wood Combustion** | |
|---|---|---|
| capital | £560,000/MW [1] | Austria, dh, max 5y old, >1y in operation, 0.5-10 MW (2000) |
| | £975,000/MW [1] | Denmark, dh, max 5y old, >1y in operation, 0.5-10 MW (2000) |
| | £395,000/MW [1] | France, Sweden, dh, max 5y old, >1y in operation, 0.5-10 MW (2000) |
| | ~£1m/$MW_e$ [2] | general estimate for UK biomass plant |
| | £865,000m/$MW_e$ [3] | 20 $MW_e$ (1996) |
| | £2.0m/$MW_e$ [3] | 2 $MW_e$ (1996) |
| | £2.4m/$MW_e$ [4] | 20 $MW_e$, conventional forestry (1996) |
| | £2.4m/$MW_e$ [4] | 20 $MW_e$, SRC (1996) |
| | £1.0m/$MW_e$ [5] | Ireland (2000) |
| | ~£1m/$MW_e$ [6] | 25 $MW_e$, Netherlands, based on ~30% efficiency (2000) |
| | £600,000/MW [7] | 3.1 $MW_e$, Italy (2000) |
| | £3.3m/$MW_e$ [8] | 3.4 $MW_e$ (2000) |
| | £3.2m/$MW_e$ [8] | 4 $MW_e$, CHP (2000) |
| | £3.3m/$MW_e$ [8] | 3.5 $MW_e$, CHP, (2000) |
| | £3.9m/$MW_e$ [8] | 3.6 $MW_e$, CHP (2000) |
| | £1.2m/$MW_e$ [8] | 44 $MW_e$, CHP (2000) |
| O&M | £400,000/y [2] | |
| | £580,000/y [3] | 20 $MW_e$ (1996) |
| | £1.2m/y [4] | based on 2.5% of capital cost (1996) |
| | £0.008/kWh [5] | Ireland (2000) |
| | £0.0014/kWh [7] | 3.1 $MW_e$, Italy (2000) |
| labour | £500,000/y [2] | |
| | £220,000/y [3] | 20 $MW_e$ (1996) |
| fuel (delivered) | £25-45/odt | see chapter 6 of this report |
| steam turbine | £135,000/MW [9] | 10-30 MW, Italy (2000) |
| gas turbine | £975,000 [7] | 3.1 $MW_e$, Italy (2000) |
| heat exchange recuperator | £120,000 [7] | 3.1 $MW_e$, Italy (2000) |

| | | |
|---|---|---|
| generator | £275,000/MW [9] | 10-30 MW, Italy (2000) |
| gas cleanup+ residue treatm | £68,500/MW [9] | 10-30 MW, Italy (2000) |
| combustor | £610,000 [7]<br>£275,000/MW [9] | 3.1 $MW_e$, Italy (2000)<br>10-30 MW, Italy (2000) |
| installation | £130,000 [7] | 3.1 $MW_e$, Italy (2000) |
| fuel treatment | £68,500/MW [9] | 10-30 MW, Italy (2000) |
| total* | £1.0m/MW [9]<br>£0.004/kWh [10]<br>£0.023/kWh [10]<br>£0.014/kWh [10] | 10-30 MW, Italy (2000)<br>industrial CHP, Portugal, forest residues 1995<br>industrial CHP, Portugal, SRC 1995<br>CFB, CHP, Sweden, forest residues 1995 |

dh district heating
*including investment, fuel, O&M, clean-up, labour

[1] Starzer *et al* 2001, [2] personal communication, N Barker, F Dumbleton, [3] Moore 1996,
[4] Mitchell *et al* 1996, [5] van den Broek *et al* 2001, [6] Kwant 2000, [7] Martelli *et al* 2001
[8] Pfab *et al* 2001, [9] Maiorano *et al* 2001, [10] Ericson 2001

## Poultry combustion

| | **Poultry Combustion** | |
|---|---|---|
| capital | £2.3m/$MW_e$ [1]<br><br>£2.1m/ $MW_e$ [2,3]<br>£2.3m/ $MW_e$ [3,4]<br>£2m/ $MW_e$ [5] | 10 $MW_e$, BFB, UK (2000)<br>38.5 $MW_e$, UK (1996)<br>12.7 $MW_e$, UK (1992)<br>general estimate for UK |
| operating | £1.4m/y [4,6] | 12.7 $MW_e$, UK (1992) |
| labour | £540,000 [4]<br>£500,000 [5] | 12.7 $MW_e$, UK (1992) |
| fuel (delivered) | £500,000 [5]<br>~0 [5]<br>£1.6m/y [4] | <br><br>12.7 $MW_e$, UK (1992) |

[1] http://www.eprl.co.uk/projects.htm, [2] www.caddet.co.uk/html/body_398art8.htm,
[3] http://www.fibrowatt.com/, [4] FEC Consultants Ltd, 1995,
[5] personal communication F Dumbleton, [6] http://www.caddet.co.uk/assets/no17.pdf

## Straw combustion

| | **straw combustion** | |
|---|---|---|
| capital | £1.8m/$MW_e$ [1]<br>£1.9m/MW [2]<br>£2.9m/$MW_e$ [3]<br>£2m/$MW_e$ [4]<br>£5.1m/$MW_e$ [5] | 36 $MW_e$, UK (2000)<br>20 $MW_e$ (1994)<br>CHP, Denmark (1995)<br>General estimate for UK<br>1.25 $MW_e$, CHP (2000) |

| | | |
|---|---|---|
| O&M | 1.6m/y [4]<br>£900,000/y [3] | <br>CHP, Denmark (1997) |
| | 500000 [4]<br>£435,000 [2] | <br>20 $MW_e$ (1994) |
| fuel (delivered) | £35/odt<br>£1.8m/y [4]<br>£4.3m/y [2] | see chapter 6 of this report<br><br>20 $MW_e$ (1994) |

[1] http://www.eprl.co.uk/projects/ely.htm, [2] FEC Consultants Limited, 1994,
[3] http://www.caddet-re.org/assets/1-97art3.pdf, [4] personal communication, F Dumbleton,
[5] Pfab 2001

## Wood gasification

| | **wood gasification** | |
|---|---|---|
| capital | £3.5m/$MW_e$ [1] | 6 $MW_e$, co-generation, demo (1995) |
| | £2.9m/$MW_e$ [1] | 10 $MW_e$, electricity only (1995) |
| | £0.9-1.1m/$MW_e$ [1] | early commercial ~30 MW |
| | £930,000/ $MW_e$ [2] | 55 $MW_e$, co-generation |
| | £1.4m/ $MW_e$ [2] | 15 $MW_e$ |
| | £0.7-1.1m/ $MW_e$ [3] | future adv BIG-CC, >100 MW |
| | £785,000 [4] | 2 $MW_{th}$, CHP, Germany (2000) |
| | £2.0m [4] | 6 $MW_{th}$, CHP, Germany (2000) |
| | £2.1m/ $MW_e$ [4] | 0.5 $MW_e$, Germany (2000) |
| | £1.8m/ $MW_e$ [4] | 1.4 $MW_e$, Germany (2000) |
| | £2.0m [5] | 3.1 $MW_e$, Italy (2000) |
| | £2.4m/ $MW_e$ [6] | 20 $MW_e$, conv forestry (1996) |
| | £3.1m/ $MW_e$ [6] | 20 $MW_e$, SRC (1996) |
| | £1.5m/ $MW_e$ [7] | Ireland, atmospheric, available 2010 |
| | £950,000/ $MW_e$ [7] | Ireland, fixed bed, CHP |
| | £620,000/ $MW_e$ [7] | Ireland, advanced BIG-CC, av 2025 |
| | £1.5m/ $MW_e$ [8] | matured |
| O&M | £600,000/y [8] | |
| | 0.13p/kWh [5] | 3.1 $MW_e$, Italy (2000) |
| | 0.68p/kWh [7] | Ireland, atm, available 2010 |
| | 3.73p/kWh [7] | Ireland, adv BIG-CC, av 2025 |
| labour | £700,000 [8] | |
| fuel (delivered) | £25-60/odt | see chapter 6 of this report |
| | £2.3/GJ [1] | forest fuel, Sweden (1995) |
| | £1.7/GJ [1] | SRC chips, UK (1995) |
| HRSG+ turbines | £340,000/MW [9] | 10-30 MW, Italy (2000) |
| gas turbine | £975,000 [5] | 3.1 $MW_e$, Italy (2000) |
| heat exchange recuperator | £155,000 [5] | 3.1 $MW_e$, Italy (2000) |
| generator | £275,000/MW [9] | 10-30 MW, Italy (2000) |
| gas cleanup + | £100,000/MW [9] | 10-30 MW, Italy (2000) |

residue treatment

| | | |
|---|---|---|
| gasifier | £680,000 [5] <br> £340,000/MW [9] | 3.1 $MW_e$, Italy (2000) <br> 10-30 MW, Italy (2000) |
| installation | £130,000 [5] | 3.1 $MW_e$, Italy (2000) |
| fuel treatment | £136,000/MW [9] | 10-30 MW, Italy (2000) |
| total* | 4.1p/kWh [10] <br> 6.7p/kWh [10] | forest residues, Sweden, co-gen (1995) <br> SRC, UK, el only (1995) |

* including investment, fuel, O&M, clean up and labour.

[1] Bauen 2001, [2] Ståhl *et al* 2001, [3] Faaij *et al* 2001, [4] Pfab *et al* 2001, [5] Martelli *et al* 2001, [6] Mitchell *et al* 1996, [7] van den Broek *et al* 2001, [8] personal communication F Dumbleton, N Barker, [9] Maiorano *et al* 2001, [10] Ericson 2001

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ASSI | Area of Special Scientific Interest |
| BAT | Best Available Technique |
| BFB | Bubbling Fluidised Bed |
| BIG-CC | Biomass Integrated Gasification Combined Cycle |
| CCGT | Combined Cycle Gas Turbine |
| CCL | Climate Change Levy |
| CFB | Circulating Fluidised Bed |
| CHP | Combined Heat and Power |
| CV | Calorific Value |
| DEFRA | Department of Environment, Food and Rural Affairs |
| dnc | Declared Net Capacity |
| DTI | Department of Trade and Industry |
| EA | Environment Agency |
| EAL | Environmental Assessment Level |
| EIA | Environmental Impact Assessment |
| EQS | Environmental Quality Standards |
| ESP | Electrostatic Precipitator |
| FCA | Forestry Contracting Association |
| GHG | Greenhouse Gases |
| GWP | Global Warming Potential |
| ha | Hectare |
| HER | Hydrologically Effective Rainfall |
| HGV | Heavy Goods Vehicle |
| IPM | Integrated Pest Management |
| IPPC | Integrated Pollution Prevention and Control |
| IRR | Internal Rate of Return |
| LA | Local Authority |
| LPG | Liquefied Petroleum Gas |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| MBM | Meat and Bone Meal |
| MJ | Mega Joule |
| MSDS | Material Safety Data Sheet |
| MSW | Municipal Solid Waste |
| NETA | New Electricity Trading Arrangement |
| NFFO | Non-Fossil Fuel Order |
| NFPA | Non-Fossil Purchasing Agency |
| $Nm^3$ | Normal cubic metre |
| NNR | National Nature Reserve |
| NPK | Nitrogen, Phosphorus, Potassium |
| O&M | Operation and Maintenance |
| Odt | Oven dry tonnes |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PC | Predicted Concentration |
| PEC | Predicted Environmental Concentration |
| PF | Pulverised Fuel |
| POPC | Photochemical Ozone Creation Potential |

| | |
|---|---|
| PPC | Pollution Prevention and Control |
| ppm | Parts per million |
| RDF | Refuse Derived Fuel |
| RO | Renewable Obligation |
| ROC | Renewable Obligation Certificate |
| RPI | Retail Price Index |
| RQO | River Quality Objectives |
| SAC | Special Area for Conservation |
| SCR | Selective Catalytic Reduction |
| SEPA | Scottish Environment Protection Agency |
| SNCR | Selective Non-Catalytic Reduction |
| SPA | Special Protection Area |
| SRC | Short Rotation Coppice |
| SSSI | Site of Special Scientific Interest |
| t | Tonne |
| TEQ | Toxic Equivalent |
| UHC | Unburnt Hydrocarbons |
| UKBAP | UK Biodiversity Action Plan |
| VOC | Volatile Organic Compound |
| WHO | World Health Organisation |
| y | Year |