TRANSPORT AND SUPPLY LOGISTICS OF BIOMASS FUELS: VOLUME 1 - SUPPLY CHAIN OPTIONS FOR BIOMASS FUELS

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Contractor
Transport Studies Group,
University of Westminster
Scottish Agricultural College

Prepared by:
J Allen (University of Westminster)
M Browne (University of Westminster)
H Palmer (Scottish Agricultural College)
A Hunter (Scottish Agricultural College)
J Boyd (Scottish Agricultural College)

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EXECUTIVE SUMMARY

SCOPE AND OBJECTIVES OF THE PROJECT

The aim of the project has been to examine the options for supplying biomass-fuelled electricity generating stations with fuel of the right specification, in the right quantity at the right time from resources which are typically diverse and often seasonally dependent. The study covers in detail the elements which make up the supply chain for each biomass fuel from the point at which the resource is lying on the ground after harvesting through to delivery at the power station. Growing and harvesting of biomass are only addressed where they have implications for biomass logistics and transport arrangements and delivered cost. The study has assessed the delivered cost, environmental impact of biomass fuel supply and other relevant non-technical issues.

Biomass fuels included in the study are:

- wood waste from conventional forestry operations
- short rotation coppice (i.e. wood grown as a fuel crop)
- straw left as a crop residue from cereal crops
- miscanthus (an energy crop which could be grown on surplus farm land)
- farm animal slurries for anaerobic digestion

INTRODUCTION

The attractions of biomass as a fuel include factors such as:

- it is a sustainable source of fuel compared with fossil fuel.
- increased use of biomass fuels (together with reductions in the use of fossil fuels) will help to reduce emissions of pollutant gases.
- the use of biomass fuels will help to ensure the security of fuel supply in the UK.
- the use of biomass offers the social and economic benefits of employment creation.
- the visual benefits of increased planting of coppice crops and forestry (as well as the role that this plays in encouraging wildlife).

However there are a number of significant problems, some of which will need to be addressed by means of logistics management. The problems include:

- the economic cost of producing energy from biomass. Unless cost reductions can be achieved in the delivered cost of these fuels they will be unable to compete financially with other sources of energy.

- Biomass power stations have a number of environmental impacts that need consideration when thinking about the pros and cons of using biomass. These include the visual impact of the building, the atmospheric pollutants and noise produced at the plant.

- In addition the production and supply of biomass energy has a number of negative impacts including the environmental impacts associated with transport movements including pollutant emissions, noise, visual intrusion and the potential for road accidents.

Logistics activities (i.e. transport, storage and handling) must be managed in an integrated way to achieve successful use of biomass as a fuel for generating power.

THE IMPACT OF BIOMASS CHARACTERISTICS ON LOGISTICS COSTS

Transport is a very important element in the supply chain for biomass fuels. It is the key link in the supply chain, joining together the discrete activities and points in the chain which can include harvesting, storage, handling and delivery to the power station.

Road transport will, in nearly all cases, be the chosen mode for the movement of biomass fuel and can account for anything up to 70% of total delivered fuel costs, depending upon the biomass type.

Storage facilities at the power station will affect transport arrangements; a power station with a small on-site stock level (e.g. a few days supply) will require more regular, evenly spread deliveries than a plant with a large storage capacity.

Several transport related factors will vary from one supply system to another and will affect the transport costs within the supply system. These include:

- vehicle size - the larger the vehicle, the lower the cost per tonne of moving a load (because lorries exhibit economies of scale).

- transport distance (but note that increases in transport distance will result in less than proportionate increases in the total transport cost per vehicle load).

- terminal time (i.e. the time spent by vehicles at a terminal loading and unloading - if expensive transport equipment is unproductive for a significant amount of time during terminal activities this will lead to inefficient utilisation rates).

MANAGEMENT ISSUES IN THE BIOMASS SUPPLY CHAIN

It is essential that power stations receive a smooth, consistent supply of biomass fuel that meets the specified quality criteria. Therefore the biomass supply system must be able to operate in an efficient and reliable manner.

Integration between supply chain activities is necessary if this efficiency is to be achieved in harvesting, handling, storage and transport. A number of different parties are likely to be involved in the supply chain, including farmers and forest owners, agricultural and forestry contractors, transport companies, fuel suppliers and power station operators; co-ordinating activities will be essential in achieving reliability and low cost.

Only by considering the entire supply chain associated with delivery of biomass fuel to power stations in an integrated manner is it possible to gain a better understanding of total delivered costs, and to consider ways in which the supply chain can be efficiently organised and managed to reduce these costs.
To help investigate this we developed a series of spreadsheet models that we have called Supply Chain Option models.

SUPPLY CHAIN OPTION MODELLING APPROACH

The Supply Chain Option models have been designed to incorporate and cost in detail all the activities involved in the supply of fuel from the point at which it is lying on the ground after harvesting through to final delivery to a power station.

The basis of the cost calculations used in the model is the cost of supplying one tonne of dry matter to a power station[1]. This cost is based on the time that any necessary supply activity takes to complete

[1] The cost of supplying wood to the power station, calculated per tonne of dry matter. This is not to suggest that oven dry biomass is supplied to the power station; wet biomass is supplied but our cost calculations are based on the dry matter present in the biomass. The delivered costs produced by the models refer to the actual costs in supplying the fuel on a dry matter basis; they do not therefore include profit margins for contractors (forestry, agricultural and transport contractors).

together with other input costs that go to make up the delivered cost (e.g. the cost of purchasing biomass fuel).

A Supply Chain Option model has been developed for each of the fuels considered in the project. While there are differences in some of the activities involved in supplying these fuels due to the production method and the characteristics of the fuel which have to be reflected in the modelling work, we have produced models which are compatible. This compatibility is important as it facilitates comparison between the costs of fuel supply systems for different biomass fuels within one broad analytical approach.

SUPPLY CHAIN OPTION MODEL CAPABILITIES

The Supply Chain Option modelling approach has been used to:

- obtain an understanding of the delivered cost of different supply chain options for each biomass fuel and compare the delivered costs produced by different supply systems for each fuel
- to investigate similarities and differences in the cost of supply chain options between biomass fuels;
- explore the key logistics cost drivers in the supply chain options for each biomass fuel
- conduct sensitivity analyses with respect to key cost drivers and various parameters used in the initial base case models
- examine where cost reductions could be achieved within the fuel supply chains

Assumptions that are common to all biomass fuels are documented in section 3.5; assumptions specific to a given fuel type are documented in appendices 1 to 5.

OUTPUTS FROM THE SUPPLY CHAIN OPTION MODELLING

Analysis of supply chain costs for each biomass fuel has been divided into three parts:

- total delivered cost to power station.
- breakdown of total delivered costs into its constituent parts and examination of how these costs accumulate along the supply system.
- the activity costs for each supply system (i.e. the importance of cost categories including purchase, harvest, handling, transport and storage in the total delivered cost).

Detailed consideration of the road transport operations and costs for each biomass has been included, together with sensitivity analysis of the effect of road transport distance on delivered cost. Other factors considered in the sensitivity analysis include the delivered costs of biomass fuel if delivered directly to power stations rather than being stored for several months, the effect on delivered costs of a range of decomposition rates for chipped material during storage, and the impact of increases in diesel and labour costs.

DELIVERED COSTS OF BIOMASS FUELS

Forest fuel - the modelling indicates that for forest fuel, the supply system resulting in the lowest delivered cost at the power station is one in which unchipped fuel is supplied. This would then have to be chipped by a centralised chipper at the power station. This chipping cost has not been included in the delivered cost and in order for this system to be the most cost effective, the cost of centralised chipping must be less than £5 per tonne of dry matter.

The terrain chipping system results in the highest delivered cost of all supply systems considered. This is due to the two road transport stages and doubling handling of the wood chips required.

Short rotation coppice - the difference in delivered cost between the cheapest and most expensive supply systems modelled for coppice is not very large. Delivered costs in the cheapest system are only 13% lower than the most expensive system.

The results indicate that the delivered cost of fuel produced using a direct cut and chip harvesting supply systems and stick harvesting supply systems are broadly similar. However, if decomposition of chips during storage can be reduced then direct cut and chip systems would be able to achieve lower delivered costs than stick harvesting systems.

Straw - the results show that straw supply systems producing large Hesston bales have substantially lower delivered costs than systems involving the production of small rectangular bales or roll bales. The modelling suggests that intermediate storage of large Hesston bales (i.e. two road transport movements and double handling) will have delivered costs that are approximately 10% higher than systems involving on-farm storage and then direct road transport to the power station.

Miscanthus - the modelling indicates that a supply system producing baled miscanthus is likely to have lower delivered costs than a direct cut and chop system. In the modelling, the delivered costs per tonne of dry matter are approximately 20% lower for baled miscanthus than for chopped material.

Animal slurry - the supply system involving the use of the largest payload (23 tonnes) articulated road tanker permissable produced the lowest delivered costs for animal slurry.

The results suggest that a supply system using a high speed agricultural tractor with an agricultural slurry tank trailer to supply slurry is capable of producing a slightly lower delivered cost than if using a rigid road tanker of the same payload. Therefore using powerful agricultural equipment rather than haulier-operated road tankers can result in lower supply costs in certain circumstances.

Comparison of delivered costs of biomass fuels - forest fuel, coppice, straw and miscanthus
Our Supply Chain Option modelling suggests that the total delivered costs and the breakdown of these costs between activity cost categories are, as would be expected, significantly different from one biomass fuel to another. The range of delivered costs produced by the supply systems modelled for each biomass fuel are shown in the figure below.

The range of delivered cost for biomass supply systems
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N.B. Forest fuel supply system D, which involves the supply of unchipped forest fuel to the power station, has not been included in the above diagram as the cost we have calculated for this system (£27 per tonne of dry matter) does not include the cost of centralised chipping and is not, therefore, a final delivered cost. The modelling shows that the delivered cost per tonne of dry matter for large rectangular Hesston bale straw systems are lower than the costs of other biomass fuel supply systems. This is due to the fact that there are no growing costs for straw (as it is a by-product). In addition, such straw supply systems already exist commercially, serving markets such as the animal feed and bedding and the mushroom composting industry.
Therefore these supply systems have been subject to a long period of supply chain planning and machinery developments in order to make them as efficient as possible. The same is not true (or at least not to the same degree) of the supply chains for other biomass fuels.

Forest fuel supply systems provide the next lowest delivered costs per tonne of dry matter at power station in our modelling. The supply of unchipped residues has been calculated to have the potential to achieve a similar delivered cost as large rectangular Hesston straw bales. However these residues would have to be processed and the cost of centralised chipping at the power station would result in higher final delivered costs than those in the straw systems.

The delivered costs for the short rotation coppice supply systems that we have modelled are, on average, approximately 50% greater than the delivered costs of forest fuel supply systems (approximately £33 per tonne of dry matter in forest fuel systems compared with £50 per tonne of dry matter in coppice systems). The main difference between these two fuels is that coppice has to be grown specifically for biomass supply and therefore the costs of this are all attributable to the biomass supply system, whereas forestry material is a waste by-product and the costs of growing this material are not borne by the biomass industry.

The miscanthus systems modelled indicate that delivered costs are likely to be as high as, if not higher than, short rotation coppice. Again a major cost component is likely to be the money that will have to be paid to farmers to encourage them to grow miscanthus on their land.

For all biomass fuels in which the use of intermediate storage systems have been modelled, the results suggest that this is likely to result in a higher delivered cost than a system in which there is only one road transport movement (direct from farm/forest store to power station). In a supply system with intermediate storage the biomass will have to be transported twice by road transport vehicles (first from farm/forest to intermediate store and then after storage from store to power station). Use of an intermediate store will add in the region of 10% to 20% to delivered costs, as a result of the additional transport and handling costs incurred.

In devising a supply strategy for a power station, the fuel supplier is likely to have to operate a range of different systems to ensure that biomass supply can be maintained all year round. For example, a fuel supplier supplying straw will probably have to make use of an intermediate store supply system as well a farm store supply system. Although according to our work the farm store system would be preferable to intermediate storage in terms of delivered cost, it is unlikely that farm stores could be accessed by road transport vehicles during certain periods of the year and therefore intermediate stores would also have to be available. Therefore whilst delivered cost comparisons between different supply systems are important, it must be borne in mind that in reality a fuel supplier is likely to have to adopt a number of supply systems to be able to ensure a balanced fuel supply strategy in which the delivery of biomass on a regular year round basis is essential to the functioning of the power station.

Delivered costs of animal slurry

Direct comparisons between the delivered costs of animal slurry systems that we have modelled and other biomass fuels are not advisable due to the different energy content and the extremely low dry solids content of the slurry compared with other fuel types. In addition, the animal slurry systems modelled are based on one-way transport distances of 10 kilometres compared with 40 kilometres for each of the other biomass fuels.

The major cost in animal slurry supply systems is the transportation and handling cost. Minimising transport distance in slurry systems will be critical in achieving lowest delivered costs possible. By using the largest road transport tankers legally permissible transport costs can be minimised per tonne of slurry delivered. However the largest vehicles may have difficulty operating on small roads connecting cattle and pig farms to the centralised digester in some locations. In such situations the use of road transport tankers with smaller payloads or high speed agricultural tractors (e.g.Fastracs) hauling agricultural tankers would be necessary.

Effect of road transport distance on delivered cost

Delivered costs are relatively insensitive to transport distance for most of the biomass fuels studied in this project; this is true of forest fuel, short rotation coppice, straw and miscanthus. The results of the modelling show that a transport distance from farm/forest to power station of 80 kilometres (ie a round trip distance of 160 kilometres) will produce delivered costs that are only 5% to 15% greater than for a transport distance of 40 kilometres (round trip distance of 80 kilometres). Several factors explain the limited effect of increased transport distances on the delivered cost of most biomass fuels. These include:

- the proportion of delivered cost accounted for by transport (trip and terminal) costs (these account for between 15% and 40% of delivered costs in all supply systems modelled other than animal slurry).

- average trip speed is likely to increase as transport distance increases (since a greater proportion of the journey will be conducted on higher category roads) and therefore any increase in distance will result in a less than proportionate increase in trip time and hence trip costs. Conversely, as transport distance decreases, average speed over the journey will fall and therefore trip time and hence trip costs will fall by a less than proportional amount.

- terminal costs will remain the same even when transport distance changes.

The delivered cost of animal slurry is more sensitive to transport distance than for the other biomass fuels studied. In these supply systems a transport distance of 20 kilometres is likely to result in delivered costs between 30% and 65% higher than when transporting the slurry 5 kilometres (depending upon the supply system used). This is explained by the proportion of delivered cost accounted for by transport activities in these supply systems (i.e. transport and handling are by far the most important costs in these systems, to a far greater extent than in supply systems for other biomass fuels).

However, although the modelling work undertaken suggests that delivered cost is relatively insensitive to the distance the biomass is transported for most fuel types, in order for biomass schemes to prove economic they must strive to produce the lowest delivered costs possible. Therefore by sourcing fuel from closer rather than more distant locations, cost savings can be achieved and these may prove to be crucial to the financial viability of generating electricity from biomass fuel.

FACTORS INFLUENCING TRANSPORT DISTANCE

The catchment area for the biomass resource and hence the transport distance over which biomass will have to be moved between storage locations and power stations will depend upon a number of key factors. These include the:

- size of the power station and the conversion technology used

- crop yield that is achieved

- proportion of land around the power station planted with biomass energy crops (ie coppice and miscanthus), or crops that have biomass as a byproduct (ie straw) or density of forestry in the case of forest fuel

- availability of the material for biomass resource (e.g. straw has competing uses and therefore only a proportion of the total produced will be available for use in biomass schemes).

MODELLING THE TRANSPORT SYSTEMS TO SERVE POWER STATION REQUIREMENTS

Using information obtained from planning applications and our knowledge of biomass transport from the Supply Chain Option modelling, we have analysed the transport requirements of biomass power stations. This involves consideration of the ways in which decisions made by the power station managers and the local planning authority will affect the transport system needed to serve straw, coppice and animal slurry fuelled power stations.

The transport system requirements for these biomass power stations have been modelled in terms of: -

- vehicle deliveries to the power station (per day and per year)
- maximum number of round trips per vehicle per day
- road transport vehicles and drivers required
- vehicle kilometres travelled (per day and per year)

The table below shows the number of vehicle deliveries required per day, the total annual kilometres performed and the vehicle fleet requirements for power stations using different biomass fuels. Full details of the assumptions on which the table is based can be found in section 10.3.

Road transport requirements for biomass power station

Type and size of power station	Vehicle deliveries per day	Total annual vehicle kilometres supplying fuel to the power station	No.of road transport vehicles required
20 MW straw-fired	40	800,000	10
10 MW coppice-fired	24	480,000	6
1 MW anaerobic digester	18	90,000	4

ENVIRONMENTAL IMPLICATIONS OF BIOMASS SCHEMES

There are a number of positive environmental impacts associated with the use of biomass fuel for electricity generation that make it an attractive energy source. Many of these benefits are identified by the UK Government in their Planning Policy Guidance 22 (PPG 22) which sets out the Government's advice on the issues to be taken into account in considering planning applications for renewable energy projects in England and Wales (and the equivalent document NPPG 6 for Scotland).

However, the use of biomass fuel for electricity generation could result in several negative environmental impacts that need to be considered in assessing the relative merits of any specific proposed biomass scheme. In PPG 22 the government recognises this, "sites proposed for the development of renewable energy sources will often be in rural areas or on the coast, and such development will almost always have some local environmental effects. The Government's policies for developing renewable energy sources must be weighted carefully with its continuing commitment to protecting the environment" (DOE, 1993).

As well as the negative impacts that will result from the construction and operation of a biomass power station, there are also several negative impacts associated with the transport and logistics supply chain for biomass fuels. These include:

- fuel consumed in mechanically harvesting, processing, handling and transporting the fuels from

farms and forests to power stations;
- fire risks associated with large stores of highly combustible materials;
- effluent run-off from stores;
- health risks associated with mould growth during storage;
- environmental impacts associated with transport movements including vehicle pollutant emissions, vehicle noise and the addition to existing traffic levels that a biomass scheme will result in, and hence the increased potential for road traffic accidents.

Most negative environmental impacts of transport and logistics will manifest themselves at a local scale and will be dependent upon the specific location and scale of a scheme. The physical and human geography of the site and its surrounding area (in terms of its natural physical features such as the topography, geology and ecology, the population density, existing land use patterns, road infrastructure and traffic flows) will determine the significance of this impact. Therefore such negative impacts must be considered in relation to a specific site and catchment area over which the biomass fuel will be sourced.

It is important that the environmental impacts of using biomass fuel (both positive and negative) are carefully considered in any planning applications for such schemes. This should also occur at a strategic level in determining the role that biomass should play in future energy policy.

Research has indicated that the consideration of the public's perception of biomass is also likely to be an important factor if the biomass industry is to gain the widespread support of the general population of the UK. The local public are likely to be concerned about the possible environmental impacts of the biomass fuel supply chain in terms of factors such as the visual impact caused by large storage facilities, the increase in freight traffic on minor roads, the noise involved in processing operations such as chipping, the energy used in supplying the biomass to power stations and the pollution occurring at the power station itself. It is important that the public are involved at an early stage in the biomass planning process and that schemes are carefully chosen and planned to minimise environmental impacts and disruption to local life.

CONCLUDING REMARKS AND RECOMMENDATIONS

All the supply systems modelled in this report are plausible and have the potential to be used in providing fuel for power stations. It is critical that a balanced fuel supply strategy is adopted that is capable of supplying the quantity of biomass required by the power station at the right time, at the right quality all year round. Therefore several different fuel supply systems are likely to have to be operated in providing fuel to the power station to ensure this security of supply. What is therefore important is not attempting to find the single lowest cost system, but instead determining the necessary systems to guarantee supply at all times and then attempting to minimise delivered costs for each of these systems.

The results in the report have indicated that the cheapest supply systems will often not be capable of supplying fuel all year round. The lowest cost options tend to involve on-farm or in-forest storage and there will be periods during the year that these stores will not be accessible due to weather and track surface conditions and other activities taking place on the farm or in the forest. Therefore use of intermediate stores with good quality access at all times will be necessary; supply systems involving intermediate storage will have higher delivered costs than on-farm/in-forest storage due to the double handling and road transport that they entail. However, given that they are necessary, what is important is how to operate and manage these systems to produce the lowest possible delivered cost.

Given the differences in the supply chain requirements for each biomass fuel, it is not possible to develop a research and development strategy spanning all of them. Hence we cannot say that by concentrating on one aspect we will be able through R&D to drive down delivered costs for all biomass types. But by comparing the biomass resources in the manner we have it is possible to identify the way in which the relative maturity in different supply chain systems can help to reduce the costs incurred throughout the supply chain.

A further strength of the present study is the way in which it incorporates an entire supply chain perspective from the point of harvest through to delivery at the power station. By doing this it is possible to consider the interrelationship between all the activities necessary in order to deliver fuel in an efficient way to a power station and it is this need for a co-ordinated approach that will influence the operational and commercial viability of biomass fuelled power generation.

Despite the comprehensive nature of the research there are a number of areas that could be benefit from further work. These include planning and public participation, management of the supply chain and operational issues.

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1. INTRODUCTION AND OBJECTIVES

This document is the final report for the `Transport and Supply Logistics of Biomass Fuels' project which began in May 1994. The project has been funded by the Department of Trade and Industry and managed on their behalf by ETSU.

Five types of biomass fuel are included in the project: forest fuel, short rotation coppice, straw, miscanthus and animal slurry.

1.1 Introduction

Biomass is the living material produced on the planet by the process of photosynthesis. It has been used for thousands of years as a source of energy and is today a major fuel in terms of the quantities used worldwide. In fact, more people depend on biomass for energy worldwide than on any other fuel (UN, 1991).

A number of different primary fuels are referred to as biomass and these are often categorised in four groups:

- wood from existing forestry operations (such as is available from premature clearfell and thinning forestry operations);

- crop residues such as cereal straw;

- energy crops grown specifically for biomass such as willow and poplar trees grown on a short rotation basis on arable land and high energy yielding grasses including miscanthus, spartina and reed canary grass;

- human and animal excrement including cow and pig slurry.

There are a range of conversion technologies available for making use of biomass. The primary fuels can either be used directly (for example burning wood on a stove to produce heat) or can be converted into secondary fuels such as liquid or gaseous fuels through the use of technologies such as gasification, pyrolysis and anaerobic digestion. Both primary and secondary biomass fuels can be used to produce heat, mechanical power or electricity (or a combination of these).

Renewable energy sources (of which biomass is one type along with other renewables such as wind power, solar power, hydro-electric power, tidal power etc) are likely to provide a growing proportion of the world's energy needs in future for a number of key reasons:

- fossil fuel resources are finite;

- the price of fossil fuel is likely to increase as resources are used up;

- the sustainability and abundance of renewable energy;

- increased research and development is likely to reduce the divergence between the cost of renewable and non-renewable energy;

- concern about the environmental impact of using non-renewable energy.

The European Commission have funded a significant number of renewable energy research projects in recent years as part of the initiative to increase the use of renewables in electricity generation. The

Commission hopes to triple the contribution that renewable energy makes to electricity production by the year 2005 (DTI, 1994).

The specific attractions of using biomass as a fuel for generating electricity (the use studied in this project) have been widely noted and include the following factors:

- it is a sustainable source of fuel compared with fossil fuel - resources are replenished in relatively short periods of time (such as in the case of short rotation coppice for example) or are available on a continual basis (such as animal wastes).

- increased use of biomass fuels (together with reductions in the use of fossil fuels) will help to reduce emissions of pollutant gases. Biomass fuels have a neutral carbon balance; although carbon dioxide is released in the use of these fuels, as long as crops and trees are replanted as fast as they are used much of this carbon dioxide will be re-absorbed. These fuels also have very low levels of sulphur and other noxious gases/toxins in comparison with fossil fuels thereby reducing acid rain.

- the use of biomass fuels will help to ensure the security of fuel supply in the UK. By producing fuel in the UK, dependence on fuel imports will be reduced thereby giving the country more control over fuel supply. This will make the country less vulnerable to fluctuations on world energy markets.

- it leads to social and economic benefits of employment creation (both in constructing and operating power stations and also the related activities of growing, storing and transporting the biomass fuel). Biomass offers a new use for arable land no longer required for food crop production as a result of the EC Common Agricultural Policy Set-Aside scheme.

- the visual benefits of increased planting of coppice crops and forestry.

- the role that coppice crops and forestry play in encouraging wildlife.

However there are a number of significant problems associated with using biomass fuel to generate electricity some of which will need to be addressed by means of logistics management. The problems include:

- the economic cost of producing energy from biomass. Unless cost reductions can be achieved in the delivered cost of these fuels they will be unable to compete financially with other sources of energy. Therefore, given that electricity production decisions in the UK tend to be determined by cost considerations, in order to get some such schemes up and running the UK government is making subsidies available to developers of such plants through the Non-Fossil Fuel Obligation for England and Wales (NFFO) and the Scottish and Northern Ireland Renewable Orders (SRO and NI-NFFO).

- the biomass industry is in its infancy in the UK and there is a lack of agreement regarding suitable approaches to a wide range of issues from the growing and harvesting of biomass through to handling, transport and conversion. This is to be expected given the lack of existing large scale electricity generating biomass schemes in the UK. A research and development programme has been progressing in the UK in recent years to address these issues (this has been managed by ETSU). However the biomass industry will take time to develop as companies from other backgrounds (such as agriculture and forestry) become involved and many issues will not be fully resolved until biomass power stations are operational in the UK.

- biomass power stations have a number of negative environmental impacts that need consideration. These include the impact of the chosen location for the plant upon archaeological sites, nature conservation and water resources, the visual impact of the building, the atmospheric pollutants and noise produced at the plant, and any transmission lines required to connect the plant into the existing grid system.

- the production and supply of biomass energy also has a number of negative impacts which need to be taken into account. These include factors such as the fossil fuel consumed in mechanically handling and transporting the fuels from farms and forests to power stations, the fire risks associated with large stores of highly combustible materials and the environmental impacts associated with transport movements (likely to be by road freight vehicles in the UK) including pollutant emissions, noise, visual intrusion, the potential for road accidents and the addition to existing traffic levels this new traffic will result in.

What is clear from the list of problems is that organisation and management of logistics activities (such as transport, storage and handling) in an integrated manner is a key issue in the successful use of biomass as a fuel for generating power.

1.2 Scope of the project

The end users or potential users of biomass fuels can be considered at two different scales. At the lower end are the heat users such as rural industries and institutions and at the other end of the scale are biomass fuelled electricity generating stations or stations firing biomass co-fired with fossil fuels. Small scale heat users are not expected to encounter significant problems with fuel supply logistics and supply of fuels to this category of plant will not feature in this study; the focus is on large scale users.

The aim of the project has been to examine the options for supplying the end user with fuel of the right specification, in the right quantity at the right time from resources which are typically diverse and often seasonally dependent. The study covers in detail the elements which make up the supply chain for each biomass fuel from the point at which the resource is lying on the ground after harvesting through to delivery at the power station. Growing and harvesting of biomass are only addressed where they have implications for biomass logistics and transport arrangements and delivered cost. The study has assessed the delivered cost, environmental impact of biomass fuel supply and other relevant non-technical issues.

Biomass fuels included in the study are:

- wood waste from conventional forestry operations
- short rotation coppice (i.e. wood grown as a fuel crop)
- straw left as a crop residue from cereal crops
- miscanthus (an energy crop which could be grown on surplus farm land)
- farm animal slurries for anaerobic digestion

1.3 Objectives of the project

The project aims to provide a detailed level of understanding about biomass fuel supply so that it is possible to address four key objectives:

- to outline suitable systems for the supply of biomass fuels to power plants and identify the delivered costs associated with these supply systems;
- to identify the relative cost importance of each of the supply chain activities that make up the delivered cost for each biomass fuel and where future development efforts might be best directed in order to reduce delivered fuel costs;
- to examine the impact on the environment of the transport and logistics arrangements considered, in terms of factors such as total vehicle movements, fossil fuel used in transportation and logistics and other environmental effects of biomass supply associated with logistics.
- to consider the geographic distribution of biomass resources in relation to size and location of potential power stations.

This report contains discussion of the logistics and transportation considerations for biomass fuels, the definition of appropriate logistics systems for each biomass fuel included in the project, modelling the delivered costs of these biomass supply systems to power stations for each fuel together with examination of the management and operation of fuel supply systems and their environmental impact.

A companion report contains details of work undertaken to establish the geographic distribution of existing and potential biomass resources in the UK and modelling of potential power station sizes and locations in relation to this resource data.

1.4 Report outline

Chapter 2 of the report discusses the importance of transport and logistics management in the supply of biomass fuels to power stations.

Chapter 3 explains the Supply Chain Option modelling developed within this project in order to analyse the supply and logistics costs for the different biomass fuels studied; outlining the methodology and approach taken to this modelling, the data collection required and the nature of the output that the model produces.

Chapter 4 to 8 contain definitions of the systems modelled and the results of the Supply Chain Option modelling for each biomass fuel (i.e. forest fuel, short rotation coppice, straw, miscanthus and animal slurry - a separate chapter is devoted to each biomass fuel). Each chapter begins with a discussion of the important transport and logistics considerations for that fuel, followed by explanations of the specific supply systems we have modelled. The results of the modelling of these base cases are then presented with total delivered costs, activity costing and detailed road transport analysis for each system. The sensitivity analysis undertaken for these supply systems is then presented.

In Chapter 9 the results of the Supply Chain Option modelling for each separate biomass fuel are compared and contrasted, and conclusions drawn.

Chapter 10 considers the transport system requirements and planning for a biomass-fuelled power station. First, a review of details obtained from an analysis of biomass planning applications is made. This gives insight into how restrictions that may be imposed by the local authority could influence the operation of the transport system. Second, the key factors that determine the average transport distance over which biomass fuel will have to be sourced (i.e. the catchment area for the power station) are considered. Third, the influence that power station size, delivery window and transport distance will have upon the transport system are examined.

The environmental impact of the logistics and transport arrangements for biomass fuel supply are considered in chapter 11. This chapter begins with an overview of the positive and negative environmental impacts of biomass fuel. This is followed by examination of the environmental impacts that arise in the supply of each of the biomass fuels (i.e. in the transport and logistics activities). An energy analysis of the fossil fuel directly consumed in supplying biomass to a power station is then presented. The chapter concludes with consideration of the public perception of the environmental impact of biomass schemes.

Concluding remarks and recommendations are contained in chapter 12.

2. LOGISTICS AND TRANSPORT

2.1 Importance of logistics

Logistics is now a widely used and understood term throughout the business world, and refers essentially to the management of supply chains in commerce and industry. Precise definitions vary, but the common thread is a concern for the movement and storage of goods, together with the associated information flows, from the beginning to the end of the supply chain. So, for a manufacturing company, logistics management could include:

- the procurement and sourcing of raw materials or components
- inwards transport
- materials handling and storage and the link to production processes
- the final distribution of finished products to customers

Therefore logistics costs include storage costs, together with the financial cost of holding stock or inventory, handling costs, transport costs, packaging and administration.

The costs of these activities (transport, storage, handling and so on) can be considerable. It is not unusual for them to amount to some 10% of the total sales value of products produced by a manufacturing company. Of course their importance as a proportion of the final price of goods varies according to the product in question. For products with a low value to mass ratio the significance of logistics costs in their final price is likely to be considerable.

Transport is a key element of logistics costs - amounting on average to 35% of total logistics costs according to a recent survey by the Institute of Logistics (Institute of Logistics, 1995). Logistics management has been referred to as "joined up thinking" and indeed it is this aspect of considering the trade-offs and interrelationships between different activities taking place in a supply chain (transport and storage for example) that lies at the heart of logistics planning.

Specific issues of biomass transport, storage and handling are discussed in the following sections.

2.2 The impact of biomass characteristics on logistics costs

When considering the logistics costs associated with a particular load, such as biomass fuel, there are a number of key factors about the characteristics of the product that need to be considered.

The particular characteristics of any given product will have an impact upon the distribution system for that product. The product characteristics that will influence the distribution system can be classified in three categories: volume to weight ratio, value to weight ratio and special characteristics (Rushton and Oxley, 1989).

<u>Volume to weight ratio</u>

Both the volume and weight characteristics of a product are likely to have a significant impact upon transport costs. Distribution systems tend to deal with products with low volume to weight ratios more efficiently than products with high ratios (examples of products with low ratios include dense products such as sheet steel and hard woods, whilst low ratio products include many food items, flowers and feathers). This is because products with a low volume to weight ratio tend to fully utilise the carrying capacity of a road freight vehicle, handling equipment and storage space. Meanwhile high ratio products occupy more space and result in the under-utilisation of vehicle/handling equipment weight constraints, and therefore raise transport and storage costs.

Products with a low volume to weight ratio are said to have a `high bulk density', whilst products with a high ratio have a `low bulk density'. Bulk density is defined as the mass per unit of gross volume (i.e. it takes account of the solid volume factor - the ratio of the volume of the solid to the volume it occupies when stacked - Nellist et al, 1993a).

<u>Value to weight ratio</u>

The higher the value of the product, the greater the potential for absorbing the transport and storage costs (i.e. the smaller the proportion of the final cost of the product accounted for by transport and storage). By using the value to weight ratio it is possible to consider the distribution costs associated with a product in terms of the value per unit weight of that product.

Products with low value to weight ratios (such as sand, ore, coal and gravel and biomass fuels) tend to be associated with higher transport costs (as a proportion of total delivered cost) than products with high ratios (for example electronic equipment and computers). However, conversely, the storage costs for products with high value to weight ratios are greater than those for products with low ratios; this is explained by the level of capital tied up in the stock and the need for expensive, secure warehousing.

<u>Special characteristics</u>

There are a number of other characteristics of a product which affect the selection of an appropriate transport, storage and handling system. The fragility of a product will determine the packaging requirements to safeguard the product during transportation and handling. The perishability of a product will affect the conditions under which it must be moved and stored and the speed at which it must travel through the supply chain. Certain products, such as animal slurry, possess hazardous characteristics and must therefore be moved, handled and stored in isolation from other products and within stringent regulations.

2.3 Key transport and storage considerations for biomass logistics

<u>Transport</u>

Transport is an extremely important element in the supply of biomass fuel to the power station. It is the key link in the supply chain (i.e. all the activities that have to take place between the point of production either on-farm or in-forest, through to the point of use at the power station). Transport joins together all these activities in the supply chain, which can include harvesting, processing (e.g. chipping and baling), handling, storage and conversion and the locations in which they occur.

As well as being significant in any consideration of biomass fuel systems because of the role it plays in making the fuel flow smoothly between the point of production and consumption, transport is also important as a result of the costs associated with it. Transport can account for anything up to 70% of total delivered fuel costs, depending upon the biomass type.

Given the typical locations for biomass fuel sources (on farms and in forests) the transport infrastructure is usually such that road transport will be the only potential mode for collection of the fuel. In other countries where biomass fuel is used (such as Sweden and America), other factors that favour the use of road transport include the distances over which the fuel is transported (which tend to be relatively short) and the greater flexibility that road transport can offer in comparison with other modes.

Even where alternative modes such as rail and inland waterway do exist they often struggle to compete on cost (this is obviously highly dependent upon journey distance and quantity transported) and service quality in terms of factors such as flexibility, ease of scheduling and reliability.

As a result road transport will, in nearly all cases, be the chosen mode for the movement of biomass fuel and, therefore, the focus of this report is on transport costs and regulations in relation to road haulage. However, although other transport modes such as rail, inland waterway and pipeline are not likely to be widely, if at all, used in the distribution of biomass at present, it is important to recognise that these options do exist and may become of greater interest if the cost or efficiency of road transport were to change dramatically in the future.

Storage

Most electricity generation plants to which the biomass fuels are supplied will have very limited on-site storage facilities. This is due to the space and facilities required to hold stock and the costs; both the physical costs of stockholding and the financial cost of holding stock (i.e. the cost of having money tied up in stock).

In the case of biomass that is harvested over a relatively short period of the year (such as straw and short rotation coppice), large quantities will have to be stored in order that the supply is spread evenly over the course of a year. This will require storage facilities either where the fuel is produced or at intermediate storage facilities (where fuel from a number of suppliers could be stored). As well as raising issues about who will be responsible for storage, this also has implications for the point in the supply chain at which storage costs will arise and who will bear these costs (and the impact that money tied up in stock will have upon cash flow).

The size of the storage facility at the power station will also affect the transport arrangements. A power station with a relatively small on-site stock level (e.g. a few days supply) will require more regular, evenly spread deliveries than a plant with a large storage capacity. Low levels of stockholding at the power station will result in the reliability and flexibility of transport becoming increasingly important.

2.4 Further transport and supply system considerations

Several transport related factors will vary from one supply system to another and will affect the transport costs within the supply system. Three factors are important in understanding the underlying nature of transport costs:

- vehicle size
- transport distance
- terminal time (time spent by vehicles at a terminal loading and unloading)

These factors are explored later in the report specifically in relation to the transport of biomass fuels. The short section that follows simply summarises a number of principles about these factors.

Vehicle size

The simple principle here is that in general the larger the vehicle, the lower the cost per tonne of moving a load. This is because lorries exhibit economies of scale; for example only one driver is required no matter whether a large vehicle carrying 24 tonnes or a small vehicle carrying 4 tonnes is considered. Nevertheless, it should be noted that the smaller the vehicle, the lower its hourly operating costs.

Therefore the trip cost per vehicle load will be lower for a small vehicle than for a large one. The terminal cost per vehicle load will also typically be lower for a small vehicle than a large one as the time taken to load the vehicle will be less. However some elements of terminal time will remain approximately the same regardless of vehicle size such as vehicle sheeting and the weighing and sampling of loads.

However since large vehicles have much greater carrying capacities than small ones (a maximum size, lightweight articulated lorry can carry up to 24.5 tonnes of product compared with about 4 tonnes in a small rigid vehicle) when the unit costs of transport are considered, the larger vehicles have lower terminal and trip costs per tonne transported.

So, in most cases there are significant benefits in using the biggest vehicles possible. In the case of biomass fuels with generally low bulk densities (especially straw and miscanthus), it can be the case that a transport vehicle is unable to reach its payload (i.e. the vehicle is full but it has not reached a maximum permitted gross vehicle weight of 38 tonnes). However in such a situation it is important that the vehicle dimensions are as large as legally allowed in order to maximise the internal volume of the vehicle. But in some situations, such as in certain forest environments, the size of the transport vehicle used can be limited due to physical constraints such as road surface quality and terrain.

<u>Transport distance</u>

Transport distance is important in many supply chain decisions. Critically, the impact of distance on costs is such that total transport cost per kilometre generally falls as transport distance increases. As a result, increases in transport distance will result in less than proportionate increases in the total transport cost per vehicle load. Therefore the transport distance can be significantly increased without this having a proportionate effect on transport costs. There are two main reasons for this.

- in the case of supply systems involving loading at a farm or in a forest the initial transport movement will be on a road or track where a lorry has a low average speed. As the journey continues larger roads will generally be used and average speeds will increase. Increased average speeds mean that costs that accrue on a time basis are lower per unit of distance covered as average speeds increase.

- as trip lengths increase, terminal time becomes a less significant proportion of total activity time. As a result the terminal costs can effectively be spread over a greater number of kilometres.

<u>Terminal time</u>

Efficient loading and unloading operations are a feature of good distribution management. Although terminal time is important, the way transport vehicles are used must also be considered. For example, there will be many operations that are superficially very similar with respect to terminal time (i.e. the time a vehicle spends at the terminal loading and unloading). However, there may be a critical difference. In one case the whole of an articulated vehicle (i.e. the tractor unit and trailer) remains during the loading operation, while in another instance, only the trailer unit is left and the tractor unit is used to collect a trailer that has been pre-loaded.

The result of this difference is that in one case terminal costs per vehicle are far higher than in the other. This is explained by the fact that the hourly cost of the tractor and trailer far exceeds the cost of just a trailer. This demonstrates the increase in terminal cost that can arise from using expensive equipment unproductively.

2.5 Management issues in the biomass supply chain

The management of biomass fuel supply chains will have to be organised in a co-ordinated and thoroughly planned manner if the fuel is to be delivered to the power station at the times required each day and at the correct fuel specification on a year round basis. Rather than each activity in the chain being planned and conducted in isolation, it is extremely important that the supply chain (from point of production through to supply to a power station) is viewed as a whole. Only in this way will it be possible to achieve integration between activities and hence efficiency in the supply of biomass fuels.

A number of different parties are likely to be involved in the biomass supply chain, including farmers and forest owners, agricultural and forestry contractors, transport companies, fuel suppliers and power station operators. In order that the supply of fuel is smooth and reliable it will be necessary for all these parties to plan and work together in an open environment.

It is likely that one party, the fuel supplier, will take overall responsibility for management of the supply chain. In addition there are advantages (through reduced risk and simpler negotiation) if the management at the power station has to deal with a few large fuel suppliers rather than having to deal with numerous companies throughout the supply chain.

The period of activity has implications for the organisation of the supply chain and has a significant impact upon the equipment and labour used. For example, outright purchase of specialised equipment may be more preferable in a system where operations continue throughout the year in comparison to one in which the activity is limited to a specific part of the year. In the case of the latter, it is necessary to consider whether equipment can be put to other uses when it is not needed for the main activity (as in the case of the straw contractor using their vehicle tractor units for general haulage operations outside of the straw season) or whether existing equipment can be adapted. Alternatively, subcontractors can be used; this removes the need to purchase the equipment and achieve a sufficient annual productivity from it. However the use of subcontractors has its own advantages and disadvantages and can make the co-ordination of the supply chain more complex.

The labour used in carrying out activities such as harvesting and handling will also be affected by the continuity of supply of the product. Products with a short supply season generally have to make use of seasonal, often non-specialist labour.

The timing of different activities will differ between biomass fuels; this will be determined by the growth/supply cycle of the fuel. Some of the biomass fuels will be supplied at source all year round (for instance animal waste and some forest fuel) while others will only be harvested at a particular period of the year (e.g. coppice, straw and miscanthus). Therefore all of these issues will be relevant to those involved with the supply of biomass fuel and will require careful consideration.

It is extremely important that power stations receive a smooth, consistent supply of biomass fuel that meets the specified quality criteria. Therefore the biomass supply system must be able to operate in an efficient and reliable manner. Both the physical aspects of the supply chain (i.e. harvesting and handling operations, store location, transport equipment and operations etc) and also management of these activities and the organisations performing them in order to supply fuel (i.e. supply chain co-ordination) will be of prime importance.

By considering the entire supply chain associated with delivery of biomass fuel to power stations in an integrated manner it is possible to gain a better understanding of total delivered costs, and to consider ways in which the supply chain can be efficiently organised and managed in order to reduce these costs. Only through such reductions in the cost of delivered fuel will biomass become economically competitive with other forms of energy for electricity generation.

3. SUPPLY CHAIN OPTION MODELLING

3.1 Objectives

In order to explore the total delivered costs of biomass fuel associated with different supply systems and to be capable of making cost comparisons between systems for one fuel and between different biomass fuel types we have developed what we refer to as "Supply Chain Option Models". These models assist us in building up an overall understanding of the logistics and transport costs of supplying fuel from a farm or forest to a power station through a detailed analysis of where costs arise in the supply system and the relative importance of different cost components and activities. The list below outlines the uses to which the Supply Chain Option models have been put. To:

- obtain an understanding of the delivered cost of different supply chain options for each biomass fuel;
- compare the delivered costs produced by different supply systems for each fuel;
- compare supply chain options and their associated costs between different biomass fuels;
- explore the key logistics cost drivers in the supply chain options for each biomass fuel;
- conduct sensitivity analyses with respect to key cost drivers and various parameters used in the initial base case models;
- examine where cost reductions could be achieved within the fuel supply chains.

3.2 Approach taken to defining supply systems and specifying parameters

In defining appropriate supply systems for each biomass fuel and obtaining the necessary parameters for these supply systems it has been necessary to use a number of different approaches. These include:

- interviews and discussions with people with recognised expertise with respect to each of the different biomass fuels or the activities associated with their supply;
- interviews and discussions with people with particular expertise with respect to particular equipment (such as road vehicles or tractors);
- use of trial data from reports that have been published (from ETSU projects and other work);
- use of manufacturers' data about their equipment (i.e. the productivity of the equipment and the purchase costs);
- study tours to Sweden and Denmark to discuss forest residue, coppice and straw logistics parameters in countries with significant experience of biomass systems and consider the applicability in the UK;
- where information and data has not been available from any of the above sources, it has been necessary for the project team to use their own expertise and best judgement to determine suitable parameters.

The Supply Chain Option models take account of the following issues and activities in the supply of biomass fuels from farms and forests to power stations:

- harvesting
- processing (chipping and baling)
- in-field/forest handling
- in-field/forest transport
- fuel storage on-farm/in-forest
- road transport vehicle loading and unloading
- road transport trip
- fuel storage at intermediate store

The end point in our analysis is the delivery of the fuel to the power station, the load sampling and weighing and the unloading of the transport vehicle.

The parameters required in order to model biomass fuel supply systems range from the activities that take place in the supply of fuel and the order in which they occur, to the equipment and labour required for these activities, to the productivity rates and costings for these activities. The list below shows the various categories of parameters that it has been necessary to consider for each of the biomass fuels:

- characteristics and specification of each biomass fuel
- volume and weight capacities for road transport vehicles
- road categories used and speeds achieved in transporting fuel
- productivity rates for farm and forestry equipment
- harvesting and handling equipment and labour requirements
- operating costs of transport, handling and harvesting equipment used in supply
- storage systems and their location
- dry matter losses and changes in moisture content of biomass during storage
- other wastage of biomass in the fuel supply system
- power station requirements (i.e. quantity, quality, delivery pattern)
- other factors and cost inputs (processing, money paid to farmers etc)

Examples of the "other factors and cost inputs" referred to in the above list include:

- prices paid to farmers/foresters for biomass
- harvesting and extraction costs for forest fuel
- crop yield data for straw, miscanthus and coppice

Many of the parameters required relate to the logistics activities that will have to take place in order for biomass fuel to be supplied from farm/forest to power station. Table 3.1 illustrates the activities for which logistics parameters have been collected, together with the specific factors associated with each activity for which information was required.

Defining good practice is difficult when practice does not currently exist or it exists for different purposes. Also, the productivity of any equipment will be dependent upon the particular operating conditions that it is functioning under and who is responsible for the operation. The equipment used in biomass supply will be operating in a wide range of conditions and its productivity will be dependent upon a number of factors including the ground conditions, the

Table 3.1: Factors to consider for each activity

Fuel Harvesting and processing	In-field or forest handling	In-field or forest transport	On-farm or forest storage	Loading road vehicles	Transport of the fuel by road	Intermediate storage	Unloading of road transport vehicles	Power station requirements
Harvesting system Baling Bundling Chipping Chunking	Equipment used Labour requirements Productivity rates for the equipment Operating costs	Equipment used Labour requirements Transport distances Transport speeds Vehicle capacity Operating costs	Storage system used Storage site rental Maintenance costs Insurance and security costs Storage period Fuel losses during storage	Equipment used Labour requirements Productivity rates for the equipment Operating costs	Equipment used Labour requirements Types of road used Transport distances Transport speeds Vehicle capacity Operating costs	Storage system used Storage site rental Maintenance costs Insurance and security costs Storage period Fuel losses during storage	Equipment used Labour requirements Productivity rates for the equipment Operating costs	Quantity of fuel required Specification of fuel (moisture content, chip size etc) Delivery requirements (days per week, hours per day)

flatness of the land and the weather conditions. Precise details of the supply system will vary from one scheme to another (e.g. transport distances, locations of store, storage systems used, etc). Therefore, in some instances it has been difficult to specify precise parameters for a particular activity or piece of equipment. However, the parameters and input values used in the modelling are based on our best judgement and our view of the cost of suitable systems and equipment. We do acknowledge that developments in the biomass industry will inevitably lead to changes in delivered costs in future.

3.3 Methodology

The Supply Chain Option models have been developed in such a way that it is possible to explore a wide range of fuel supply systems for each of the fuel types included in the project. The models have been designed to incorporate and cost in detail the activities involved in the supply of fuel from the point at which it is lying on the ground after harvesting through to final delivery to a power station.

Other activities that take place, or costs that arise, in the supply of fuel but which do not lie directly within the scope of this project have either been incorporated in the models or included as input costs. These costs (such as the cost of growing/purchasing fuel from farmers and forest owners and the costs of harvesting) have been included in the models as we felt that it was important that the models could produce a total delivered fuel cost at the power station. Without this capability it would be difficult to determine the relative importance of the logistics and transport costs.

The basis of the cost calculations used in the model is the cost of supplying one tonne of dry matter to a power station[2]. This cost is based on the time that any necessary supply activity takes to complete (and from this it is possible to calculate the cost of that activity given the hourly operating cost of equipment used and the cost of labour required) together with other input costs that go to make up the delivered cost (e.g. the cost of purchasing/growing biomass fuel). From this it is possible to derive the cost per tonne of dry matter for that particular activity. The delivered costs produced by the models refer to the actual costs in supplying the fuel on a dry matter basis; they do not therefore include profit margins for contractors (forestry, agricultural and transport contractors).

A Supply Chain Option model was developed for each of the fuels considered in the project. While there are differences in some of the activities involved in supplying these fuels due to the production method and the characteristics of the fuel which have to be reflected in the modelling work, we have produced models which are compatible. We have achieved this compatibility by standardising the approach used in the models in several respects:

- use of the same calculating methods in each model;
- derivation of total delivered costs and the costs of each activity on a per tonne of dry matter basis in each model;
- structuring the models for each fuel in the same way;
- using the same database of equipment operating costs and storage costs for each fuel.

This compatibility is extremely important as it facilitates comparison between the costs of fuel supply systems for different biomass fuels.

[2] The cost of supplying wood to the power station, calculated per tonne of dry matter. This is not to suggest that oven dry biomass is supplied to the power station; wet biomass is supplied but our cost calculations are based on the dry matter present in the biomass.

The supply systems we have modelled for each fuel are intended to represent efficient and cost effective ways of supplying biomass fuel to power stations in schemes in which the fuel is used to generate electricity. The supply of biomass fuel to a power station is best thought of as an industrial process rather than as an agricultural or forestry operation; it involves the year round supply of large quantities of fuel on a regular and timely basis. In order to be cost effective these supply systems will tend to:

- make use of capital intensive, high productivity machinery;
- involve the expertise of specialist contractors (agricultural, forestry and transport) rather than farmers and small scale forest owners. However there are opportunities for the latter to be involved in growing fuels and making fuel resources and/or land available;
- incorporate an entire supply chain perspective from point of harvest through to delivery at power station; they therefore need to take account of all activities necessary to achieve fuel supply and integrate the necessary supply chain activities in a smooth and co-ordinated manner;
- minimise the downtime of expensive equipment and hence maximise equipment productivity (to give an example, in the case of road transport rather than entire articulated vehicles and their drivers being present on farm/in forest during loading activities that take significant time to complete, such as chipping direct to lorries, the systems are planned so that drivers will drop off a trailer for filling and haul another full trailer whilst this loading task is undertaken).

3.4 Costing approach used in the supply chain option models

The Supply Chain Option models calculate the cost of delivered fuel on a dry matter basis, and costs are expressed per tonne of dry matter (with the exception of animal slurry for anaerobic digestion which has been costed on a wet tonne basis). This makes it very straightforward to make comparisons between different supply systems (e.g. square bales v round bales, or coppice sticks v chips) and between biomass fuels (e.g. straw and coppice). Without converting costs to this base, we would be producing costings for biomass fuel on a tonne of wet material basis and the dry matter content would vary from one supply system to another and from one biomass fuel to another. We would not then be comparing like with like. However in calculating transport, handling and other costs we have obviously calculated the cost of handling the fuel wet (as this is what will actually happen in supplying biomass) and have then converted this into a cost per tonne of dry matter.

Additionally, wastage occurs in fuel supply systems. This can, for example, occur during storage when fuel decomposes and also in operations such as harvesting and chipping when material is dropped on the ground rather than in the trailer or container in which it was intended to be deposited.

Wastage of useful biomass may occur at any stage of the supply chain. Examples include:

- spillage due to misalignment of discharge spout in cut and chip short rotation coppice and miscanthus harvesting;
- disintegration of bales due to twine breakage;
- loss of bales from loads due to inadequate roping/strapping;
- non-recoverable dust and fine particles produced during chipping;
- loss of dry matter arising from decomposition of wood chips in storage;
- spoilage of top layer of bale stacks due to rain.

Wastage is taken account in the Supply Chain Option modelling in the following manner: costs of activities arising in the supply of a biomass fuel prior to a loss of biomass (this could be due to harvesting, chipping, storage etc) are adjusted to take into account the extra biomass that has to be produced to compensate for these losses. Therefore the way in which we have dealt with losses reflects the fact that if wastage occurs then it will be necessary to produce more than one tonne of dry matter in order to supply one tonne of dry matter to the power station. It is essential to reflect this in the work as such losses have significant implications for the delivered cost of biomass fuel.

There are several different types of cost involved in the Supply Chain Option models. Some are simple inputs to the total delivered cost while others have to be derived from other inputs related to the particular characteristics of the biomass fuel and the supply system used. The different types of costs are outlined below.

- Given costs not calculated within the models - the model calculates costs from the point of harvest through to the point of supply at power station. However, in order to derive total delivered fuel costs it has been necessary to obtain costs for several activities and events that lie outside the scope of the project. These include money paid to growers of biomass by fuel suppliers and harvesting and extraction costs for forestry residues;

- Costs of resources used in the supply of fuel which can be treated independently of other factors and input directly into the models. For example, the use of twine for straw or miscanthus bales;

- Costs associated with the use of equipment - this includes all activities which require the use of equipment such as handling equipment, agricultural tractors and road transport vehicles. These costs are based upon the time taken to complete the activity and the hourly operating costs of the equipment including labour costs (see appendix 7 for further details of equipment operating costs);

- Storage costs which include the stockholding cost, the site storage rental and the insurance of the biomass while in store. These costs are calculated from a number of inputs that have to be specified such as the value of the fuel in the store, the time period for which the fuel is stored, the type of store used etc (see appendix 8 for further details).

3.5 Assumptions made in the modelling

The systems modelled for each biomass fuel and the results of the Supply Chain Option modelling for these different supply systems are contained in Chapters 4 to 8; each fuel type is considered in a separate chapter. The main set of results for each fuel (referred to as the base cases) represent the costings for each system that has been considered and represents the delivered costs for biomass based on the parameters and data we have collected during the project.

In modelling these base case supply systems it has been necessary to make a number of assumptions about the biomass fuel, the equipment and facilities used in the supply chain and their costs, productivity rates and many other factors. Assumptions that are specific to a given fuel type are documented in Appendices 1 to 5.

However several important assumptions are common to all base case biomass fuel supply systems types in the Supply Chain Option modelling. These are:

- road transport distances from farm/forest to power station have been set at 40 kilometres (one way distance) for forest fuel, short rotation coppice, straw and miscanthus. In the case of animal slurry, the road transport distance from farm to centralised anaerobic digester has been set at 10 kilometres (one way distance). The delivered costs are based on the round trip distance of the road transport vehicle as it will be travelling from farms/forests to power station and back again in biomass transport systems. Therefore the round trip road transport distance in the base cases is 20 kilometres for animal slurry and 80 kilometres for all other fuels.

- In all supply systems other than animal slurry we have assumed that, if possible, use will be made of the largest road transport equipment possible (in terms of volume and/or gross vehicle weight) in order to minimise the unit costs of transport. In supply systems in which maximum size transport vehicles may not be able to operate (e.g. on certain forest roads) we have also modelled the use of smaller road transport vehicles.

- vehicle speed assumptions on different categories of road and track are given in Appendix 6.

- it has been assumed that all road transport vehicles will have to be weighed on a weighbridge and the load sampled upon arrival at a power station.

- all vehicle loads will have to be properly secured and sheeted if transported in an unenclosed vehicle.

- the storage period has been set at six months in all forest fuel, coppice, straw and miscanthus supply systems modelled. This has been selected as the average storage time for biomass fuels as they will generally be harvested at a specific time of year but will have to be supplied to power stations in constant quantities on a regular, year round basis. For animal slurries the average storage period has been set at one week.

- in the case of forest fuel, coppice, straw and miscanthus it has been assumed in the base cases that fuel will be stored in the open air (i.e. that no use is made of covered buildings and/or ventilated systems). This is due to the capital costs associated with more sophisticated storage systems especially when considering the quantity of fuel that will have to be stored. Clearly, in reality, some fuel suppliers will be able to make use of existing buildings that are no longer used for their originally intended purpose. We have however discussed alternative storage strategies in the sensitivity analysis.

- in chip storage systems for forest fuel, coppice and miscanthus, dry matter losses have been assumed to occur at a constant rate of 4% per month. In bale storage systems (straw and miscanthus) the entire top layer of bales have been assumed to be unsuitable for supply to the power station and hence represent dry matter losses.

- the delivered cost calculations do not include a profit element for contractors and the fuel supplier.

- the modelling assumes a perfectly matched system. This may prove difficult to achieve in practice. During activities in which one piece of equipment is dependent upon another, if one piece of equipment is not available when required then the other piece of equipment will be unable to work productively and downtime will occur (e.g. in direct cut and chip coppice harvesting in which a tractor and trailer run alongside the harvester, and when the trailer is full leaves the field and is replaced by another tractor and trailer).

3.6 Outputs from the supply chain option modelling

The analysis for each fuel in chapter 4 to 8 is divided into three parts: (i) the total delivered cost to power station, (ii) consideration of the breakdown of total delivered costs in each of the supply systems and examination of how these costs accumulate along the supply system, and (iii) the activity costs for each supply system are discussed (i.e. the importance of cost categories including harvesting, handling, transport and storage in the total delivered fuel costs).

Explanation of breakdown of total delivered costs

The Supply Chain Option modelling calculates all the costs of supplying biomass to the power station in the order in which they occur. These costs are presented in the relevant chapter for each biomass fuel and reflect the importance of different costs and how the cumulative delivered cost builds up along the supply chain.

Explanation of activity cost categories

By considering the different types of costs that occur in supplying biomass fuels to power stations in an activity-based manner, it is possible to determine the overall importance of these activity costs (i.e. in terms of the proportion of total delivered cost that they account for). By identifying different activities, and hence categories of cost, we can gain an understanding of the relative importance of each activity and this helps us to consider how much attention and effort should be placed on trying to conduct an activity in a different manner in order to reduce the costs associated with that activity. For instance, if the cost associated with a particular activity within the supply chain only accounts for 5% of total delivered cost, it would not generally warrant the same level of attention (in terms of developing strategies and technologies to reduce it) than an activity that represented 30% of total delivered cost.

We have allocated all the costs that can arise in the supply of biomass fuel to one of five activity cost categories. These cost categories are:

- purchase
- harvesting
- handling
- transport
- storage

In thinking about costs in this way, it is important to realise that the costs that make up the "activity cost" do not necessarily all occur at the same point in the supply chain. Instead, they are all costs that arise from a similar activity at some point within the chain. For example, handling occurs at many different points in most biomass supply chains (such as on the farm, at the storage point, loading the vehicles etc). Therefore when considering handling as an activity cost category we are referring to all the handling within a biomass supply system and the total handling cost that it results in. The five activity cost categories are made up of the following operations and events:

Purchase
This refers to the price paid to producer (i.e. farmer/forest owner) for their fuel. This is made up of the resource/growing cost of the biomass (i.e. the cost of preparing the land, planting and establish and treating the biomass during growth) together with an amount the farmer will have to be paid as a financial incentive to grow biomass fuel rather than put his land to an alternative use.

Harvesting
This activity cost heading includes:

- harvesting
- baling
- chipping (either during harvesting, by mobile chipper or at the power station)
- in the case of forest residue supply systems this activity cost also includes the cost of extracting the material from the stump to the forest landing or roadside.

Handling
We have defined this activity cost category to include the following:

- building field heaps of bales

- loading and unloading transport equipment (the downtime cost of the road transport vehicle is included as a handling cost while it is being loaded and unloaded)

- stacking biomass into stacks or piles at the store and power station

- loading residues or coppice stick into a mobile chipper

Transport
This activity cost category includes tasks which solely involve the transport vehicles in transporting biomass from the field, from the farm store and from the intermediate store:

- in-field transport distance (i.e. the actual trip from field to farm store/steading)

- roping/strapping and sheeting of transport vehicles (and removing these at the destination)

- Container transfer time (picking up and taking off of demountable container)

- trailer coupling time (coupling articulated trailers to heavy goods vehicle road tractors)

- road transport distance (i.e. the actual road transport trip)

- sampling and weighing of the load on the vehicle at the power station

Storage
This includes the following costs which can arise either at a farm/forest store or an intermediate store:

- storage site rental

- interest on stock

- insurance/maintenance of stock

(See appendix 8 for further details of each of these storage costs).

Explanation of detailed road transport analysis

We have also conducted a detailed analysis of the road transportation stages from the farm store/forest landing and from the intermediate store to the power station for each of the supply systems modelled.

Essentially there are two types of activity that make up the cost of transport: the terminal cost and the trip cost. The terminal cost is the cost arising from the time the vehicle spends inactive at its origin and destination. At its origin the vehicle has to be loaded, the load has to be secured (by sheeting, strapping etc), and trailers may have to be coupled to road tractor unit by the driver in the case of an articulated vehicle. At its destination, the vehicle has to be unsheeted or unstrapped and unloaded. If the destination of the journey is the power station, the load carried by the vehicle will also have to be weighed and sampled before it can be unloaded. All of these activities take time to complete and therefore result in costs which can be derived from the hourly operating cost of the vehicle.

The trip cost is the cost of the journey from the origin to the destination when the vehicle is in motion. It is derived from the total time that the vehicle is active (i.e. on the road or forest road/farm track) between these two points. The trip time is dependent upon the speed of the vehicle on different types of road surface and the distance between the origin and destination.

The total transport cost for any particular stage of biomass transport can be calculated by adding together the terminal cost and the trip cost.

The efficiency of the road transport operation (and hence the transport cost per tonne of dry matter) will depend upon:

- vehicle size (gross vehicle weight);
- load weight carried on each vehicle;
- bulk density of the biomass when transported;
- loading and unloading times;
- sheeting/strapping times to secure the vehicle load;
- sampling and weighing times at the power station;
- total transport distances between different points in the supply chain and the distance travelled on different road surfaces;
- vehicle speeds on different road surfaces.

The detailed road transport analysis is only concerned with transport stages that require the use of large goods vehicles for road transport; it does not include consideration of the in-field and in-forest transport stage (e.g. from the field to the farm store using agricultural transport).

Sensitivity analysis

In addition to producing delivered costs for each of the supply systems we have defined and modelled (i.e. the base cases), we have also examined the effect of changes to several of the assumptions made in modelling these base cases. This sensitivity analysis is presented within each chapter after the base case modelling. The Supply Chain Option models have been rerun to consider the following factors:

- different road transport distances. For forest fuel, coppice, straw and miscanthus one way road transport distances of 20 and 80 kilometres (i.e. round trip distances of 40 and 160 kilometres respectively) have also been considered. In the case of animal slurry one-way road transport distances of 5 and 20 kilometres (i.e. round trip distances of 10 and 40 kilometres have also been explored.

- the delivered costs of biomass fuel if delivered directly to power stations rather than being stored for several months.

- the effect on delivered costs of dry matter losses other than 4% per month for chipped material during storage.

- the benefits of improved compaction/loading of unchipped forest residues and coppice sticks onto road transport vehicles on transport costs and total delivered costs.

- the additional costs of returning liquid digestate to farms for spreading on the land in animal slurry systems.

- the effects of increases in diesel fuel prices and labour costs on total delivered cost.

Several other issues have been addressed in the sensitivity analysis which did not involve rerunning the Supply Chain Option models. These include:

- alternative input values for the money paid to farmers to grow coppice and miscanthus, the money paid to farmers and forest owners for their straw and forest fuel.

- how improvements in mobile chipper productivity could reduce delivered cost in forest fuel and coppice systems.

- how the costs of different harvesting and extraction systems will affect the total delivered costs of forest fuel systems.

4. FOREST FUEL

4.1 Logistics and supply issues

Harvesting

Harvesting in this review is defined as the process of felling the trees (only a relevant cost in whole tree harvesting and integrated harvesting systems), separation of the `residue' (i.e. branches and small roundwood) from the timber crop, extraction of the residue from the forest and primary processing of the residue.

The main potential sources of wood fuel from coniferous plantations are whole conifer trees from early thinning or premature clearfell operations, and residues arising from later thinnings or clearfellings where a timber crop is the primary product.

A number of forest fuel harvesting systems exist, both in the UK and other countries. These systems have been extensively studied and attempts made at economic evaluation in order to identify the most suitable systems for various British conditions (Centre for Biomass Technology, 1993; Killer, 1994; Mitchell et al, 1990 and 1993; Mitchell and Hankin, 1993). The main differences between the systems relate to:-

- the point at which the forest fuel is produced (for example at stump, at an intermediate processing point, or at the end user);
- the point at which the forest fuel is processed to form chips/chunks;
- the vehicles and equipment used to extract either the unprocessed or processed fuel out of the forest.

The various possible harvesting systems are described below:-

Residue harvesting systems
There are two types of residue harvesting system:

- terrain harvesting/chipping systems in forests being thinned/clearfelled for timber, as used, for example, in lowland forests in SE Britain (also found in Denmark - Centre for Biomass Technology, 1993). Year-round operation in the UK, totally mechanised and requiring high capital investment and hence productivity.
- residue extraction by forwarder to forest landing/roadside as used, for example, in Kielder. The residue can then be stored at a forest landing until required for supply to a power station at which point it can either be chipped using mobile chippers and then transported as chips or can be transported in an unchipped form. Alternatively the residue can be transported (either immediately after harvest or following storage at landing) to an intermediate storage facility which is accessible at times when road transport vehicles may have difficulty entering the forest due to ground conditions. If delivered to the power station in an unchipped form, the plant will need to have a centralised chipping facility.

Integrated harvesting systems
In an integrated harvesting system, whole trees are felled and extracted to a forest road or landing where roundwood and residue are separated during processing. This system can be used for both thinnings and clearfell.

These residues can then be stored at the processing point, and then either chipped and transported or transported in an unprocessed form to the power station.

Whole tree harvesting systems
In whole tree harvesting systems, wood for fuel is the only product of the harvesting operation and the system is generally applicable to smaller tree sizes. Processing can occur at stump or at landing; the system is mostly used for early thinnings but can also be used for premature clearfell. The terrain chipping approach involves chipping at stump and then forwarding of chips either direct to storage point or to roadside for onward transport by a heavy goods vehicle (HGV).

Landing-based systems involve felling and extraction of the tree to a landing where either storage can take place followed by chipping and transport or the fuel can be chipped immediately and then moved on to store or point of use.

Availability of residue/chip stockpile areas within the forest, and access to these areas, is extremely important if secondary operations involving residue harvesting and extraction for biomass are not to interfere with the primary timber operations.

In-forest storage

Requirements for in-forest storage will vary depending on the harvesting system used, and the location and processing/storage capacities of intermediate points and the end user. Other important factors are the requirements of the end user in terms of dry matter, and the system of payment for the wood - for example, some end-users will buy wood for fuel on a calorific value basis, making the economics of an intermediate storage (and drying) period in the forest favourable. Storage can either occur pre-processing (i.e. as piles of brash) or after processing, as piles of comminuted material. In-forest storage locations should be accessible by road transport vehicles and should not therefore require significant deviations from the forest road network. Also important is the availability of space for storage and turning and manoeuvring of large road haulage vehicles and handling equipment.

During storage the residues or chips can undergo changes to their composition (in terms of changes in dry matter content and dry matter losses) and such changes will affect the energy value and handling and processing properties of the wood.

In the case of unprocessed material, drying occurs by natural transpiration of the wood, the rate of this transpiration being affected by the amount of rainfall, the relative humidity, and exposure of stores to wind and sun. This natural drying results in an average reduction in moisture content from approximately 50% to around 37% to 40%, if the wood is left for at least five months (Centre for Biomass Technology, 1993; Mitchell et al, 1990). Extraction of the fuel can take place during the drier months, minimising damage in the forest. Stores can then be utilised over the winter, when the demand for fuel will be highest and the ability to extract fuel from the forest greatly reduced.

The harvesting systems used in some locations will involve chipping at, or directly after, harvesting but the chips may not be required immediately by the end user. The timing of chipping of stored piles of brash may also have to take place when there is no immediate demand for the wood (e.g. when a mobile chipper becomes available). The processed wood could then be stored in the forest, before transport either to an intermediate storage point or to the end user.

Research has been carried out into the changes in the properties of wood chips when stored in open and covered stacks, and the way that these changes affect the dry matter content and hence energy value of the wood (Mitchell et al, 1990; Nellist et al, 1993a).

If left in uncovered stacks in UK conditions, the moisture content of the wood chips can actually increase (as they absorb water). Dry matter losses also tend to occur at the same time for wood chips, with average energy losses being recorded as over 4% per month for small chips (Mitchell et al, 1990). If stacks are covered, both changes in moisture content and dry matter losses tend to be lower.

Intermediate storage

An intermediate storage and/or distribution facility (at a location outside the forest) may be used if storage within the forest is not possible and/or the end-user does not have the space to store more than a few days supply of fuel. Intermediate storage may also prove beneficial if it is not possible to use maximum sized vehicles to haul residues out of the forest.

However, intermediate storage of unprocessed and processed residues and the associated additional handling will add considerably to the cost of the delivered-in fuel, as will the cost of providing an additional storage facility, particularly if this involves constructing such a facility and/or laying concrete or hard standing.

It is important to note that a certain quantity of forest fuel will have to be stored at the power plant (i.e. several days buffer stock) so that it is capable of producing and supplying electricity as and when required. Such a buffer stock is likely to be required at all power plants generating electricity from any of the biomass fuels considered in this project.

Loading, handling and unloading

Machines used for forest fuel extraction and transport in the UK have tended to be conventional or modified forestry and agricultural machinery, for example forwarders, large agricultural tractors and trailers, with the harvesting system itself determining the size and type of machinery used.

A range of purpose built harvesting and particularly chipping machinery is becoming more widely available, having been developed for use in Scandinavian conditions, but it would appear that existing machinery will continue to be used and adapted for loading and unloading operations.

The purchase of machinery specifically for fuel harvesting, handling, loading and unloading and processing operations by forestry contractors will obviously depend on the demand for the end product, and the ability of contractors to operate on a scale that will justify their capital investment.

Loading of chips is generally carried out either by front end bucket loader, by blowing chips directly from the chipper into the transport vehicle, or, in some cases by a crane-mounted grab. Chips can also be tipped from forwarder bunks into containers for onward road transport. Unloading of chips can be achieved by tipping or a walking floor system built into the transport vehicles.

If the fuel is transported in an unprocessed form it is generally loaded into a road transport vehicle by a crane-mounted grab, which can also be used to compress the residue once loaded and thereby increase the quantity transported (without compression the volume constraints of the vehicle body are likely to be reached before maximum payload is achieved). Unloading of the fuel is usually achieved by a fixed crane at the power station.

Road transport

The density of wood chips varies according to their moisture content, and the type of material (e.g. small or large chips, high/low proportion of fines etc.) and this affects the efficiency of the transport operation.

The bulk density of unchipped fuel can be improved through compression with a heavy-duty loading crane once it has been loaded. Wood chip density can be increased by utilising high pressure blowers for loading as opposed to bucket loaders.

The choice of road transport vehicle will depend to a certain extent on the harvesting system, and also the quality of access within the forest. Unchipped fuel will be extracted from the forest by forest machinery (e.g. forwarders) and then moved from forest to power station in tippers. The road transport of wood chips is likely to involve the use of road-based tipping trucks. Terrain-chipping systems may adopt the use of containerised transport, where interchangeable containers can be left at the forest roadside or chipping point.

The supply system options for forest fuel are shown in Figure 4.1 below. The biomass supply chain for integrated harvesting begins at the "process" stage (i.e. when the timber and biomass are separated) whereas it begins with felling for whole tree harvesting and collection for residue harvesting.

Figure 4.1: Supply system options for forest fuel

Figure Not Available Electronically

4.2 Forest fuel supply systems modelled

We examined five systems for supplying forest fuel from the forest to a power station.

Forestry systems A to D described below, involve the use of either residue harvesting, integrated harvesting or whole tree harvesting systems to harvest the material and then the unchipped material is extracted to the forest landing. The system descriptions below describe the systems from the point at which the material has been deposited at the landing.

Supply system E is a terrain chipping system (which can be used in conjunction with either residue or whole tree harvesting) in which the material is chipped at stump by a forwarder mounted chipper and transported directly to demountable containers at the roadside which are collected by a road transport vehicle.

System A

Forest thinnings/residues are stored at the forest landing (the "store" is a long pile on the forest floor at the landing). After the storage period the thinnings/residues are chipped directly into a 38 tonne (GVW) articulated tipper trailer with an internal body volume of 90 m^3 using a forwarder and chipper. The driver arrives in the tractor unit to collect the tipper trailer (dropping another empty trailer at the same time) and then transports the chips to the power station where they are discharged (either by tipping the vehicle body or by using a walking floor or "Ejectaload" system - see Appendix 12.4).

This supply system has a number of benefits:

- the wood fuel is stored in an unchipped form and is therefore unlikely to undergo decomposition (dry matter losses) and is likely to experience reductions in moisture content levels (i.e. as the material dries).

- During chipping only the road trailer is present at the storage site. Given that chipping is a relatively slow process, due to low rates of productivity achieved by mobile chippers, this would result in significant downtime and hence terminal costs if the road tractor unit and driver were present during chipping and loading. By using an articulated vehicle it is possible for the driver to decouple the trailer and be transporting another trailer of chips to the power station whilst chipping to the trailer is occurring.

- the fuel is transported in a chipped form, thereby utilising the maximum weight capacity of the road transport vehicle. It is very difficult, if not impossible, to utilise the weight capacity if transporting unchipped residues.

Figure 4.2: Forest fuel supply - system A

Figure Not Available Electronically

System B

Forest thinnings/residues are stored at the forest landing for the duration of the storage period. They are then chipped into a chip heap. From the heap they are loaded into a 32 tonne (GVW) rigid tipping vehicle using a loading shovel. This chipping and loading strategy is more appropriate when using a rigid road transport vehicle than chipping directly to the vehicle (as in system A) because a rigid vehicle cannot be decoupled and therefore the entire vehicle and driver have to be present during the loading process. The time taken to achieve a fully loaded vehicle when chipping directly to a rigid vehicle would result in significant terminal time costs given the hourly operating cost of the vehicle and driver. The chips are then transported to the power station by the road transport vehicle where the load is discharged.

In this system we have explored a similar supply strategy to that in system A, the key difference being the size of the road transport vehicle used. Large volume (i.e. 90 m^3) 38 tonne gross weight vehicles may not be capable of operating within some forest environments. In such circumstances it will be necessary to use smaller road transport vehicles such as the one modelled in this system which has an internal body volume of 65 m^3. However when using a rigid vehicle (i.e. the motor unit and the carrying unit are constructed as a single unit) it is necessary to use an alternative chipping and loading strategy to that described in system A. By producing chips prior to the arrival of the road vehicle and then loading these chips directly to it, the loading time and hence the cost associated with loading can be greatly reduced. This allows the road vehicle to spend more of its time deployed transporting fuel (i.e. it can be used more productively).

Figure 4.3: Forest fuel supply - system B

Figure Not Available Electronically

System C
Forest thinnings/residues are stored at the forest landing for several months and are then chipped directly into a 38 tonne (GVW) articulated tipper trailer with an internal body volume of 90 m^3. The HGV driver arrives to collect the trailer (dropping another empty trailer at the same time) and transports the chips to an intermediate store. The chips are unloaded by the vehicle at the intermediate load and built into a stack by a loader. They are stored here before being loaded onto the same specification of road transport vehicle and transported to the power station.

This system is similar to the Swedish emergency terminal system, in which a storage area is established outside of the forest so that chips can be sourced from here during periods when the forest cannot be accessed due to poor weather and bad forest road conditions or when forest roads are subject to repairs. Given that forest roads in the UK will not be accessible at all times of year but power stations will require deliveries on a year round basis, a system such as this will be necessary as part of a balanced fuel supply strategy.

The actual operations involved in this system are similar to system A except that, rather than the fuel being stored unchipped in the forest and then chipped and delivered direct to the power station, the fuel is stored in the forest for several months and then in the drier weather is chipped and transported to an intermediate store outside of the forest and unloaded here for storage. Possible locations for such intermediate stores include old industrial sites and ex-airfields which may possibly have concreted ground and/or covered buildings for chip storage which would be difficult to financially justify laying or constructing within the budget of a biomass scheme.

Whilst this system involves double handling of the fuel (i.e. two road transport movements) from the forest to the power station and the costs associated with this, it attempts to do this in the least costly and most beneficial manner (in terms of fuel quality) possible. By storing the fuel in an unchipped form at the forest landing for a period of time the fuel is unlikely to decompose. In addition rather than transporting these low bulk density residues (which therefore have high unit transport costs), these are chipped prior to transport to reduce transport costs to, and handling costs at, the intermediate store.

Figure 4.4: Forest fuel supply - system C

Figure Not Available Electronically

System D

In this system forest thinnings/residues are stored at the forest landing. They are then loaded, in an unchipped form, into a 38 tonne (GVW) articulated tipper trailer with an internal body volume of 90 m^3 by a grapple crane (the head of which is used to compact the residue into the vehicle body thereby improving its bulk density and hence the weight of the load carried). The HGV driver collects the full trailer, dropping off another empty one for filling, and transports the material to the power station where they are unloaded by a grapple crane. The forest fuel is chipped at the power station using a centralised chipper.

Centralised chipping is likely to be less expensive than in-forest chipping (due to the productivity of the centralised chipper) and gives the power station operator far greater control over chip specification. However the costs per tonne of transporting unchipped material is higher than chip transport due to the lower bulk density of unchipped residues. The modelling of this system allows us to make these cost comparisons between the costs of chipping in forest followed by transport to power station (systems A and B) with the costs of centralised chipping.

Figure 4.5: Forest fuel supply - system D

Figure Not Available Electronically

System E

This system involves terrain chipping (as used in forests of even terrain such as Thetford Forest). The chips are then extracted by forwarder to the roadside/landing. They are loaded directly into 30 m^3 demountable containers, two of which are collected by an articulated vehicle at a time and taken to an intermediate store (the driver drops off two empty containers when collecting two full ones). The chips are unloaded and stacked by a loader and remain here for the storage period. They are then loaded into a 38 tonne (GVW) articulated tipper vehicle by a loader and transported to the power station.

This system makes use of demountable containers for the transport of wood chips to an intermediate store. These containers lend themselves to this type of operation as they are relatively inexpensive and sturdy and can be left at several points around the forest adjacent to the forest road for collection by a road transport vehicle.

One of the major problems associated with this system are the losses in dry matter that are likely to occur if the chips are stored for any length of time. Therefore terrain chipping systems could provide wood fuel directly into the power station after the chips have been produced at stump and in this way reduce the storage losses. This could be planned as part of a balanced fuel supply strategy, with wood fuel from other harvesting systems in which unchipped material is produced at harvest and therefore less problematic to store, being used to supply when fuel from terrain systems is unavailable.

Figure 4.6: Forest fuel supply - system E

Figure Not Available Electronically

4.3 Results of supply systems modelled

Total delivered cost at the power station from systems modelled

Table 4.1 below shows the total delivered cost calculated using the Supply Chain Option model for forest material supplied to power stations for each of the supply systems previously defined. Although the model calculates the delivered cost and the cost of each activity per tonne of dry matter, the wet tonne cost and cost per gigajoule (GJ) of energy are also given, together with the dry matter content of the fuel upon delivery in each system.

Table 4.1: Delivered cost for forest fuel systems
(all costs have been rounded to the nearest £ except £/GJ)

	System A	System B	System C	System D	System E
Delivered cost (£/wet tonne)	18	19	21	15	18
Delivered dry matter content (%)	60	60	60	60	50
Delivered cost (£/tonne dry matter)	32	34	37	27	35
£/GJ	1.82	1.94	2.12	1.56	2.13

System D can be seen to produce the lowest delivered cost at power station. This system involves supplying unchipped material which is then chipped as required by a centralised chipper at the power station. This chipping cost has not been included in the delivered cost and therefore, in order for this system to be the most cost effective, the cost of centralised chipping must be less than £5 per tonne of dry matter for this system to have a lower delivered cost (including centralised chipping) than the next cheapest supply strategy, system A (i.e the difference between a delivered cost of £32 per dry tonne in system A and £27 in system D).

System E results in the highest delivered costs. This is the terrain chipping system with the chips being extracted and immediately hauled away from the forest to an intermediate store. This system therefore involves two road transport stages and doubling handling of the wood chips.

The relative cost efficiency of supply systems on a cost per tonne of dry matter basis is slightly different to the relative efficiency on a cost per GJ basis as the latter takes account of the water present in the delivered fuel. This water has to be burnt off during combustion and therefore the lower the dry matter content of the delivered fuel, the lower its net calorific value per tonne.

Therefore when comparing, for instance, system D and system E, system D is approximately 22% less expensive than system E per tonne of dry matter delivered but is 27% cheaper per GJ due to the higher dry matter content (and hence higher energy value) of the fuel delivered in system D.

The difference between cost per tonne of dry matter and cost per GJ is generally less significant when making comparisons between supply systems for the same biomass fuel (e.g. forest fuel supply systems) than when comparing the delivered costs of different biomass fuels (e.g. forest fuel and straw systems). This is explained by the different net calorific values (dry basis) of different forms of biomass fuels.

Breakdown of total delivered cost

Table 4.2 shows the breakdown of the total delivered costs for all of the forest fuel supply systems. In systems A, B and D the forest fuel is delivered direct from the forest store to the power station. Therefore, as shown by the table, the final cost items to arise in each of these systems is the sampling and weighing of the load on the transport vehicle and the cost of unloading this vehicle when it arrives at the power station at the end of the journey from the from the forest.

Table 4.2: Breakdown of total delivered costs for forest fuel supply systems

Table Not Available Electronically

Systems C and E involve intermediate storage and therefore incur additional costs associated with two transport stages (from forest to intermediate store and then from intermediate store to power station) and the consequent double handling of the forest fuel. These additional costs are clearly reflected in the table.

The key difference between system A and B is the size of the transport vehicle used and the chip processing/lorry loading operation. In system A, a 38 tonne articulated vehicle capable of carrying a load of 90 m^3 is used, whereas in system B a 32 tonne (GVW) rigid vehicle with a carrying capacity of 65 m^3 is used. Lorry size may be limited to the latter in some forest environments and hence alternative chipping/vehicle loading strategies such as the one outlined in system B will be necessary. The costs shown in the table indicate the higher trip costs per tonne of dry matter that result from using a smaller vehicle (trip cost of £7.72 per tonne of dry matter in system B compared with £6.28 in system A). The cost of transporting the fuel can be seen to be one of the most significant (in terms of proportion of total delivered cost) and therefore the size of the vehicle used will have a significant impact upon delivered costs of forestry fuel.

Another important cost in systems A, B and C is the cost of chipping material in the forest prior to transport (either to an intermediate store or the power station). In each system this can be seen to cost approximately £10 per tonne of dry matter. This cost is related to the relatively low productivity rates of such chippers (in this modelling we have assumed that the chipper used in capable of producing 15 wet tonnes of chips per hour). The issue of chipper productivity rates and their effect on system cost and organisation are addressed in greater detail in section 4.4.

System D involves the transport of unchipped residues to the power station. The cost of transporting this material is approximately £9 per tonne of dry matter in the system modelled and is therefore more expensive than chip transport. (This assumes an articulated vehicle with 90 m^3 body is used and that the residues can be compacted to a bulk density of 180 kg/m^3; if such equipment is not used and/or compaction not undertaken the cost of transporting unchipped material can be expected to be substantially higher). Even with compaction it is not possible to utilise the maximum payload of the transport vehicle and this has the effect of increasing the cost per dry tonne for the journey. Given that the transport vehicle used in system D and A is exactly the same and the transport distance travelled and road categories used in both systems are the same it is possible to make a direct comparison between *road trip costs* for unchipped residue transport and chip transport (£9 per dry tonne compared with £6 per dry tonne for wood chip - ie approximately 50% greater).

However, despite the greater road trip costs per tonne, our modelling work suggests that the *total delivered cost* per tonne of dry matter in system D is approximately £5 to £10 cheaper than in systems in which material is chipped prior to transport. Therefore, if centralised chipping at the power station can be conducted for less than this amount, transporting unprocessed fuel may prove to be the cheaper option. This approach has the added advantage of giving the power station operator control over the chipping function.

System C includes two storage locations (in forest and at an intermediate store) and is intended as a source from which fuel could be delivered at times when the forest is not accessible. In modelling this system the equipment used to supply fuel has been defined as exactly the same as that used in system A and therefore by comparing the delivered cost of fuel in each it is possible to determine the additional costs that are likely to arise from having to transport and handle fuel twice before delivery. System C produces a delivered cost that is approximately £5 per dry tonne higher than system A and this therefore represents the additional cost of double handling (it is important to note that this additional cost of £5 per dry tonne also reflects the fact that the material is stored in chipped form at the intermediate store and is assumed to undergo dry matter losses of 8% during this two month storage period in the modelling).

The modelling suggests that transporting wood chips in containers (system E) will be more expensive than in articulated lorries. In system C and E wood chip is transported the same distance from forest to intermediate store. In the case of the container system the cost of the trip is approximately £7 per dry tonne and the cost of loading and unloading the containers are both approximately £1.40 per dry tonne. This compares with a trip cost of £4.00 per dry tonne for an articulated vehicle (system C), a loading cost of approximately £0.40 per dry tonne and an unloading cost of approximately £0.20 per dry tonne. The higher costs of using containers are due to the smaller payload that they carry and also the time taken to load and unload containers.

Differences between costs for which original input values were the same are due to dry matter losses in the systems. For example, as discussed in the supply system definitions, the price paid to the forest owner (shown as the "Price paid to producer" in the table) was set to £2 per tonne of dry matter for all forest supply systems. This cost has remained as £2 in system D, as this system has not experienced any dry matter losses. However in all the other systems the original £2 input has been inflated to take account of dry matter losses that are defined as having occurred either during storage or during chipping (see Appendix 1 for details of assumptions made about losses in forestry supply systems).

Similarly, whilst the cost of harvesting and extraction was set at £10 per tonne of dry matter for all of the forest fuel systems modelled, the differences in this cost shown in the table are explained by the extent of dry matter losses occurring after the harvesting and extraction activity in each of the systems. The cost differences reflect the extra forest fuel that has to be produced to compensate for these losses.

Activity cost categories

Figure 4.7 shows the importance of each of the activity cost categories in the forestry supply systems we have modelled. The graph shows that across all the supply systems we have modelled, the key activity cost categories are harvesting and extraction, handling and transport costs. The cost of purchasing the fuel from the forest owner and the cost of storage can be seen to represent a relatively minor proportion of total delivered costs in all systems.

Figure 4.7: Activity costs for forest fuel supply systems

Figure Not Available Electronically

Due to the reasons discussed above, transport costs are higher as a proportion of total delivered cost in system D and E than in the other systems. Transport costs account for approximately 40% of total delivered cost in both of these systems. This compares with only approximately 25% in each of the other systems.

Handling costs in system D and E are lower than in the other systems (they account for approximately 10% of delivered cost in both compared with 20% to 25% in other systems). This is due to the reduction in handling time that can be achieved by either chipping at stump or chipping material at the power station (given the relatively low productivity rates of the mobile chippers used at forest landings/stores, it takes a long time to feed the material into the chipper).

A harvesting and extraction cost of £10 per tonne of dry matter represents between 35% and 45% of total delivered cost in the systems modelled.

Storage costs (the physical costs of the store, insurance of the forest fuel and stockholding costs) are relatively low in all systems due to the nature of the storage systems modelled. Storage costs represent around 5% of delivered cost per tonne of dry matter in the supply systems. However dry matter losses during chip storage and chipping losses affect the costs of all activities prior to storage as more forest fuel has to be produced than is actually required by the power plant operator in order to compensate for these losses. The costs of this additional production is reflected in the cost of these activities.

Detailed road transport analysis

A detailed breakdown of the road transport activity within each of the supply systems modelled is shown in Table 4.3. As supply systems C and E have two road-based transport stages (first from forest to an intermediate store and then from intermediate store to the power station) the table shows the analysis of each of these stages separately followed by the overall transport analysis for both stages combined.

Table 4.3: Road transport analysis of forest fuel supply systems

Table Not Available Electronically

In systems in which forestry material is chipped direct to an articulated transport trailer, the terminal time (time spent inactively by the road transport vehicle at its origin and destination) can be seen to be extremely high in comparison with systems in which pre-chipped material is loaded into the vehicle. For example, systems A and C both involve direct chipping to transport trailers in the forest and result in total terminal times of approximately 2.5 to 3 hours. This compares with a total terminal time of only 47 minutes in system B in which heaps of pre-chipped material are loaded into the vehicle. Therefore in system A and C the terminal time expressed as a proportion of total transport time (terminal time plus trip time) is high (approximately 50%) in comparison with system B (21% terminal time).

System D also has a relatively high total terminal time (approximately 1.75 hours) due to the time that it takes to load unchipped forest fuel into a trailer and compact it and then unload it at a power station.

However the terminal costs per vehicle load in system A, C and D are not significantly higher than in system B. This is because in systems A and C the chipper is chipping direct to an articulated trailer which is not an expensive piece of equipment. Similarly in System D the unchipped residues are loaded into an articulated trailer. If instead the road tractor and trailer (i.e. an entire articulated vehicle) and lorry driver or rigid vehicle and driver had been present throughout the vehicle loading process the terminal costs would be far higher due to the much greater hourly operating cost of such a vehicle in comparison with just a trailer (see appendix 7 for further details of hourly operating costs of equipment).

In all of the forestry supply systems, trip costs per vehicle load can be seen to be far greater than terminal costs per vehicle load (trip costs representing anything between approximately 60% and 80% of total transport costs). This is a desirable situation as trip costs reflect that the vehicle is undertaking active work and being productive, whilst the vehicle is unproductive during terminal time.

The trip costs per tonne of dry matter vary between the different systems. This is due to the size of the vehicle used and the load weight it can carry which depends upon the maximum payload of the vehicle and the bulk density of the biomass. Therefore in system B, a 32 tonne (gross weight) rigid tipping vehicle with an internal volume of 65 m^3 is used. This restricts the load carried to 10.7 tonnes of dry matter and this has the effect of making the trip cost per tonne of dry matter higher than other systems in which larger payload and volume vehicles are used to transport the chip with the same bulk density (e.g. system A).

Given the wet bulk density of chips produced for forestry fuel, road transport vehicles used to transport chip are likely to achieve their maximum payload thereby minimising the total transport cost per tonne for that vehicle (systems A and C - 23.1 wet tonnes achieves maximum payload for these 38 tonne (gross weight) vehicles and system B - 17.9 wet tonnes achieves payload for this 32 tonne vehicle).

In system D unchipped material which has been compacted with the head of the loading grapple is transported. The load weight carried is far less than in a wood chip transport system (e.g. system A) due to the lower bulk density of the load (180 kg/m^3 compared with 275 kg/m^3 for wood chips in system A). This has the effect of making the trip cost per tonne of dry matter carried higher in system D than in system A (£8.96 compared with £6.28).

The speed at which the vehicle travels dictates the distance it can cover in a given period of time. Therefore, in supply systems in which a high proportion of transport is undertaken on forest roads where vehicle speed is low this will result in relatively high trip costs per kilometre. This is borne out by the difference between the trip cost per kilometre in the two systems (C and E) which have two transport stages. In system E for example the trip cost per kilometre from the forest to the intermediate store is £1.78 compared with a trip cost of only £0.96 between the intermediate store and the power station. The latter stage is conducted over good road surfaces and hence average transport speed is far higher.

The total transport cost per kilometre per tonne load is often referred to as the `load moving cost'. This figure reflects the cost of moving one tonne of material a distance of one kilometre. From the table it can be seen that system A has the lowest overall load moving costs of all the forest supply systems at £0.10 per tonne of dry matter per kilometre. The load moving cost for other systems is between £0.12 and £0.19 per tonne of dry matter per kilometre.

4.4 Sensitivity analysis for forest fuel

Road transport distance

The distance that forest fuel has to be transported by road from the forest to the power station will depend upon the locations from which fuel is sourced, the availability of the resource and the location and size (i.e. annual fuel requirement) of the power station. In any one biomass scheme, distances of transport movements will vary significantly and variation in transport distance between schemes is also likely.

The same supply systems as defined in section 4.2 were run for different road transport distances to that used in the base cases of 40 kilometres one way (80 kilometres round trip). Two alternative transport distance scenarios were modelled:

- 20 kilometres one way transport distance (i.e. 40 kilometres round trip) - this is half the road transport distance in the base cases.

- 80 kilometres one way transport distance (i.e. 160 kilometres round trip) - this is double the road transport distance in the base cases.

In modelling these alternative transport scenarios it has been assumed that as haul length increases there is greater opportunity to use better quality and hence faster roads (e.g. single or dual A roads). Additionally, as haul length increases the proportion of the total journey spent on relatively slow forest roads becomes less significant, this also has the effect of increasing the average speed for the journey. As transport distance falls the converse is true. See appendix 1 for further details of these assumptions.

The effects of these alternative transport distance scenarios on the delivered cost of forest fuel for each of the supply systems modelled are shown Figure in 4.8 (together with the delivered costs in the base cases of 40 kilometres).

Figure 4.8: Effect of road transport distance on delivered costs

Figure Not Available Electronically

As explained above, as the road transport distance from the forest to the power station increases, the average vehicle speed over the journey is also likely to increase. Therefore transport distance has an important impact on journey time (and hence trip cost and delivered cost). Doubling the transport distance will result in less than proportionate increase in trip costs and halving the transport distance will mean a less than proportionate decrease in trip costs.

The figure shows that a one way transport distance of 20 kilometres (i.e. half the distance in the base cases) results in a decrease in delivered cost per dry tonne of 8% to 14% in the systems modelled (approximately £2.50 to £4 per dry tonne). When expressed as a proportion of delivered cost, transport (i.e. trip and terminal costs) accounts for between 15% and 30% at a one way distance of 20 kilometres (in the base cases transport accounted for between about 25% and 40% of total delivered cost).

If forest fuel were transported 80 kilometres between forest and power station the model suggests a rise in delivered cost of between 8% and 15% of delivered cost (between about £2.50 and £4 per dry tonne depending on the supply system). At this distance transport represents approximately 30% of total delivered cost per tonne of dry matter in systems A to C and about 45% in systems D and E.

The analysis shows that whilst, as would be expected, transport distance does have an effect upon delivered costs of forest fuel, the effect is not very significant. The results suggest that halving or doubling transport distance reduces or increases delivered cost by approximately 10% per tonne of dry matter. This implies that the delivered cost of forest fuel is relatively insensitive to changes in transport distance; once the vehicle has been loaded it can travel a relatively long distance before delivered costs increase substantially.

Therefore several factors limit the effect of increased transport distances on the delivered cost of forest fuel. These are:

- the proportion of delivered cost accounted for by transport (trip and terminal) costs;

- terminal costs remain the same even when transport distance changes;

- average trip speed is likely to increase as transport distance increases and therefore any increase in distance will result in a less than proportionate increase in trip time (and hence trip costs). Conversely, when transport distance decreases, trip time and hence trip costs fall less than proportionately.

Harvesting and extraction costs

In all the base case supply systems the cost of harvesting and extraction has been assumed to be £10 per dry tonne. However trials and research undertaken in the UK (Mitchell et al, 1990; Mitchell and Hankin, 1993; Forest Industry Group, 1996) show that this cost will vary significantly depending upon the forest from which the fuel is supplied and the appropriate harvesting strategy (see Appendix 1 for further discussion of potential harvesting and extraction costs).

Harvesting and extraction costs could be as low as £7 per dry tonne (i.e. 30% lower than the input cost used in the base case) and as high as £20 per dry tonne (100% higher than in the base cases). Using these alternative values, a harvesting and extraction system that was 30% cheaper than that assumed in the base cases (i.e. £7 per dry tonne) would produce delivered costs approximately 10% lower than in the base cases (between £24 and £34 per dry tonne at the power station). A harvesting and extraction cost of £20 per dry tonne would result in delivered costs that were approximately 30% to 35% higher than in the base case run (i.e. £37 to £47 per dry tonne).

Clearly the harvesting and extraction activities are key cost components in forest fuel supply and will be a significant determinant of the delivered cost of fuel.

Transport of unchipped forest fuel

In supply system D forest fuel is transported in an unchipped form. In the base case it was assumed that a bulk density of 180 kg/m^3 could be achieved when loading the road transport trailer with an independent crane by compacting the residues with the head of the crane. It may be possible to achieve a greater compaction than this and therefore the Supply Chain Option model was rerun to examine the effect of a 20% improvement in compaction rate (i.e. 215 kg/m^3). If this were possible it would reduce the trip cost per tonne of dry matter for this system by approximately 16% (i.e. approximately £1.50 per tonne of dry matter).

If this higher compaction rate of 215 kg/m^3 could be achieved and additionally it was possible to use a larger capacity transport vehicle to transport the unchipped residues, this would help to further reduce transport costs and hence total delivered cost for the system. If a road transport vehicle with a body volume of 100 m^3 could be used (clearly a vehicle of this size would not be appropriate on some forest roads in the UK) this would reduce the trip cost by approximately 25% in comparison with the base case.

Both of these strategies could be explored as means by which the cost of road transport and thereby delivered costs could be reduced in a system supplying unchipped material to the power station. It would also reduce the total number of deliveries required.

However, some forest roads in the UK will prevent the use of a road transport vehicle of even 90 m^3 as modelled in the base case for supply system D. If instead it was only possible to use a rigid vehicle of 65 m^3 the modelling suggests a delivered cost at the power station of approximately £33 per tonne of dry matter in comparison with £27 when using a 90 m^3 vehicle in the base case. When the cost of centralised chipping is added to this figure, the cost of the system may well exceed the cost of a system in which forest fuel is chipped prior to transport. It is therefore essential that use is made of the largest vehicles possible (i.e. in terms of volume) when transporting residues with insufficient bulk density to make use of the payload that can be carried by the transport vehicle in order to control transport and thereby delivered costs.

Dry matter losses of wood chips during storage

In supply system E the forest fuel is chipped at stump and then transported immediately by road to an intermediate store. In the base case it has been assumed that the fuel is stored for six months and that dry matter losses occur at an average rate of 4% per month. This has a significant effect upon the cost per tonne of dry matter supplied to the power station as more fuel must be harvested and stored to compensate for these losses. Dry matter losses could be significantly different from this 4% figure and therefore the model was rerun to explore the effect of different degrees of dry matter loss during storage. This is shown in Table 4.4.

Therefore if dry matter losses can be kept below 4% per month this will have an extremely beneficial impact upon delivered costs and could make this supply system as cost effective as some of the alternative forest fuel supply systems considered. However the use of expensive storage and drying systems to achieve this end are unlikely to be affordable in biomass schemes. Work by Ellis (1995) has shown the cost of energy used to dry the chips could be as high as £18 per tonne of dry matter and that simply cooling the chips with forced ventilation could cost approximately £3 in energy bills per dry tonne with dry matter losses still occurring at a rate of 3% per month. In addition the cost of building a covered store would probably cost approximately £5 to £10 per dry tonne. Therefore the use of such storage and drying systems for such a low value product as biomass appear somewhat unlikely.

Table 4.4: Delivered cost for supply system E for different average monthly rates of dry matter loss assuming 6 month storage

	Loss of 0%	Loss of 2%	**Loss of 4% (base case)**	Loss of 6%	Loss of 8%
Delivered cost (£/tonne dry matter)	28	31	35	41	50

In a supply system such as system E in which chips are produced at harvest it would be most appropriate to deliver these chips directly to the power station for immediate use. This would prevent significant dry matter losses during storage and would also prevent the costs of storage (i.e. physical costs of the land, insurance and stockholding costs). Running the model for immediate delivery in system E produces a delivered cost of approximately £25 per tonne of dry matter; this is approximately 30% lower than the base case scenario for system E in which it is stored and undergoes losses. Therefore, wherever possible, it would seem sensible to deliver material that is chipped at harvest directly to the power station. Other material that can be stored in an unchipped form is less likely to suffer dry matter losses and is therefore more suitable for storage and later delivery.

Mobile chipper productivity

In supply systems A, B and C the fuel is chipped by a mobile chipper at the forest landing/roadside prior to road transport to the power station. The chipper productivity has been assumed to be 15 wet tonnes per hour and therefore it takes a long time to fill a large road transport vehicle of 90 m^3. This results in large periods of downtime for the road transport vehicles if the supply chain is not well managed.

If chipper productivity could be increased this would reduce the amount of time that vehicle loading takes and hence reduce the cost of the loading operation. It is also probable that, although a more powerful chipper with a higher productivity rate than that modelled would have higher operating costs, it would reduce the cost of mobile chipping per tonne of dry matter produced as the cost of feeding the chipper would also be reduced.

However, it is important to ensure that mobile chippers with higher productivity rates are capable of producing wood chips of a suitable quality for use at a power station (i.e. in terms of chip size produced and variability in the chip size).

Diesel fuel and labour costs

Two important cost factors in all biomass supply systems are the cost of fuel (i.e. diesel for road transport vehicles, forestry and agricultural equipment) and the cost of labour. Costs of both of these inputs could rise significantly in the future and therefore the Supply Chain Option models were rerun to examine the effect of increases in the inputs on the delivered cost of forest fuel.

Fuel costs could rise significantly in future if government were to implement higher rates of fuel duty as part of an environmental taxation strategy. A recent report by the Royal Commission on Environmental Pollution (1994) has suggested that fuel prices should be raised by 9% per annum. If such an approach were taken fuel costs would rise by approximately 40% by the year 2000. Running this increased fuel cost scenario for forestry fuel supply systems increases the delivered cost by between 2% and 4% in comparison with the base case costs.

Labour rates could rise in the next few years as a result of shortages in lorry drivers due to stricter eyesight tests. More stringent drivers' hours regulations would result in the need for haulage companies to recruit more drivers for the same workload.

We have therefore modelled the combined effect of a 25% increase in labour rates with the 40% increase in fuel costs described above. This has the net effect of increasing the delivered cost of forest fuel by between 4% and 7%.

Summary of sensitivity analysis results

To conclude this chapter the sensitivity tests conducted and their effect on the delivered cost of forest fuel are summarised in Table 4.5. The table should be read in conjunction with the full text on each sensitivity test which precede this section as we have examined plausible and likely assumptions for each particular test rather than applying a standard change in input values for all tests.

Discussion and comparison of sensitivity analyses for the different biomass fuels is contained in Chapter 9.

Table 4.5: Summary of sensitivity analysis results for forest fuel systems

Sensitivity test	Effect on delivered cost

Road transport distance	*
Harvesting & extraction costs	**
Transport of unchipped forest fuel (compaction rate and/or vehicle size)	*
Use of rigid vehicle rather than articulated vehicle for transport of unchipped forest fuel	**
Dry matter loss of wood chips during storage	**
Diesel fuel and labour costs	*

N.B. Effect of the different sensitivity tests on delivered cost are shown by the following:

* less than 15% change in delivered cost
** more than 15% change in delivered cost

5. SHORT ROTATION COPPICE

5.1 Logistics and supply issues

Short rotation coppice (SRC) is likely to be grown on cultivable or arable and improved grass land, and harvesting, handling and transport systems will tend to be highly mechanised.

Harvesting

Two potential harvesting systems have been identified as being suitable for UK conditions. These are:-

- direct cut and chip systems
- stick harvesting

The choice of system and harvesting machinery will depend on the scale of operations to be carried out (for example, whether a contractor will be working on a number of farms, or an individual grower harvesting only his own crop). Also the end-user specification will affect the choice of harvesting system, and hence the need for storage facilities.

At some point in the supply system chipping must occur; this can either be during harvest, at the farm steading prior to transport, at an intermediate storage facility or at a centralised chipping facility at the power station.

Direct cut and chip systems
These systems are based on principles used in other agricultural crops, where the whole crop is cut and chipped in a single operation (e.g. forage harvesting of grass or maize for silage, sugar cane harvesting).

Direct cut and chip systems are most likely to be operated by contractors or growers co-operatives, as investment in machinery will be high. The optimum time for harvesting coppice is during the winter, when the leaves have fallen and the moisture content is at its lowest, so this will not conflict with the harvesting of other forage or combinable crops.

In general, the material, once chipped, is blown into containers or agricultural trailers as the machines move through the crop. The chips are then either stored on farm or transferred to bulk haulage trailers for road transport to an intermediate storage facility.

Stick harvesting systems
Stick harvesting systems involve a number of operations before the final product (chips) is available at the power station. Sticks are cut with one pass of either a self-propelled or trailed machine. The sticks may be bundled by the same machine, or left in loose piles in a wind-row. The bundles or piles of sticks can then be collected - for example by a front-end loader or a forwarder or loaded onto an agricultural tractor and trailer, and then can be stored on site (e.g. on the headland or in a field adjacent to the farm yard).

The advantages of this system as opposed to cut and chip harvesting are that it generally involves lower investment in machinery, and if it is necessary for the wood to be stored uncovered for a significant period, the sticks tend to dry out without decomposing.

Storage

Chip stores will need to be easily accessible, with space for loading and vehicle manoeuvring. It is unlikely that purpose built structures will be constructed for chip storage because of the cost of such facilities. However if existing farm buildings are available these will be made use of. Outside storage for significant periods of time is likely to result in dry matter loss, but this will have to be endured in supply systems where existing structures are not available. The chips are likely to be stored on a hard standing (concrete would be preferable but is generally regarded as too expensive to lay for such a low value product).

Sticks on the other hand can be stored either at the field edge, or at any convenient location around the farm. It is preferable if the storage location is easily accessible to road haulage vehicles either from the farm steading, farm tracks or the roadside.

Loading, handling and unloading

The agricultural nature of the crop means that it is highly probable that a significant amount of agricultural machinery will be used or adapted for use (rather than using purpose-built, specialist equipment), and operators will soon adapt their agricultural systems to SRC products. Only in the largest scale contractor-operated systems is it likely that specialist machinery will be used for loading and handling operations.

Friction between chips and steel or timber (lorry and trailer sides, hopper sides, etc) may be high. If so, it may prove difficult to empty vehicles by tipping, especially if the load has been compacted during transport or left to stand overnight. (Friction coefficients between straw and steel are greatly affected by moisture content and the same may be true of wood chips). In such scenarios walking floor or "Ejectaload" systems for unloading of chips would be preferable (see appendix 12.4).

Road transport

Road transport of SRC material will be responsible for a significant proportion of the total delivered cost of the fuel. Load density will be a major determinant of transport efficiency, with chips having a greater bulk density than sticks, and therefore more cost-effective to transport over long distances. Bulk lorry and trailer combinations (up to 38 tonne gross vehicle weight and 90 m^3 internal body volume) are likely to be used.

Figure 5.1 shows the most likely supply system options for short rotation coppice from harvest to point of utilisation at the power station.

Figure 5.1: Supply system options for short rotation coppice

Figure Not Available Electronically

5.2 Short rotation coppice supply systems modelled

Five supply systems have been set up to consider short rotation coppice supply from the field to the power station.

System A
This is a direct cut and chip harvesting operation using a large Claas Jaguar self-propelled harvester with coppice header. The chips are blown into an agricultural tipping trailer pulled by a tractor that runs alongside the harvesting machine. The tractor and trailer travel to the farm storage area when fully

loaded and the chips are tipped from the trailer (the number of tractors and trailers needed in such a system to ensure that the harvesting machine can remain productive is dependent upon the field size, the out of field distance to the store and the speeds that can be achieved during this journey). The chips are stored on hard standing.

After storage, the chips are loaded into a 38 tonne (GVW) articulated HGV bulk tipping vehicle with an internal body volume of 90 m^3 by a front end loader with a bucket attachment. The HGV tipping vehicle transports the chips to the power station where the load is discharged by the driver.

The advantage of the direct cut and chip harvesting system is that the coppice is cut and chipped in a one pass operation. The productivity rates of such direct cut and chip harvesters are also higher than stick harvesters. This results in direct cut and chip harvesting systems being less expensive than harvesting as sticks and then chipping sticks when required for delivery.

A major problem of the direct cut and chip approach is that chips will have to be stored for significant periods of time and are likely to undergo dry matter losses before being delivered to the power station. Also sinkage of trailers and damage to soil structure and under drainage may occur in this harvesting system.

By using a tractor and agricultural tipping trailer to collect the chips produced by the harvester, this ensures that the harvesting machine can achieve higher productivity rates than if the chips are blown into a trailer trailed by the harvester which then has to be uncoupled from the harvester when full and an empty trailer attached.

Figure 5.2: Short rotation coppice supply - system A

Figure Not Available Electronically

System B

This is also a direct cut and chip harvesting operation, using the same self propelled harvesting machine as in system A (Claas Jaguar with coppice header). The chips are blown into an agricultural tipping trailer pulled by a tractor, which runs alongside the harvesting machine. The tractor and trailer travel to the farm steading when fully loaded and the chips are tipped from the trailer. These chips are then loaded into a 38 tonne (GVW) articulated HGV bulk tipping vehicle with an internal body volume of 90 m^3 by a front end loader with a bucket attachment within a couple of days of harvest.

The HGV tipping vehicle transports them to an intermediate store, where the load is discharged and then built into a stack by a front end loader. The chips are then stored here until required for supply to a power station. Transport from the intermediate store to the power station is also undertaken by the same type of articulated HGV tipping vehicle; the vehicle is loaded with chips by a front end loader at the store and then discharges the chips upon delivery at the power station.

This system is identical to coppice supply system A to the point at which chips are unloaded by the agricultural tractor and trailer at the farm steading. However, rather than the chips being stored on farm as in system A, they are transported by HGV to an intermediate store located between the farm and the power station. This system invariably involves double handling of the fuel (i.e. two road transport movements are necessary before the chips are delivered to the power station) and this will give rise to costs that are not incurred in supply system A.

However such a supply strategy is likely to be required in a secure fuel supply strategy as, although farms may not be accessible all year round, power stations will require coppice on a constant basis. By using an intermediate store that is accessible at all times of year regardless of weather and road conditions and farm operations this security of supply can be guaranteed.

Figure 5.3: Short rotation coppice supply - system B

Figure Not Available Electronically

System C

This is a stick harvesting system. For the purposes of the modelling we have assumed the use of a Segerslatt Empire 2000 stick harvester. The harvester cuts the sticks and bundles them and then lays the bundles on the headland. The bundles are loaded onto a tractor and farm trailer by a front end loader with suitable attachments and transported to the farm storage area where they are stacked and stored.

When required at the power station the bundles are loaded into a chipper by a front end loader with suitable attachment and chipped direct to HGV articulated tipping trailer. The driver then arrives in the HGV tractor (38 tonne gross weight and internal body volume of 90 m^3) and collects the trailer and transports it to the power station. (dropping off another empty trailer at the farm for further chips to be chipped into). The chips are discharged by the vehicle on arrival at the power station.

In stick harvesting systems, the sticks have to be processed (i.e. chipped) at some point in the supply chain. This can occur either on the farm or at the power station. By carrying out chipping on the farm with a mobile chipper the transport costs can be reduced as chipped material is cheaper to transport than stick bundles given the lower bulk density and awkward shape of the latter.

Mobile chippers have relatively low productivity rates which result in lengthy loading times when chipping directly to large articulated HGVs; this leads to a significant degree of unproductive time for the road transport vehicle. It is therefore preferable to have only the road trailer present during the chipping process and the road tractor unit and driver can be hauling a loaded trailer of chips to the power station while this is taking place.

For this system to work effectively with only one mobile chipper, the time taken by the road transport vehicle to haul chips to the power station, deliver them and then drive back to the farm should be greater than the time taken for the chipper to fill a trailer with chips, otherwise the transport vehicle will have to wait for the next full trailer when it arrives back at the farm. To overcome this problem it would be possible to use more than one chipper or to use the approach described in system D.

Figure 5.4: Short rotation coppice supply - system C

Figure Not Available Electronically

System D
This system is also a stick harvesting and bundling system and is exactly the same as system C in terms of harvesting, in-field transport and farm storage. After on-farm storage the stick bundles are loaded into a chipper by a loader with suitable attachment and chipped to a heap at the farm steading. They are then loaded from the heap into a 38 tonne articulated HGV tipping vehicle with an internal body volume of 90 m^3 by a loader with loading shovel. This road transport vehicle then transports the chips to the power station where they are discharged.

Producing chips from the sticks prior to road transport minimises haulage costs per tonne carried; this system represents an alternative approach to that described in system C. Instead of chipping directly to an HGV trailer, it is possible to produce the chips prior to the arrival of the HGV, chipping them to a heap. Then when the road transport vehicle arrives it can be loaded immediately and relatively rapidly by a loader from the heap, thereby ensuring that the terminal time of the HGV is limited.

Figure 5.5: Short rotation coppice supply - system D

Figure Not Available Electronically

System E
This is another stick harvesting system. It is the same as systems C and D in terms of harvesting, in-field transport and farm storage. However rather than the stick bundles being chipped and loaded onto the road transport vehicle (as in systems C and D) they are loaded onto an HGV flatbed/timber trailer as unchipped bundles by a grapple crane. They are transported as unchipped bundles of coppice sticks on the road transport vehicle to the power station. The stick bundles are then unloaded by a fixed crane at the power station and chipped at the power station by a centralised chipper.

As with forest fuel, centralised chipping may prove to be less expensive than chipping on the farm prior to transport (due to the productivity of the centralised chipper) and also allows the power station operator greater control over specification of the chipped material. However the disadvantage of this approach is that costs per tonne for the transport of unchipped coppice sticks is higher than chip transport due to the lower bulk density of the unchipped material and its shape which tends to make poor use of the transport vehicle. Research by the Forestry Authority (1995) has shown difficulties in achieving payloads of greater than 10 wet tonnes of sticks and this is the assumption used in our modelling. Such payloads are far lower than can be achieved when transporting chipped material in which vehicles with payloads of approximately 23 tonnes can achieve maximum payload if the volume of the vehicle body is sufficiently large.

The modelling of this system allows us to make cost comparisons between the costs of stick harvesting systems in which the sticks are chipped on the farm prior to transport (systems C and D) with the costs of centralised chipping.

Figure 5.6: Short rotation coppice supply - system E

Figure Not Available Electronically

5.3 Results of supply systems modelled

Total delivered cost at the power station for the systems modelled

Table 5.1 shows the total delivered cost calculated using the Supply Chain Option model for short rotation coppice supplied to power stations for each of the supply systems defined above.

Table 5.1: Delivered cost for short rotation coppice systems
(all costs have been rounded to the nearest £ except £/GJ)

	System A	System B	System C	System D	System E
Delivered cost (£/wet tonne)	24	26	26	27	29
Delivered dry matter content (%)	50	50	60	60	60
Delivered cost (£/tonne dry matter)	47	52	50	51	54
£/GJ	2.87	3.13	2.89	2.91	3.10

From the table it can be seen that system A, which involves direct cut and chip harvesting and on-farm storage of chips, produces the lowest delivered cost at the power station (on a wet tonne, dry tonne and GJ basis) of all the coppice supply systems modelled.

System E which is a stick harvesting system in which the sticks are transported to the power station in an unchipped form and are then chipped at power station results in the highest delivered cost per tonne of dry matter, but not per GJ (the cost per GJ is extremely similar to system B - the reason for the difference in the delivered dry tonne costs but similarity of the delivered cost per GJ of these two systems is explained by the higher dry matter content of the fuel in system E).

However the difference in delivered cost between the cheapest and most expensive supply systems for coppice is not very large. Delivered costs per tonne of dry matter are only 13% lower in the cheapest system (system A) than in the most expensive system (system E). It is also important to note that the results indicate that the delivered cost of fuel produced using a direct cut and chip harvesting supply systems (A and B) and stick harvesting supply systems (C, D and E) are very similar.

Breakdown of total delivered cost

The breakdown of the total delivered costs for all of the five short rotation coppice supply systems that we have modelled are shown in Table 5.2. In the two direct cut and chip systems (system A and B), the dry matter losses that we have assumed occur during storage result in the need to grow and harvest more coppice than is required by the power station in order to be able to supply the required quantity after storage. This accounts for the higher "price paid to producer" per tonne of dry matter in these systems than the stick harvesting and storage systems in which such losses are assumed not to occur. Therefore dry matter losses during storage have an important effect upon delivered costs of coppice in these supply systems. Without these losses the direct cut and chip systems would have significantly lower delivered costs per tonne of dry matter than the stick harvesting systems.

The results show that the chipping of coppice sticks at the farm using a mobile chipper prior to transportation (system C and D) will cost in the region of £7 per tonne of dry matter. The alternative to chipping sticks prior to transport is to transport them unchipped and then process them at the power station using a centralised, high productivity chipper, this supply option is modelled in system E. It can be seen that the delivered cost of unprocessed sticks has been calculated to be approximately £3 per tonne of dry matter higher than on-farm chipping and chip transport and this excludes the cost of chipping the sticks at the power station so the difference would be even greater once this had been undertaken.

Table 5.2: Breakdown of total delivered costs for short rotation coppice supply systems

Table Not Available Electronically

The reason for unprocessed stick supply having a higher delivered cost than stick harvesting systems in which sticks are processed prior to transportation is that the cost of transporting sticks far exceeds the cost of chip transport (system E: stick transport - approximately £9.50 trip cost per tonne of dry matter; systems C and D: chip transport - £4.50 trip cost per tonne of dry matter). As well as trip costs being higher for sticks than chips, the cost of loading lorries is also significantly higher due to the greater time taken for this activity and the lower bulk density of bundled sticks.

In the system definitions we have assumed that it is only possible to get a relatively small load of coppice sticks onto a road transport vehicle, this is due to the shape and size of the sticks which prevents the use of the total vehicle bed area when using a maximum dimension articulated trailer (research by the Forestry Authority supports this assumption - Forestry Authority 1995). Therefore, given these load size limitations, this option of transporting unchipped sticks and then chipping at power station appears to be more expensive than chipping prior to transport, despite the relatively high cost of mobile chipping. However further research is clearly required to determine whether the stick load that can be carried by a road transport vehicle could be significantly improved by, for example, cutting the stick bundles, or loading them on the vehicle in a more space efficient manner. We have explored the effect of this on delivered cost in the sensitivity analysis in section 5.4.

The results indicate that there is no significant difference in the delivered costs of systems C and D (two different strategies for coping with the interface between on-farm chipping and transport).

Of the two direct cut and chip systems explored (systems A and B), the results of the modelling suggest that system A is less expensive. This is to be expected given that system A involves on-farm chip storage and then transport direct to power station, while system B involves transport to an intermediate store, storage and then transport to power station and therefore additional handling of the coppice chips. The modelling suggests that intermediate storage will add approximately £4 to £5 to the delivered cost per tonne of dry matter. However system B is likely to be required to some extent in direct cut and chip supply strategies as farm stores may not be accessible all year round.

Activity cost categories

Figure 5.7 shows the importance of each of the activity cost categories in the coppice supply systems we have modelled. As can be seen from the figure the most significant activity cost is the purchase cost of the coppice (this cost represents the price farmers would have to be paid to encourage them to grow coppice on their land). This accounts for between approximately 40% and 55% of delivered cost in the coppice systems we have modelled (we have used an input value of £20 per dry tonne to represent the purchase cost). The other major activity cost categories are handling and transport; their relative importance differs between the systems modelled.

Figure 5.7: Activity costs for short rotation coppice supply systems

Figure Not Available Electronically

Together transport and handling costs account for between approximately 25% and 50% of total delivered cost in the systems we have considered. They are highest in system E, which is to be to expected as this system involves the transport of unchipped sticks.

Handling costs in direct cut and chip systems (A and B) are far lower than in the stick harvesting systems (they account for around 10% of delivered cost in systems A and B compared with about 20% to 25% in stick systems C to E). This is due to the difficulty of handling stick bundles as well as their lower bulk density. For example, if 100 wet tonnes of coppice sticks and coppice chips had to be moved from the field to the farm store, the number of trailer loads moved would be far higher for the sticks than for chips. Consequently the handling time for the sticks would also be greater (given the greater number of vehicle movements required to move the same load weight and the difficulty in handling sticks compared with coppice chips).

Storage costs (the physical costs of the store, insurance of the coppice and stockholding costs) are relatively low in all systems; they account for between 4% and 7% of delivered cost in the supply systems modelled. However dry matter losses during chip storage and chipping losses affect the costs of all activities prior to storage as more coppice has to be produced than is actually required by the power plant operator in order to compensate for these losses. The costs of this additional production is reflected in the cost of these activities.

Detailed road transport analysis

Table 5.3 shows the results of the detailed road transport analysis of coppice supply systems.

Table 5.3: Road transport analysis of short rotation coppice supply systems

Table Not Available Electronically

The bulk density of wet coppice chip is likely to be sufficiently high that all road transport vehicles used to transport chipped material are likely to achieve maximum payload (i.e. the maximum tonnage that the vehicle is allowed to legally carry on public roads). As a result of achieving maximum payload, the transport cost per tonne for coppice will be minimised for the road transport vehicle used in the operation (i.e. the total transport cost per journey, which is virtually constant regardless of payload, can be spread over the greatest number of tonnes possible). The road transport vehicles used in supply systems modelled involving chip transport (systems A to D) do achieve maximum payload (23.1 wet tonnes for these vehicles).

Terminal times can be seen to be far greater in system C than all of the other systems. This is due to the direct chipping of stick bundles to an articulated trailer prior to transport. This is a lengthy process due to the relatively low productivity rate of the chipper. However the terminal costs per vehicle load in this system are not appreciably higher than in the other systems as the hourly operating cost of an articulated trailer is relatively low. If the road tractor and trailer (i.e. the entire articulated vehicle) and the lorry driver were present during this chipping/loading process the terminal costs would be far higher than in other systems.

System B is the only coppice supply system involving two road transport stages (from farm to intermediate store and from intermediate store to power station). The effects of the double handling involved in such a supply system are reflected in the total terminal time and terminal costs for this system (80 minutes and approximately £45 per vehicle load) which are significantly higher than in system A in which the same transport and handling equipment are used but there is only one transport stage (from farm direct to power station - this results in a total terminal time of approximately 50 minutes and a terminal cost of around £24 per vehicle load).

System B also effectively demonstrates the effects of transport speed on transport costs per kilometre. On the first stage of transport (farm to intermediate store) average vehicle speed is lower due to the nature of roads that have to be travelled on; this results in a trip cost per kilometre of £1.29 (£4.48 per dry tonne). On the second transport stage from intermediate store to power station road quality is likely to be far better (i.e. there is greater likelihood of being able to use A and B roads rather than minor public roads) and this will result in improved average journey speed. In the modelling, the trip cost per kilometre from intermediate store to the power station is £0.65 per kilometre (£2.26 per tonne of dry matter), approximately half the cost of the first stage.

System E is the transport of unchipped stick bundles. As can be seen from the table the relatively low weight of load (10 wet tonnes) that can be carried has a significant impact upon the trip cost per tonne of dry matter carried (£9.52 compared with approximately £4 to £6 in the other systems).

The total transport cost per kilometre per tonne load (i.e. the load moving cost) is virtually the same in systems A, C and D (£0.08 to £0.09 per kilometre per dry tonne) while system B produces an aggregate cost of £0.13 per kilometre per dry tonne and system E (stick transport) results in a load moving cost of more than double the lowest cost chip systems (£0.19 per kilometre per dry tonne).

5.4 Sensitivity analysis for short rotation coppice

Road transport distance

The base case systems modelled for coppice described above assumed a road transport distance of 40 kilometres from the farm to the power station. In this section the effect of different transport distances on the delivered cost of coppice for these same supply systems is considered.

The supply systems (defined in section 5.2) were run for road transport distances of:

- 20 kilometres one way transport distance (i.e. 40 kilometres round trip) - half the road transport distance in the base cases.
- 80 kilometres one way transport distance (i.e. 160 kilometres round trip) - double the road transport distance in the base cases.

In modelling these alternative coppice transport scenarios it has been assumed that as transport distance increases there is greater opportunity to use better quality and hence faster roads (e.g. single or dual A roads). Additionally, as haul length increases the proportion of the total journey spent on relatively slow farm tracks and minor public roads is reduced, this also has the effect of increasing the average speed for the journey. As transport distance falls the converse is true. (These assumptions can be found in appendix 2).

The result of these transport distances on delivered cost are shown in Figure 5.8 (together with the delivered and costs in the base cases of 40 kilometres).

Figure 5.8: Effect of road transport distance on delivered costs

Figure Not Available Electronically

The figure effectively illustrates that delivered cost is relatively insensitive to the distance the coppice has to be transported. For a one-way transport distance of 20 kilometres, delivered costs per tonne of dry matter are approximately 5% lower than for a distance of 40 kilometres (approximately £1.75 to £3.75 per dry tonne depending on the supply system). Delivered costs for a haulage distance of 80 kilometres are approximately 5% to 10% higher than for 40 kilometres (approximately £2.50 to £5.50 per dry tonne).

Given that in the base cases modelled, a one-way transport distance of 40 kilometres (80 kilometres round trip) only accounted for between 15% and 30% of total delivered cost, changes in transport distance will, within certain limits, have a relatively minor impact upon delivered costs of coppice at the power station. Many of the costs associated with handling and transporting coppice (such loading and unloading the vehicle, sheeting the vehicle, dropping empty and coupling up full trailers, weighing the vehicle and sampling the fuel at the power station) will remain the same regardless of the transport distance and therefore once these have been taken into account the coppice can be transported relatively long distances (for a biomass scheme) without delivered costs increasing substantially. However it is important to note that in biomass schemes it is vital that delivered fuel costs are kept as low as possible if schemes are to prove economic and therefore any increase in delivered cost could affect the economic viability of using coppice for this purpose.

<u>The cost of purchasing coppice</u>

As the base case supply systems illustrated, one of the major costs in supplying coppice to power stations is the money that farmers will have to paid to grow coppice on their land (in the base cases this represents between 35% and 55% of delivered cost). This cost includes the cost of the cuttings, preparing the ground and planting, weed control and general husbandry together with a financial incentive to make it financially attractive for farmers to become involved in coppice supply. This cost is therefore closely related to the opportunity cost of the land (i.e. its money earning potential if put to alterative agricultural uses).

In the base cases an input value of £20 per dry tonne has been used to represent the money that will have to be paid to farmers to grow coppice. If the cost were lower than £20, possibly as a result of the opportunity cost of the land falling (i.e. if the price of other crops fell) or if power station operators purchased land on which to grow coppice themselves this would obviously reduce the delivered cost of coppice.

If the price paid to farmers was £10 per dry tonne rather than the £20 per dry tonne input used in the base case modelling, this would reduce delivered cost by approximately 20% (to between £37 and £44 per tonne of dry matter, depending on the supply system used). If the price paid to farmers was greater than the figure of £20 per dry tonne used in the base case modelling this would obviously result in higher delivered costs. If, for example, the price paid to farmers was £40 per dry tonne (double the cost assumed in the base cases), this would increase the delivered costs of the base case systems by approximately 40%.

<u>Coppice crop yield</u>

Coppice crop yield will also be an important determinant of purchasing and harvesting costs. If yields are higher than the rate assumed in the base case modelling (of 9 dry tonnes per hectare per year) then this will reduce delivered costs. However if yields are less than this rate, delivered costs will be higher than those calculated in the base cases.

The effect of yield on purchase cost is difficult to define within this project but, for reference, sensitivity results for purchase costs of double and half the figure used in the base cases are given in the section above.

The model was rerun to examine the effect of alternative coppice crop yields on harvesting costs and total delivered costs, the results are shown in Table 5.4. If yields were 50% lower than the yield assumed in the base cases (i.e. 4.5 dry tonnes per hectare per year rather than 9 dry tonnes) then, assuming that the forward speed of the harvester remained the same, the harvesting costs would double. In direct cut and chip systems modelled (A and B) the harvesting costs would increase from £5 to £10 per dry tonne and total delivered cost would increase by approximately 14%. In stick harvesting systems modelled (C to E) the harvesting costs would increase from about £4 to £8 per dry tonne and delivered costs would increase by around 8%. The increase in delivered cost is lower in stick harvesting systems because harvesting costs represent a smaller proportion of delivered cost than in direct cut and chip systems.

If yields were 50% higher than assumed in the base cases (i.e. 13.5 dry tonnes per hectare per year rather than 9 dry tonnes) then delivered costs in direct cut and chip systems modelled would be approximately 4% lower than in the base cases and approximately 2.5% lower in the stick harvesting systems modelled.

Table 5.4: Delivered cost for all supply systems based on effect of higher and lower coppice crop yields on harvesting costs

	System A	System B	System C	System D	System E
Yield 13.5 dry tonnes/ha/yr (£/tonne DM)	45	50	49	49	52
Yield 9 dry tonnes/ha/yr (£/tonne DM) (Base case assumption)	47	52	50	51	54
Yield 4.5 dry tonnes/ha/yr (£/tonne DM)	54	58	54	55	58

Road transport of coppice sticks

In supply system E, in which coppice sticks are transported to the power station and are then processed at the power station by a centralised chipper, the cost of transporting sticks is extremely high in comparison with chip transport systems (with costs approximately double that of chip transport). This is due to the limited weight of the load that can has been loaded onto a transport vehicle in trials work by the Forestry Authority; the problem being the size of bundles and shape of the trees. It is possible that load weight of coppice sticks could be improved either by altering way in which the sticks are loaded (such as alternating the direction of tops and bottoms of the trees to form a continuous "sausage" of constant diameter rather than bundling them with all butt ends aligned and/or cutting the sticks into sizes that are easier to load efficiently. For example cutting the sausage into 2.5 metre lengths, securing these with net or twine and loading these widthways across the vehicle). The Supply Chain Option model suggests that if the load weight could be improved from 10 wet tonnes to 12.5 wet tonnes through improved loading of the sticks the trip cost and hence total delivered cost could be reduced by approximately £2 per tonne of dry matter in comparison with the base case (base case system E -

delivered cost of £54 per dry tonne). If transport vehicle load weight could be increased to 15 wet tonnes the delivered cost would be reduced by approximately £4 per dry tonne, making this system as cheap as the lowest cost systems (excluding the cost of centralised chipping).

Further work should therefore be conducted into the feasibility of improving stick bundling and loading and thereby increasing the weight of the stick load carried on the road transport vehicle.

Dry matter losses of wood chips during storage

In supply systems A and B direct cut and chip harvesting is used and therefore the coppice has to be stored in chip form before being supplied to the power station. In the base cases it has been assumed that the fuel is stored for a period of six months and that dry matter losses in wood chip piles occur at an average rate of 4% per month. This has a significant effect upon the delivered cost as more fuel must be harvested and stored to compensate for these losses. Research on dry matter losses is inconclusive and losses will be dependent upon prevailing weather conditions and other variable factors. Dry matter losses could therefore be significantly different from this 4% figure and therefore the model was rerun to explore the effect of different amounts of dry matter loss during storage. The results are shown in Table 5.5.

The findings suggest that if dry matter losses can be minimised this will have a very important effect upon delivered costs and could make direct cut and chip harvesting very cost effective in comparison with stick harvesting systems. However the use of expensive storage and drying systems to achieve this end are unlikely to be affordable in biomass schemes (see section 4.4 for further details).

Table 5.5: Delivered cost for supply systems A and B based on different average monthly rates of dry matter loss assuming 6 month storage

	Loss of 0%	Loss of 2%	Loss of 4% (base case)	Loss of 6%	Loss of 8%
System A - delivered cost (£/tonne DM)	38	42	47	55	67
System B - delivered cost (£/tonne DM)	40	45	52	61	76

In schemes in which power stations are fuelled by coppice it would be most appropriate for direct cut and chip systems to be used for supply of wood chips to the power station relatively soon after harvest and for stick harvesting to be used for material that is to be supplied after significant periods of storage as sticks are less likely to suffer dry matter losses and will benefit from reductions in moisture content as the water evaporates.

Mobile chipper productivity

In coppice supply systems C and D the sticks are chipped by a mobile chipper at the farm store prior to road transport to the power station. The chipper productivity has been assumed to be 15 wet tonnes per hour and therefore the time taken to fill a large vehicle of 90 m^3 is significant and can result in large periods of downtime for the road transport vehicles if the supply chain is not well planned and managed (i.e. use is made of articulated vehicles so that trailers can be detached for filling or chip is produced prior to the arrival of the vehicle both of which strategies require a high degree of co-ordination between agricultural and transport contractors).
As discussed in the case of chipping forest fuel prior to transport (see section 4.4), if the productivity rates of mobile chippers could be increased while still producing the desired chip quality this would

reduce the amount of time that vehicle loading takes and hence reduce the cost of the loading operation. It would probably also help to reduce the cost of chipping as it tends to prove expensive to feed the chipper when its productivity rate is relatively low.

Diesel fuel and labour costs

Two important cost factors in all biomass supply systems are the cost of fuel (i.e. diesel for road transport vehicles, forestry and agricultural equipment) and the cost of labour. Costs of both of these inputs could rise significantly in the future and therefore the Supply Chain Option models were rerun to examine the effect of increases in the inputs on the delivered cost of short rotation coppice.

Fuel costs could rise significantly in future if government were to implement higher rates of fuel duty as part of an environmental taxation strategy. A recent report by the Royal Commission on Environmental Pollution has suggested that fuel prices should be raised by 9% per annum. If such an approach were taken fuel costs would rise by approximately 40% by the year 2000. Running this increased fuel cost scenario for coppice supply systems increases the delivered cost by between 2% and 4% in comparison with the base case costs.

Labour rates could rise in the next few years as a result of shortages in lorry drivers due to stricter eyesight tests. More stringent drivers' hours regulations would result in the need for haulage companies to recruit more drivers for the same workload.

We have therefore modelled the combined effect of a 25% increase in labour rates with the 40% increase in fuel costs described above. This has the net effect of increasing the delivered cost of coppice by between 4.5% and 8%.

Summary of sensitivity analysis results

To conclude this chapter the sensitivity tests conducted and their effect on the delivered cost of short rotation coppice are summarised in Table 5.6. The table should be read in conjunction with the full text on each sensitivity test which precede this section as we have examined plausible and likely assumptions for each particular test rather than applying a standard change in input values for all tests.

Discussion and comparison of sensitivity analyses for the different biomass fuels is contained in Chapter 9.

Table 5.6: Summary of sensitivity analysis results for short rotation coppice systems

Sensitivity test	**Effect on delivered cost**
Road transport distance	*
Purchasing costs (price paid to farmers)	**
Effect of coppice crop yield on harvesting	*
Quantity of coppice sticks transported (if load weight could be improved by 25% to 50%)	*
Dry matter loss of wood chips during storage	**
Diesel fuel and labour costs	*

N.B. Effect of the different sensitivity tests on delivered cost are shown by the following:

* less than 15% change in delivered cost
** more than 15% change in delivered cost

6. STRAW

6.1 Logistics and supply issues

Straw is available from late July (winter barley and oilseed rape) through until early October (wheat). Now that a high percentage of UK cereals are autumn-sown, farmers require straw to be cleared quickly from their fields. However, in years when the weather allows uninterrupted harvesting, the season of straw availability may be much shorter.

Wheat straw has a greater potential as a biomass resource than barley or oat straw. This is because it is not as popular for livestock feed or bedding and a significant proportion of it is concentrated in areas where livestock production is limited.

Harvesting

Once lying in the field the straw could be processed in three ways for supply as biomass fuel:

Bales - virtually all straw in UK is handled as bales. Overseas power plants using straw appear to be standardising on the largest size of rectangular bale, often referred to as the `large Hesston bale' (approx 2.4 m x 1.2 m x 1.2 m).

A supply chain where large numbers of farmers baled their own straw might have to accept various types and sizes of bales (almost certainly including both rectangular and roll types) and the power plant would also require to handle the same range of bales. Management would be very much simpler if a very small number of contractors, all using similar machines, baled all the straw for one power plant.

Straw wafering - wafering machinery is not yet available commercially and research suggests that it is economically uncompetitive in comparison with baling equipment.

Chopped straw - straw can be picked up from the field by forage harvester, chopped and blown into trailers or lorries. The costs of chopping together with the costs of storage and transport is likely to result in chopped straw only being considered for small-scale local use.

It is therefore likely that biomass supply systems using straw to produce electricity will involve the production and supply of baled straw.

Storage

Straw is left to dry in the field before baling. Moisture contents have to be below about 20% (i.e. 80% dry matter content) to avoid moulding during storage, and baling is therefore weather-dependent. Once baled, straw is usually moved immediately out of the field to a storage site so that farmers can continue with ploughing and ground preparation. For the purposes of a biomass operation, the baled straw is likely to be stored in relatively large stacks either on-farm or at an intermediate point between farms and power station. The siting of this intermediate store (i.e. it could be near the farm, near the power station or at some point in-between) is likely to vary between schemes.

Absorbed moisture reduces the net energy value of straw proportionately and can result in combustion difficulties. Those who store straw usually make stacks as high as possible, to minimise the quantity directly exposed to rain. The economic costs and physical problems involved with sheeting of bale stacks means that in many situations the most economical method of storage may be to make very high stacks of bales, without sheeting, and to set up a compost-making enterprise nearby for straw unusable in biomass schemes.

Disused wartime airfields appear to be ideally suited for bulk straw storage, because they have large areas of concrete, and are generally located on level sites in the main arable areas in the east of the country.

Loading, unloading and handling bales

Straw handling is a mature activity with well developed systems and equipment. These established approaches can be used in the supply of straw as a biomass fuel.

Densities are low with all types of standard agricultural baler. Bale density and bulk density are not the same, and both values have been considered during the study.

Bale densities are generally in the range 110-150 kg/m^3, the lowest densities resulting from use of fixed-chamber type roll balers and the highest densities from rectangular balers. Experimental machines have delivered higher density bales.

Rectangular bales can be stacked together so that the bulk density is not much less than the bale density. With roll bales in normal stacking patterns, the bulk density can be no more than 78% of the bale density.

Thus the bulk density of straw bales could range from 86 kg/m^3 (78% of 110 kg/m^3, for roll bales made at high speed) to 150 kg/m^3 (the most dense rectangular bales, stacked tightly together). High forward speed during baling tends to reduce the density of roll bales.

Large bales are handled on farms by various types of loaders and fork lifts, of which the most versatile is the rough terrain boom-type loader. Large arable farms will generally have a materials handler of this type available. Loader grabs are available to handle two or three large bales at a time.

In-field handling time can be reduced through use of trailed bale accumulators, collecting up to three large bales together rather than dropping single bales randomly over the field. Several types of self-loading bale carrier are marketed to allow rapid transport of three to ten large bales at a time from field to farm steading. These would not be suited to long distance road transport.

Lorries are sometimes taken for loading onto stubble fields which are level and firm, but this cannot be guaranteed in the UK climate. In certain areas where fields are very well served by farm roads (e.g. former airfields in E England) it may be convenient to carry bales by fork lift direct from the field to the lorry. On most farms double handling is necessary (field --> steading/roadside; steading/roadside --> lorry).

Road transport

Bale transport in the UK is normally undertaken using flat-bed articulated or drawbar road transport vehicles. Given the bulk density of straw bales, drawbar systems (i.e. a rigid lorry and trailer) can carry a greater number of large Hesston bales than an articulated vehicle given the extra bed area available when using this vehicle.

Roping or strapping of bales is essential for road transport by flat-bed vehicles. Netting/sheeting of lorry loads of straw is not usual in the UK. Some straw does escape from loads, especially where lorries on rural roads brush against trees. Any handling operation tends to produce some loose pieces of straw, and these often blow away during the first few miles of any journey. Blown straw is unsightly and can lead to numerous complaints, though is seems unlikely to have any long-term environmental effects. Local highway authorities may well insist that straw transported in biomass supply systems will have to be netted or sheeted to prevent these problems.

The most likely supply chain options for straw supplied to a power station from harvest to point of utilisation are shown in Figure 6.1 below.

Figure 6.1: Supply system options for straw

Figure Not Available Electronically

6.2 Straw supply systems modelled

Five supply systems have been studied for straw transport. These are each described below. As well as supply systems for large Hesston rectangular bales which are commonly used in biomass fuel supply systems in Denmark (systems C, D and E), we have also modelled supply systems for small rectangular bales (system A) and roll bales (system B).

In all of the straw systems making use of on-farm storage this is assumed to comprise bales being stored in a stack in a field. It is assumed that bales are not sheeted or covered, and therefore a proportion of the stack will be lost due to exposure to the weather (see appendix 3 for further details).

System E involves storage of straw bales at an intermediate store. This is a store that is not located on-farm and requires transport of the bales on a road transport vehicle to deliver them to the store. It is located between the point of production and the power station. At the intermediate store we have assumed that the bales are stacked on hard standing. As with farm stores, it is assumed that bales are not sheeted or covered, and therefore a proportion of the stack will be lost due to exposure to the weather.

System A

The first system involves the production and supply of small rectangular bales in a flat-8 formation. These bales are 0.9 m x 0.45 m x 0.35 m and have a typical weight of 0.018 tonnes when baled. The bale accumulator is attached behind the baler, and this arranges the bales in sets of 8. The flat-8s are stacked up into heaps of 56 using a loader with flat-8 grab. The heaps are taken to the farm steading by a transfer weight carrier pulled behind a medium sized tractor.

At the farm store a loader and flat-8 grab are used to build a stack. The small bales tend to be less stable than larger rectangular bales and are therefore only stacked to a height of 5.4 metres (12 bales high). They are stored in the stack after which they are supplied to the power station.

The flat-8 grab is used to load the bales onto a 35 tonne (gross weight) flatbed articulated lorry which transports the bales to the power station. They are unloaded from the road vehicle at the power station by a front end loader with grab.

Flat-10 systems provide faster handling than flat-8 methods, but are not commonly used, and the longer bales required are more liable to distortion.

Figure 6.2: Straw supply - system A

Figure Not Available Electronically

System B

The second system examined involves the production of large roll bales; these are 1.22 m high, have a radius of 0.75 m and typically weigh 0.24 tonnes (wet weight) when baled. The roll bales are loaded onto a tractor and trailer by a loader with a grab and are then carted to the farm store. Here they are

built into a stack with the loader (5 bales high on their vertical axis).
The bales are stored on-farm until they are required for supply to the power station. From here they are loaded onto a 35 tonne (gross weight) flatbed articulated vehicle (with a front end loader) and transported to the power station. Handling of bales at the power station involves the use of a front end loader with grab (i.e. to unload the lorry).

Figure 6.3: Straw supply - system B

Figure Not Available Electronically

System C
This system represents an operation producing large Hesston rectangular bales. These bales have dimensions of 2.44 m x 1.22 m x 1.22 m and a weight after baling of approximately 0.5 tonnes (wet weight).

In this system the bales are built into heaps of ten bales by a loader with grab and are then moved (ten at a time) by a self-propelled bale carrier (referred to in this report as a "Transtacker") to the farm store where they are built into stacks nine bales high by a loader and grab. They are stored here until required at the power station.

They are then loaded onto a 35 tonne (gross weight) drawbar flatbed road vehicle with a loader and grab and transported to the power station. They are unloaded by a loader and grab at the station.

The drawbar flatbed vehicle (a rigid vehicle with a trailer attached) has a larger bed area than an articulated vehicle due to the greater length dimensions to which it can be constructed. It is capable of carrying up to 39 large rectangular Hesston bales in one load.

Figure 6.4: Straw supply - system C

Figure Not Available Electronically

System D
This system also represents an operation producing large Hesston rectangular bales and has many similarities to supply system C. The key differences are the:

- in-field transport operation

- type of road transport vehicle used to transport them to the power station

The bales are collected in the field by a Fastrac (this being the trade name of the high speed agricultural tractor manufactured by JCB, but other brands are available) with bale collector (10 bales at a time) and then taken to the farm store where the bale collector stacks them. A front end loader then stacks the bales 9 high and they remain here until supplied to the power station.

They are loaded from the stack onto a 35 tonne (gross weight) articulated low-bodied flatbed trailer and they are transported to power station. The bales are unloaded at the power station with a front end loader.

The road transport vehicle used in this system is only capable of transporting up to 30 large rectangular Hesston bales in one load (in comparison with the 39 bales carried by the drawbar vehicle in system C). However this type of vehicle is far more commonly used by agricultural hauliers and can perhaps be more readily used in other transport operations outside of straw haulage than the drawbar vehicle.

Figure 6.5: Straw supply - system D

Figure Not Available Electronically

System E

This system also represents an operation producing large Hesston rectangular bales. As in system D, the bales are collected in the field by Fastrac with bale collector and then taken to the field gate (roadside location) where the bale collector stacks them. A front end loader with grab then loads the bales onto a 35 tonne (gross weight) articulated low-bodied flatbed trailer and they are transported to an intermediate store. The bales are unloaded at the intermediate storage location with a front end loader and placed in stacks nine bales high on hard standing. As with farm stores, it is assumed that bales are not sheeted or covered.

The bales are stored here until required for supply to the power station. The bales are loaded onto the same specification of articulated flatbed vehicles as used to transport them to the intermediate store by a loader with grab and they are then transported to the plant.

The key difference therefore between this supply system and system D is that the bales are stored at an intermediate store rather than at a farm store.

As with intermediate storage systems modelled for forest fuel and coppice, this straw supply system will require two road transport movements (from farm to intermediate store and then from store to power station) and the related vehicle loading and unloading that this entails. This system will therefore incur additional handling costs to systems with only one road transport movement (as in supply systems C and D for large Hesston bales).

However, as is the case with wood fuel and short rotation coppice, such a supply strategy is likely to be necessary in order to ensure a secure fuel supply strategy. Many farms and the fields in which the bales are stacked may not be accessible at certain times of year due to weather and farm track conditions and farm operations but power stations will require coppice on a constant, all year round basis. By using an intermediate store that is accessible at all times of year security of supply can be achieved.

Figure 6.6: Straw supply - system E

Figure Not Available Electronically

6.3 Results of supply systems modelled

Total delivered cost at the power station for systems modelled

Table 6.1 shows the total delivered cost to power station for the straw supply systems that were described above.

Table 6.1: Delivered cost for straw systems

(all costs have been rounded to the nearest £ except £/GJ)

	System A	System B	System C	System D	System E
Delivered cost (£/wet tonne)	37	36	24	24	26
Delivered dry matter content (%)	85	85	85	85	85
Delivered cost (£/tonne dry matter)	43	43	28	28	31
£/GJ	2.61	2.57	1.67	1.67	1.88

Straw systems producing large Hesston bales (systems C, D and E) can be seen to have lower delivered costs than systems involving the production of small rectangular bales (System A) or roll bales (System B). This is to be expected given the greater productivity of the equipment baling and handling large Hesston bales and the greater volume and bale and bulk density of each bale.

The modelling suggests that, of the large Hesston bale systems, system C and D produce the lowest delivered cost. System E would be expected to have a higher cost than C and D as it involves two road transport movements and additional handling.

The delivered costs of small rectangular bales (system A) and roll bales (system B) are extremely similar.

Straw supply costs show the least difference between delivered cost per wet tonne and cost per tonne of dry matter of all the biomass fuels considered. This is due to the very high dry matter content of straw bales.

Breakdown of total delivered cost

Table 6.2 shows the breakdown of the total delivered costs for each of the five straw supply systems that we modelled. The cost difference between producing small rectangular bales and roll bales (system A and B) and large rectangular Hesston bales (systems C, D and E) can be seen to be spread across a wide range of activities involved in producing and supplying bales. Key areas of cost difference include in-field transport and road transport, the stacking of bales, and the loading and unloading of bales to and from road transport vehicles. (The cost of stacking roll bales at the farm store in system B is incorporated into the unloading cost of £3.86 per tonne of dry matter).

Table 6.2: Breakdown of total delivered costs for straw supply systems

Table Not Available Electronically

The quantity of straw damaged by rainfall during storage and therefore unacceptable for use in a power station is likely to be higher for roll bales (system B) than for small and large rectangular bales. This is due to the height to which the different bale types can be stacked, roll bales cannot be stacked as high as the rectangular bales. Therefore if after storage the top layer of bales is too wet to supply (the assumption we have used in the modelling), the proportion of bale losses will be greater in a roll bale stack than a rectangular bale stack. This is the reason for the greater purchase cost for roll bales; more straw will have to be purchased than in the case of other bale types in order to compensate for losses during storage.

System C and D both involve the production of large Hesston bales, which are stored on-farm. The key differences between these systems is that system C uses a loader to build field heaps and a self propelled Transtacker for the in-field transport and a drawbar road transport vehicle for the road transport from farm store to power station. Meanwhile, system D uses a Fastrac and bale carrier for in-field transport and an articulated vehicle for the road transport. The results suggest that in-field costs of the Fastrac and bale carrier system are lower than the loader and Transtacker system (approximately £5 per tonne of dry matter to build heaps, load, transport and unload bales using a Transtacker and approximately £4 per dry tonne to load, transport and unload with the Fastrac and bale carrier).

The costs of road transport for these two systems reflect the cost benefits of using a drawbar system which can accommodate more bales than an articulated system. The trip cost using the drawbar system is approximately £3.50 per dry tonne compared with approximately £4.50 per tonne of dry matter when using the articulated vehicle.

System E is the same as system D in terms of bale collection and in-field transport, and the use of an articulated flatbed lorry. The difference between these systems is that in system E bales are stored at an intermediate store rather than on-farm and therefore requires an extra road transport stage. The results suggest that a system in which bales are taken to an intermediate store is approximately £3.50 per dry tonne more expensive than on-farm storage and then direct transport to power station. However this supply system is likely to be necessary as farm stores will not be accessible for road transport vehicles during certain parts of the year.

Activity cost categories

The importance of each activity cost category in straw supply systems are shown in Figure 6.7. This indicates that for large Hesston bales (systems C to E) the most important cost categories are transport, followed by baling and the purchase price of the straw. In these systems the cost of transport accounts for approximately 30% of the total delivered cost at the power station, whilst baling and purchasing the straw from farmers account for approximately 25% and 30% respectively. Handling costs in the large rectangular Hesston systems modelled account for approximately 15% of delivered cost per dry tonne.

In systems A and B the key cost categories are transport and handling. These two activities represent 63% of the delivered cost of small rectangular bales and 59% of the delivered cost of roll bales per tonne of dry matter.

Storage costs (physical costs of the store, insurance and stockholding costs) are relatively low in all systems, representing around 5% of delivered cost. However losses during storage affect the costs of all activities prior to storage as more straw than is actually required at the power station has to be produced to compensate for these losses.

Figure 6.7: Activity costs for straw supply systems

Figure Not Available Electronically

Detailed road transport analysis

Straw road transport systems have been analysed in some detail and the results of this analysis are shown in Table 6.3.

Table 6.3: Road transport analysis of straw supply systems

Table Not Available Electronically

From the table it can be seen that the drawbar transport vehicle used to carry large rectangular Hesston bales in supply system C achieves the highest load weight (19.5 wet tonnes). The load weights carried in the other supply systems range from approximately 11 to 15 wet tonnes. Therefore, due to the low bale and bulk density of straw, none of the road transport vehicles used for straw transport will be able to achieve maximum payload (23 to 24 tonnes for a 38 tonne (GVW) articulated flatbed vehicle). This has the effect of making the transport cost per tonne relatively higher than if full payload was achieved as the cost per journey is relatively constant regardless of payload.

Systems A to D all involve only one road transport stage from the farm store to the power station. In comparing these systems, the effect of bale density on the weight of the vehicle load can clearly be seen. As explained above, this has implications for the trip cost per tonne of dry matter, and as would be expected, this is higher for small rectangular and roll bales (system A and B respectively) than for large Hesston bales (systems C and D). The trip cost per tonne of dry matter for roll bales (system B) is approximately 80% greater than for large rectangular Hesston bales transported on a drawbar vehicle (system C).

The terminal time per vehicle load is far higher for small rectangular bales than in the other systems and this is due to the difficulty in handling large numbers of small bales. This has the effect of making terminal costs per vehicle load significantly higher for these bales than for other bale types. Terminal time represents between approximately 35% (for large rectangular Hesston bales) and 60% (small rectangular bales) of total transport time per vehicle load. Therefore productive utilisation of the transport vehicles is far higher in large Hesston bale systems.

System E (which involves two stage road transport of large Hesston bales) can be seen to have significantly higher terminal costs than the other large Hesston bales transport systems (C and D) due to the double handling that is necessary. As a result terminal time represents about 45% of total transport time in this system, compared with only approximately 35% in the other Hesston systems.

System E also effectively illustrates the effect of transport speed on trip costs per kilometre for straw supply systems. During the transport stage from farm to the intermediate store the trip cost for this system is £1.01 per kilometre (£3.17 per tonne of dry matter), whereas over the second stage from intermediate store to power station the trip cost is £0.60 per kilometre (£1.87 per tonne of dry matter). This difference in cost per kilometre on the two different stages is explained by the lower speeds achieved on minor roads on the first stage compared with the better quality of roads that are likely to link the intermediate store and the power station. This, as shown, has a significant effect on cost per delivered dry tonne.

The total transport cost per kilometre per tonne load (i.e. the load moving cost) is similar for system C and D (the large rectangular Hesston systems each with direct delivery from farm to power station). System C costs £0.07 per kilometre per dry tonne, while this costs £0.08 in system D. The large rectangular Hesston bale system involving intermediate storage has a load moving cost of £0.11 and the small rectangular and roll bale systems each have a cost of £0.15 per kilometre per dry tonne.

6.4 Sensitivity analysis for straw

Road transport distance

In the base case systems modelled for straw supply (see section 6.2) a road transport distance of 40 kilometres from the farm to the power station was assumed. We also modelled the effect of different transport distances on delivered costs for the same straw supply systems.

The alternative transport distances considered were:

- 20 kilometres one way transport distance (i.e. 40 kilometres round trip) - half the road transport distance in the base cases.

- 80 kilometres one way transport distance (i.e. 160 kilometres round trip) - double the road transport distance in the base cases.

In modelling these alternative transport scenarios it has been assumed that as the distance over which straw is transported increases there is greater opportunity to use better quality and hence faster roads (e.g. single or dual A roads). Additionally, as haul length increases the proportion of the total journey spent on relatively slow farm tracks and minor roads becomes less significant, this also has the effect of increasing the average speed for the journey. As transport distance falls the converse is true. (These distance assumptions for straw can be found in appendix 3).

The delivered costs per dry tonne for each supply system resulting from these different road transport distances are shown in Figure 6.8.

The results indicate that a road transport distance of 20 kilometres will result in approximately 5% lower delivered costs than a distance of 40 kilometres (£1.30 to £2.50 per dry tonne, depending upon supply system). To transport the straw 80 kilometres from farm to power station (160 km round trip) will produce delivered costs approximately 10% higher than when transporting it 40 kilometres (£2 to £3.70 per dry tonne).

Figure 6.8: Effect of road transport distance on delivered costs

Figure Not Available Electronically

As with most other biomass fuels, the delivered cost of straw is relatively insensitive to transport distance. A significant proportion of the time and hence cost in these supply systems is spent loading and unloading the vehicle and other activities during which the vehicle is inactive. Therefore although distance will, as shown, have an impact upon delivered cost the relationship is such that for a doubling of transport distance (80 kilometres rather than 40 kilometres) delivered cost per dry tonne will only increase by around 10% (i.e. a 0.25% increase in delivered cost per kilometre in this case).

In the base cases (i.e. 40 kilometres from farm to power station) transport (i.e. trip and terminal activities) accounts for approximately 30% of total delivered cost in systems supplying large rectangular Hesston bales. With the lower transport distance of 20 kilometres, transport represents approximately 25% of delivered cost and at the higher distance of 80 kilometres approximately 35%.

Price paid to farmer

In modelling the base case straw supply systems it has been assumed that the farmer will have to be paid £7 per dry tonne for the straw lying in the field. Clearly this cost is variable and dependent upon the supply of straw in any given year and the demand for straw for use as biomass as well as other competing uses.

The price paid to farmers is likely to fluctuate between approximately £5 and £10 per dry tonne. Therefore, at best, delivered straw costs could fall by approximately £2 per dry tonne (i.e. between 4% and 7% of delivered cost depending on supply system) and, at worst, rise by about £3 per dry tonne (i.e. approximately 7% to 11% of delivered cost) as a result of fluctuations in the price that will have to be paid to farmers to secure straw supply.

Dry matter losses of straw bales during storage

In the Supply Chain Option modelling it has been assumed that straw bales will be stored in a field stack before being supplied to the power station. In the base cases it has been assumed that the fuel is stored for a period of six months and that, as a result of exposure to rain, the top layer of bales in the stack will be unsuitable for use at the power station and therefore represent dry matter losses in the system. These losses have an impact upon delivered cost as more straw must be baled and stored than is actually required at the power station to compensate for these losses.

Clearly whilst the average storage period will be approximately six months if the straw is supplied regularly over the course of the year, straw supplied immediately or shortly after being baled will not be subject to these losses. Additionally, straw supplied directly after production will also avoid stacking costs at the storage site and storage costs. The Supply Chain Option models were therefore run for a situation in which the straw bales produced in supply systems A to D were delivered directly to the power station. (It was not appropriate to model this scenario for system E as this involves intermediate storage and would not therefore be a viable supply system in this situation). The results of this run are shown in Table 6.4 (together with the costs from the base cases). The delivered cost of straw when delivered directly after baling is approximately 15% to 20% lower than for the bales supplied after storage in the base cases. Reductions in delivered cost are greatest in the roll bale system (system B); this is due to higher number of bales damaged during storage as they cannot be stacked as many bales high as rectangular bales and therefore losses are greater.

Table 6.4: Delivered costs for straw supplied directly to the power station after baling
(all costs are in £ per tonne of dry matter)

	System A	System B	System C	System D
Base case (i.e. with storage)	43	43	28	28
Direct delivery	37	35	24	24

Straw could be stored in a dutch barn to prevent its exposure to rain. Clearly if such facilities already exist and are no longer required for their original purpose then this could be used to reduce any storage losses in straw supply systems. However when the cost of building such barns specifically for straw storage in a biomass supply system (to build such a barn would cost in the region of approximately £5 to £10 per dry tonne) and the quantity of biomass that would have to be stored are considered, it is apparent that the likelihood of such storage systems being constructed in biomass systems is exceptionally unlikely.

Diesel fuel and labour costs

As for other biomass types the model was run with 40% higher fuel costs (i.e. diesel) to examine the effect on delivered costs for straw. This resulted in delivered costs of straw increasing by between 3% and 4% in comparison with the base case costings (i.e. approximately £1 to £2 per dry tonne).

The combined effect of a fuel cost increase of 40% together with a 25% increase in labour rates was then modelled. This has the net effect of increasing the delivered cost of straw by between 6% and 11% compared with the base case costings.

Summary of sensitivity analysis results

To conclude this chapter the sensitivity tests conducted and their effect on the delivered cost of straw are summarised in Table 6.5. The table should be read in conjunction with the full text on each sensitivity test which precede this section as we have examined plausible and likely assumptions for each particular test rather than applying a standard change in input values for all tests.

Discussion and comparison of sensitivity analyses for the different biomass fuels is contained in Chapter 9.

Table 6.5: Summary of sensitivity analysis results for straw systems

Sensitivity test	Effect on delivered cost
Road transport distance	*
Purchasing costs (price paid to farmers)	*
Dry matter loss of straw during storage	*/** (depending on supply system)
Diesel fuel and labour costs	*

N.B. Effect of the different sensitivity tests on delivered cost are shown by the following:

* less than 15% change in delivered cost
** more than 15% change in delivered cost

7. MISCANTHUS

7.1 Logistics and supply issues

There are a number of high-yielding crops which are considered to have a certain amount of potential as sources of energy. However only Miscanthus spp. has been subject to any relatively intensive research in Europe. Most research effort has been concentrated on physiological studies of the crop, with very little literature available on any aspect of operations from harvesting to utilisation.

Harvesting

Miscanthus is harvested annually; the optimum harvest time being when its moisture content is lowest (i.e. when dry matter content is highest). Dry matter content ranges from 25% at the end of the growing season to 70% in late winter/early spring, so it is thought likely that harvesting in the UK will take place from December to March (Huisman and Kortleve, 1994; Kilpatrick, 1994). UK research conducted by ADAS indicates dry matter contents of 50% to 60% in this country (Kilpatrick et al, 1994; Bullard et al, 1995). Harvesting must be carried out before the crop starts to resprout in the spring.

Three systems of harvesting are envisaged:-

- direct cut and chop
- cut, (windrow) and bale
- cut and bundle

The requirements of the end-user will have an impact on the harvesting system chosen, but little information is available about crop utilisation for energy as yet.

Direct cut and chop systems would use modified agricultural forage/sugar cane harvesters similar to those likely to be used for direct cut and chip harvesting of short rotation coppice. Chopped material would be blown into agricultural trailers hauled by the harvester or into trailers hauled by tractors running alongside the harvesting machine.

Cut, (windrow) and bale systems - modified agricultural mowers, oilseed rape swathers and balers can handle miscanthus, with two types of bale having been experimented on in the Netherlands (Rutherford and Knight, 1992; Huisman and Kortleve, 1994; Kilpatrick, 1994). Baling increases the bale density of the harvested crop to between 140 kg/m^3 (conventional round bales) to 300 kg/m^3 (`compactrolls'). If the crop is windrowed, losses in the swath are likely to be high (10% to 30%) because of pick-up problems with the crop (Huisman and Kortleve, 1994). Existing agricultural windrowers would apparently have difficulty handling crops over two metres high (Rutherford and Knight, 1992). It would be preferable to cut and bale in a one-pass operation to reduce losses in swath but dry matter content at harvest in UK miscanthus trials may prevent this operation if long term bale storage is required (i.e. bales could mould).

Cutting and bundling systems are only likely to be used if there is a small-scale demand for whole stems of the crop - for example for geotextile uses (Rutherford and Knight, 1992; Huisman and Kortleve, 1994). It is envisaged that the same harvesting principles would be used as those operating for short rotation coppice stick harvesting or reed harvesting. This system is unlikely to be used in large scale biomass fuel schemes.

Storage

Ideally a dry matter content above 80% will be required for storage of periods over six months. Chopped material could be stored on the farm, either in covered areas if available or outside. Bales could be stored outside, stacked like straw. Bales will be difficult to dry, and if the crop is baled at less than 80% dry matter content, storage time may have to be limited to prevent moulding.

Loading, unloading and handling

It is envisaged that existing agricultural/industrial machinery will be used for handling operations. Chopped material is likely to be loaded and unloaded with a front-end bucket loader; bales with a conventional agricultural forklift or bale carrier.

Road transport

The low bulk density of the crop in the form of chopped material (it has a dry bulk density of approximately 70 kg/m^3 - Bartlett, 1996) will make road transport relatively expensive. Chopped miscanthus is likely to be transported in bulk tipping vehicles.

Bales will be transported by either articulated or drawbar flat-bed lorries (as used in straw bale transport). Research suggests that the weight of dry matter present in bales will be similar to straw bales and therefore the costs of road transport will be comparable (Kristensen, 1992).

Figure 7.1 below outlines the supply system options that could be used for supplying miscanthus as a biomass fuel from point of harvest through to delivery at power station.

Figure 7.1: Supply system options for miscanthus

Figure Not Available Electronically

7.2 Miscanthus supply systems modelled

Miscanthus has received a significant degree of attention in relation to its use in biomass fuel systems due to its high theoretical crop yield potential. However, as discussed above, to date much of the research into miscanthus has been concerned with determining the conditions the plant requires in order to grow adequately. There has been very little research into the potential supply systems for miscanthus if it was used to produce electricity at power stations, from the point of harvesting, through handling and storage to transport and delivery at the power station. Therefore, in developing strategies for miscanthus, we have had to devise supply systems that we believe could be established.

System A

This is a direct cut and chop system similar to that specified for short rotation coppice (coppice system A). This would involve using a modified forage harvester (such as the Claas Jaguar) which would cut the miscanthus, chop it and blow the chopped material into agricultural trailers pulled by tractors running alongside the harvester. When full, the tractor and trailer would travel to the farm storage area where the trailer would be unloaded. Another tractor and trailer would enter the field to run alongside the harvester. The chopped material would be stored on hard standing at the farm until required for delivery to the power station.

The chopped material would then be loaded into an articulated HGV bulk tipping vehicle with an internal body volume of 90 m^3 by a front end loader with a bucket attachment. The HGV tipping vehicle would transport the load to the power station where the load would be discharged by the driver.

Figure 7.2: Miscanthus supply - system A

Figure Not Available Electronically

System B

This system is similar to the straw supply system D. It represents an operation producing large rectangular Hesston bales from miscanthus. A self-propelled oilseed rape swather would cut the miscanthus and leave it in a swath. After a reduction in moisture content in the swath, baling machines as used in straw bale production, would be used to produce large rectangular Hesston bales. The bales would then be collected in the field by a Fastrac with a bale collector (picking up 10 bales at a time) and the Fastrac would then transport these bales to the farm store where the bale collector would deposit them. A front end loader would then stack the bales 9 high and they would remain here for until required at the power station.

They would then be loaded from the stack onto an articulated flatbed vehicle and transported from the farm store to the power station. The bales would be unloaded at the power station with a front end loader.

Figure 7.3: Miscanthus supply - system B

Figure Not Available Electronically

7.3 Results of supply systems modelled

Total delivered cost at the power station for systems modelled

Table 7.1 shows the total delivered cost to power station for the miscanthus systems we have modelled. These systems are defined above.

Table 7.1: Delivered cost for miscanthus systems
(all costs have been rounded to the nearest £ except £/GJ)

	System A	System B
Delivered cost (£/wet tonne)	40	38
Delivered dry matter content (%)	60	70
Delivered cost (£/tonne dry matter)	66	54
£/GJ	4.31	3.37

Of the two systems that we have modelled for miscanthus (system A - direct cut and chop and system B - cut and bale) the latter can be seen to produce the lower delivered cost at the power station.

The costs per wet tonne are not dissimilar in the two systems, but the lower proportion of dry matter and dry matter losses that occur in system A result in delivered costs per tonne of dry matter that are approximately 20% lower for baled miscanthus than for chopped material.

Breakdown of total delivered cost

The breakdown of delivered costs for both of the miscanthus supply systems that we have modelled are shown in Table 7.2. The work we have done suggests that the cheaper of the two harvesting systems examined for miscanthus is the direct cut and chop harvesting (approximately £7 per dry tonne). In comparison, cutting the miscanthus and then baling it is likely to cost approximately £11 per dry tonne.

However, in our modelling work we have found the chopped material to be more expensive to transport and to handle than bales due to its low bulk density (116 kg/m^3 at 60% dry matter content). Storage costs will also be greater as the chopped material will need to be stored on hard standing whereas bales can be stacked and stored in a field.

In addition chopped material is likely to experience dry matter losses if stored for significant periods of time. These losses have an important upward effect on delivered costs per dry tonne as more miscanthus must be planted and harvested than is required at the power station to make up for this shortfall. The baled system is also subject to both storage losses due to exposure of the top layer to rainfall and also losses during the production of bales from a swath (see appendix 4 for further details of these losses).

In the baled system, if the dry matter content of miscanthus at harvest is likely to be approximately 60% (i.e. 40% moisture content) and the miscanthus is cut and left in the swath and then baled at a later date when the moisture content has fallen to 30% (if this is possible), there remains a high risk that a significant proportion of the bales will mould during storage. Ideally baling should be delayed until the moisture content has fallen to 20% or below but current research into miscanthus growing and harvesting in the UK is inconclusive about whether this is achievable.

Table 7.2: Breakdown of total delivered costs for miscanthus supply systems

Table Not Available Electronically

Transport costs from the farm to the power station are likely to be lower per dry tonne for bales than chopped material. Bales will cost approximately £4.50 per dry tonne to transport whilst chopped miscanthus will cost more than twice as much, approximately £10 per tonne of dry matter. This is explained by two key factors: (i) the bulk and bale density of baled miscanthus is higher than chopped miscanthus and (ii) the volume of the bale load that can be carried is greater than volume of the vehicle used to transport chopped material.

Clearly the supply costs we have modelled for miscanthus need to be treated with caution as relatively little research has been conducted into miscanthus harvesting, storage and handling in the UK and we have therefore had to work with input values that cannot be verified from trials and experience.

Activity cost categories

Figure 7.4 shows how the delivered costs of the two miscanthus systems we have modelled are split between the activity cost categories.

This figure clearly reflects several of the points discussed above (i.e. the results indicate that cutting and baling will be more expensive than direct cut and chopping with a coppice-type harvester, and that transport of chopped material is likely to be more expensive per tonne than bale transport). Transport costs make up approximately 25% of delivered cost in the chopped material system (system A) and approximately 15% in the baled system (system B).

Figure 7.4: Activity costs for miscanthus supply systems

Figure Not Available Electronically

The most important cost component is the purchase cost (i.e. the money that will have to be paid to farmers to encourage them to grow miscanthus on their farmland). Purchasing the miscanthus costs a similar amount in both supply systems. However in relative terms it represents about 45% of delivered cost per dry tonne in the chopped miscanthus system (system A) and approximately 55% of delivered cost in the baled system (system B).

Detailed road transport analysis

Detailed analysis of the two miscanthus road transport systems modelled is shown in Table 7.3. System A is the transport of chopped miscanthus, while system B is the transport of miscanthus bales.

Table 7.3: Road transport analysis of miscanthus supply systems

Table Not Available Electronically

The load carried on road transport vehicles in the baled system (approximately 18 wet tonnes) is significantly higher than for the chopped material (10.5 wet tonnes). The difference in load weights is due to the difference in bulk density between chopped and baled miscanthus and the volume capacity of the vehicles used. This results in a large difference in trip costs from the farm to the power station for the two supply systems we have modelled. As discussed above, the cost of transporting chopped material on this journey is £10 per dry tonne, while in the baled system the cost for the same journey is approximately £4.50 per tonne of dry matter. Therefore, the low bulk density of both chopped and baled miscanthus makes it impossible to achieve a full road transport vehicle payload; this is more pronounced in the case of chopped material than bales. (To achieve a full vehicle payload of approximately 23 tonnes when using a lorry with the maximum UK gross vehicle weight of 38 tonnes to carry chopped miscanthus, the vehicle body would have to have a volume of approximately 200 m^3. This far exceeds UK road vehicle dimension limits - see appendix 10).

The terminal times for both systems are similar and the trip times are identical given that the distance and speed scenarios are the same for both systems. Terminal time represents about 30% of total transport time and therefore the road transport vehicles can spend 70% of the working day actually driving between farms and the power station.

The load moving cost (the total transport cost per kilometre per dry tonne load) has been calculated to be £0.08 per kilometre per dry tonne in the baled system (system B) and £0.18 in the chopped miscanthus system (system A).

7.4 Sensitivity analysis for miscanthus

Road transport distance

In the two base case supply systems modelled for miscanthus (see section 7.2) an assumption of a 40 kilometre road transport distance from the farm to the power station was made. Clearly in a biomass scheme supplying fuel from numerous locations to the power station transport distance will vary widely and therefore the effect of other different transport distances on the delivered cost of miscanthus were modelled. The alternative transport distances considered were:

- 20 kilometres one way transport distance (i.e. 40 kilometres round trip) - half the road transport distance in the base cases.

- 80 kilometres one way transport distance (i.e. 160 kilometres round trip) - double the road transport distance in the base cases.

In modelling these alternative transport scenarios it has been assumed that as the distance that miscanthus is transported increases there is greater opportunity to use better quality and hence faster roads (e.g. single or dual A roads). Additionally, as haul length increases the proportion of the total journey spent on relatively slow farm tracks and minor roads becomes less significant, this also has the effect of increasing the average speed for the journey. As transport distance falls the converse is true. (The transport distance assumptions made for the alternative road transport scenarios for miscanthus are based on those made for coppice and can be found in appendix 4).

The delivered costs per dry tonne resulting from these different road transport distances are shown in Figure 7.5. With a transport distance of 20 kilometres (half the transport distance in the base cases) the delivered cost per tonne of dry matter is approximately 5% lower (£2 to £4 per dry tonne). When transport distance is 80 kilometres the delivered cost is between 5% and 10% greater than in the base cases (£3 to £6 per dry tonne).

Figure 7.5: Effect of road transport distance on delivered costs

Figure Not Available Electronically

The figure clearly illustrates, as with most of the other biomass fuels considered in this project, the delivered cost is relatively insensitive to transport distance.

<u>The cost of purchasing miscanthus</u>

As the base case supply systems illustrated, one of the major drivers in the delivered cost of miscanthus is the money that farmers will have to paid to grow the fuel on their land (in the base cases this represents between 45% and 55% of delivered cost). This cost includes the cost of the plants, preparing the ground and planting, weed control and general husbandry together with a financial incentive to make it financially attractive for farmers to become involved in miscanthus supply. This cost is therefore closely related to the opportunity cost of the land (i.e. its money earning potential if put to alternative agricultural uses).

In the base cases an input value of £20 per dry tonne has been used to represent the money that will have to be paid to farmers to grow miscanthus. If the cost were lower than £20, possibly as a result of the opportunity cost of the land falling (i.e. if the price of other crops fell) or if power station operators purchased land on which to grow miscanthus themselves, this would obviously reduce the delivered cost of miscanthus.

If the price paid to farmers was £10 per dry tonne rather than the £20 per dry tonne input used in the base case modelling, this would reduce delivered cost by between approximately 15% and 20% (to approximately £56 per tonne of dry matter in the chopped system (A), and to £44 per dry tonne in the baled system (B). However, if the price paid to farmers was £40 per dry tonne (i.e. double the cost assumed in the base cases), this would increase the delivered costs of the base case systems by between approximately 30% and 37%.

Miscanthus crop yields will also be an important determinant of purchasing and harvesting costs. If yields are higher than the rate assumed in the base case modelling (of 20 dry tonnes per hectare per year) then this will reduce delivered costs. However if yields are less than this rate, delivered costs will be higher than those calculated in the base cases.

Dry matter content at harvest

In current UK trials work the dry matter content of miscanthus at harvest is in the range 50% to 60%. It would be desirable is this dry matter content could be improved (possibly by altering the time of harvest) as the energy value of the fuel would be improved and the miscanthus would be less likely to deteriorate during storage.

If dry matter content at harvest was 80% or higher it would be possible to cut and bale the miscanthus in a one pass operation (rather than cutting it, leaving it in a swath and then baling it when it has had an opportunity to dry as proposed in supply system B). The advantage of cutting and baling in one operation is that the losses that are likely to occur during baling in system B would be greatly reduced. When the baling losses (assumed to be 20% of dry matter in the base case modelling) are removed and the Supply Chain Option model rerun, the baled system (system B) produces a delivered cost of £44 per tonne of dry matter. This fails to reflect the cost of one pass harvesting and baling (as the model is still set up for separate cutting and then baling in this rerun) but indicates the extent to which the delivered cost of miscanthus bales could be reduced if dry matter content at harvest was sufficiently high to facilitate this strategy and thereby eliminate baling losses from the system.

Dry matter losses of chopped miscanthus during storage

In miscanthus supply system A, direct cut and chip harvesting is used and therefore the chopped miscanthus has to be stored in this form before being supplied to the power station. In the base case it has been assumed that the fuel is stored for a period of six months and that decomposition would occur at an average rate of 4% per month. This has a significant effect upon the delivered cost as more fuel must be harvested and stored to compensate for these losses. No research has been conducted in the UK into dry matter losses during the storage of miscanthus, and even in the case of wood chip storage, losses will be dependent upon prevailing weather conditions and other variable factors. Dry matter losses could therefore be significantly different from this 4% figure and therefore the model was rerun to explore the effect of different amounts of dry matter loss during storage. The results are shown in Table 7.4.

Table 7.4: Delivered cost for supply system A based on different average monthly rates of dry matter loss assuming 6 month storage

	Loss of 0%	Loss of 2%	Loss of 4% (base case)	Loss of 6%	Loss of 8%
System A - delivered cost (£/tonne DM)	53	59	66	77	93

Therefore if dry matter losses can be minimised this will have an extremely important effect upon delivered costs when using direct cut and chop harvesting systems. However the use of expensive storage and drying systems to achieve this end are unlikely to be affordable in biomass schemes (see section 4.4 for further details).

Direct delivery after harvest

If miscanthus was delivered directly after harvesting to the power station this would prevent dry matter losses during storage and the other costs associated with storage occurring (i.e. the cost of land, insurance and stockholding costs). The model was rerun to see the effect of removing storage from the base case supply systems. In supply system A (direct cut and chop) the delivered price falls to £50 per tonne of dry matter (compared with £66 in the base case). For direct delivery after baling in system B (in which the miscanthus is cut and then baled after a short period of time spent drying in field) the delivered costs are reduced to £45 per tonne of dry matter compared with £54 in the base case with storage losses and storage costs.

Diesel fuel and labour costs

As for other biomass types the model was run with 40% higher fuel (i.e. diesel) costs to explore the impact of increases in fuel prices on the delivered costs of miscanthus. This resulted in delivered costs of miscanthus increasing by between 1.5% and 3% compared with the base case costings (i.e. approximately £1 to £2 per dry tonne).

The combined effect of an increase in fuel cost of 40% together with a 25% increase in labour rates was also modelled. This has the net effect of increasing the delivered cost of miscanthus by between 3% and 6% compared with the base case costings.

Summary of sensitivity analysis results

To conclude this chapter the sensitivity tests conducted and their effect on the delivered cost of miscanthus are summarised in Table 7.5. The table should be read in conjunction with the full text on each sensitivity test which precede this section as we have examined plausible and likely assumptions for each particular test rather than applying a standard change in input values for all tests.

Discussion and comparison of sensitivity analyses for the different biomass fuels is contained in Chapter 9.

Table 7.5: Summary of sensitivity analysis results for miscanthus systems

Sensitivity test	**Effect on delivered cost**
Road transport distance	*
Purchasing costs (price paid to farmers)	**
Effect of miscanthus crop yield on harvesting	*
Dry matter content at harvest	*
Dry matter loss of chopped miscanthus during storage	**
Diesel fuel and labour costs	*

N.B. Effect of the different sensitivity tests on delivered cost are shown by the following:

* less than 15% change in delivered cost
** more than 15% change in delivered cost

8. ANIMAL SLURRIES

8.1 Logistics and supply issues

Slurry supply

Animal slurries that are considered suitable for energy generation from anaerobic digestion are produced by cattle and pigs. Digesters can be fed with a combination of animal slurries and wastes from the food processing industry. Adding waste from the food industry increases the dry solids content of the slurry (and thereby improves the biogas output) and also helps to secure a sufficient and reliable supply of digestible material. Poultry manure has not been included within this broad-ranging study as it is difficult to digest on account of its high nitrogen content and because the majority of poultry manure is produced either as litter or in semi-dried form, not as slurry. However it should be noted that it is possible to digest poultry manure from laying hens.

Centralised anaerobic digestion (CAD) schemes would be located in areas of high animal slurry concentration, so that transport distances from farms to the digester could be kept to a minimum. Transport distances in such schemes are likely to be relatively low in comparison with other biomass fuels (such as straw and wood) as the economics of hauling material that is approximately 90% water are not overly attractive.

Groups of dairy farmers supplying adequate slurry quantities for a large scale power plant are more likely to be found in specialist dairying regions (e.g. SW Scotland, Cheshire, Devon etc). Dairy farms which are in or near arable areas will often use straw bedding, and therefore do not produce slurry suitable for a digester.

Beef cattle are more widely spread over the country, but a large percentage of those producing slurry suitable for digestion will probably be in the dairying regions.

Volumes of excreta are fairly constant through the year though they do very according to the size of the animals and their diet. Excreta volumes have been documented in the codes of practice, recently published by MAFF and SOAFD concerned with prevention of pollution (MAFF, 1991; SOAFD, 1992). However, the quantities of slurry collected vary greatly through the year, because most dairy cows are housed 24 hours per day in winter, overnight during late autumn and early spring, and only at milking times during the summer; while beef cattle tend to be housed only during winter.

On many farms the slurry is greatly diluted by factors including rain, wash water, yard runoff and silage effluent. This reduces the energy potential, and this makes it hard to predict volumes and dry solids contents of slurries.

Beef cattle are quite frequently kept on slats with slurry storage in a cellar underneath, but separate slurry stores are more common on dairy farms. Where separate storage tanks are used these are normally open, and therefore collect rain. This has a major dilution effect, particularly if storage is in a lagoon with shallow side slopes. Some other countries (e.g. Netherlands) are moving towards covered slurry tanks.

Welfare considerations mean that most sows in future will be kept on straw bedding. Piglets and weaners may also be on straw, but they only produce small quantities of excreta. Growing and finishing pigs generally produce slurry, and will probably continue to be kept in slurry-producing systems for many years to come.

Excreta production by pigs is generally uniform throughout the year. The volume and dry solids content are affected by the feeding system, pigs fed on dry meal produce less, but drier, slurry than those on a liquid feed system.

Dilution is less variable than for dairy slurry because there are no parlour washings and milk tank washings to be added. Faulty drinkers are a common cause of unwanted dilution.

Dilution by rain in open slurry stores remains a problem, as with cattle slurry.

Slurry storage

Slurry stores which conform to current pollution control legislation are very expensive because of their size and high specification. New installations generally have to provide at least four to six months storage capacity.

If regular collection for a power plant could be guaranteed and digested slurry was stored at the plant, the farmer could manage with a smaller and cheaper store. This is the practice in Denmark where the holding capacity at the power plant is designed to store digested liquor until the farmer requires it for spreading on his land. Alternatively, the liquid digestate could be held at local storage points that are easy for farmers to access and thereby allowing them to obtain the liquid digestate when they want it without having to install expensive new on-farm storage facilities.

Loading, unloading and handling

Any animal slurries are likely to need thorough mixing before being moved from a bulk store to a power plant. Sampling for composition must be preceded by mixing.

Slurries on farms are transferred either by pumping or by sucking them into a road tanker. Many farms will not have suitable pumps available for rapid filling of tankers, and must rely on vacuum filling. However pumps can be transported on the tankers themselves.

Road transport

Two types of road tanker are available and widely used in slurry transportation: vacuum tankers (in which on-board equipment creates a vacuum in the tank and thereby sucks the slurry in through a pipe) and non-pressurized tankers which require land-based pumps or pumps attached to the vehicle to load the slurry into the tank.

The main advantages of the vacuum tanker are that firstly, it is self-loading and it is not therefore necessary to have land-based pumps available at all collection sites. However, it is important to note that the on-board equipment required to create a vacuum in the tank adds significantly to the tare weight of the vehicle (the equipment usually weighs approximately 1½ tonnes) and this reduces the payload of the vehicle (i.e. only approximately 23 tonnes of slurry can be carried on a vacuum tanker). The second advantage of using vacuum tankers is that they are not prone to the same degree of damage that pumps tend to sustain from stones and gravel in the slurry or pipework blockages caused by fibrous materials.

By using a non-pressurized tanker it is possible to achieve payloads of up to approximately 24.5 tonnes and this reduces the cost per tonne of transporting slurry. However the use of this type of tanker is dependent upon land-based pumps being available at collection sites; in the case of farms such pumps are often not installed and farm tractors are not always available when required as a source of power. Although pumps can be carried on-board by non-pressurized tankers, this option affects the payload advantage that this type of tanker has over vacuum tankers.

It is also possible for tanker trailers to be hauled by high speed agricultural tractors, especially when the distance from farms to anaerobic digester is relatively low, as tends to be the case in centralised anaerobic digestion schemes such as those in Denmark.

The road tankers can also be used to backhaul the liquid digestate that is a by-product of the digestion process. This can be taken back to the farms for farmers to spread onto their fields.

Figure 8.1 below outlines the likely supply systems for animal slurry used at a centralised anaerobic digester. It also indicates the systems that could be used for supply of the liquid digestate back to farmers for spreading on their fields.

Figure 8.1: Supply system options for animal slurry

Figure Not Available Electronically

8.2 Slurry supply systems modelled

The slurry supply systems examined are based on the centralised anaerobic digestion (CAD) of farm waste. In this system, the digester would be fed with farm wastes (cattle and pig slurries) and non-toxic, industrial organic wastes from food processing and preparation activities. However we are only considering supply systems for animal slurries arising on the farm within this research project.

Animal slurry would be stored on farms (in slurry storage tanks in the systems we have modelled) and collected regularly (we have assumed once a week in our work). The slurry would be sucked from the farm slurry storage tank into the road transport tanker and the road transport vehicle would then transport the slurry by road to the anaerobic digester where the vehicle would discharge its load. The road transport could be undertaken by either a Fastrac hauling an agricultural vacuum tanker trailer or an HGV vacuum tanker. We have explored the use of these different transport vehicles within the systems we have modelled and have thereby examined the effect of road transport vehicle payload on delivered cost (i.e. the extent to which using a vehicle capable of carrying a greater quantity of slurry will reduce the delivered costs per tonne).

Unlike the other biomass fuels, we have costed animal slurry supply on a wet tonne basis. We have done this for two reasons: (i) the dry solids content of the slurry is extremely variable due to factors such as dilution by rainwater during storage and what the animals are fed on and (ii) the centralised digester requires wet slurry and therefore it is more sensible to calculate delivered costs in this way.

The supply system options that we studied for animal slurry supply to an anaerobic digester are described below.

System A

The slurry is collected from the slurry storage tank on the farm by a Fastrac and agricultural slurry tank trailer with an internal volume of 9 m^3, capable of carrying 9 wet tonnes of slurry (this could be the farmer's own equipment but is more likely to be undertaken by a local farmer who is transporting the slurry on behalf of other farmers or a fuel supplier who has contracts for slurry supply with farmers and the digester operator). It is loaded from the slurry storage tank into the agricultural tank trailer and then is transported to the digester and discharged. The Fastrac and agricultural vacuum tank trailer then returns empty to either the same or another farm to carry out the same procedure.

Figure 8.2: Animal slurry supply - system A
(Tanker carrying capacity of 9 m^3 and 9 wet tonnes)

Figure Not Available Electronically

System B
This is the same supply system as described in system A above, except instead of a Fastrac and agricultural slurry tank trailer being used for transporting the slurry, a 17 tonne (GVW) rigid vacuum road tanker with an internal volume of 9 m^3 is used (capable of carrying 9 wet tonnes of slurry). This vehicle will drive onto the farm, collect the slurry from the farm slurry storage tank and then transport this to the centralised digester, where it discharges its load. The road transport vehicle then returns empty to the same or another farm and completes the same procedure.

Figure 8.3: Animal slurry supply - system B
(Tanker carrying capacity of 9 m^3 and 9 wet tonnes)

Figure Not Available Electronically

System C
The same supply system as used in system A and B, except in this system the vehicle being used for transportation of the slurry is a 26 tonne (GVW) rigid vacuum road tanker with an internal volume of 13.6 m^3 (capable of carrying 13.6 tonnes of slurry).

Figure 8.4: Animal slurry supply - system C
(Tanker carrying capacity of 13.6 m^3 and 13 wet tonnes)

Figure Not Available Electronically

System D
The same supply system as used in systems A, B and C, except that in this system the vehicle being used for transportation of the slurry is a 38 tonne (GVW) articulated vacuum road tanker with an internal volume of 23 m^3 (which can carry 23 tonnes of animal slurry).

Figure 8.5: Animal slurry supply - system D
(Tanker carrying capacity of 23 m^3 and 23 wet tonnes)

Figure Not Available Electronically

8.3 Results of supply systems modelled

Total delivered cost at the anaerobic digester for systems modelled

Table 8.1 shows the total delivered cost to power station for the four animal slurry systems we have modelled. The delivered costs are given in wet tonnes for animal slurry (rather than in costs per tonne of dry matter or gigajoules as in the modelling work for other biomass fuels).

System D can be seen to produce the lowest delivered cost in the modelling. This system involves the use of the largest payload (23 tonnes) articulated road tanker permissable. System C, in which a 26 tonne road tanker is used, is the next most economic supply system. Supply system A, which involves the use of a Fastrac tractor and agricultural slurry tank trailer to supply slurry from the farm storage tank to the anaerobic digester, produces a lower delivered cost than if using a rigid road tanker of the same payload (system B). Therefore using powerful agricultural equipment rather than haulier-operated road tankers can result in lower supply costs in certain circumstances.

Table 8.1: Delivered cost per wet tonne for animal slurry systems
(in £ per wet tonne to the nearest £0.10)

System A	System B	System C	System D
3.10	3.20	2.90	2.40

It is important to note that in modelling these animal slurry supply systems it has been assumed that the slurry is provided free of charge by the farmer (in return he is cleared of responsibility for treating the slurry and will be able to make use of the digested liquor). However if it was necessary to purchase slurry from farmers this would obviously increase the delivered costs. Similarly, if it were possible to charge farmers for the service of removing slurry from their farms this would reduce delivered costs to the digester.

<u>Breakdown of total delivered cost</u>

Table 8.2 shows the breakdown of delivered costs for each of the animal slurry supply systems that we have modelled.

Table 8.2: Breakdown of total delivered costs for animal slurry systems

Table Not Available Electronically

As can be seen from the table, each of the systems involves exactly the same activities, the difference is in the transport equipment that is used to haul the slurry from the farm to the power station. In systems B to D standard road vacuum tankers are used. As would be expected the larger the payload of the vehicle, the lower the cost of transport per tonne of slurry moved. System D, which uses a 38 tonne (GVW) articulated tanker, has a trip cost for the journey of £0.85 per wet tonne. This compares with £1.30 for a 26 tonne (GVW) rigid tanker in system C and £1.67 for a 17 tonne (GVW) rigid tanker in system B. Therefore the economics of using as large a vehicle as possible can be clearly seen.

In system A, although the trip cost of using a Fastrac and agricultural tanker for the journey from farm to the centralised digester is higher per tonne moved than for the 38 tonne articulated road tanker (system D) and the 26 tonne rigid road tanker (system C), the trip costs are extremely similar to those produced by the 17 tonne rigid road tanker (system B).

The cost of filling and discharging slurry from the transport vehicles are related to fill and discharge rates and the hourly operating cost of the vehicles. As the fill and discharge rates are assumed to be the same in all systems, this operation will be most expensive in system using the most expensive equipment (system D - £0.84 per wet tonne to fill the road tanker and £0.42 per wet tonne to discharge the slurry at the digester). These costs are lowest in the system with the lowest cost equipment; this is Fastrac and agricultural slurry tanker system (system A) which has a filling cost of £0.61 per wet tonne and a discharge cost of £0.31 per wet tonne.

Activity cost categories

Figure 8.6 shows the breakdown of delivered costs between the activity cost categories for the four animal slurry supply systems. This clearly illustrates that transport costs are the most important activity cost in the supply of animal slurry to an anaerobic digester. Transport costs represent between approximately 45% (in system D) and 70% (in systems A and B) of total delivered costs per wet tonne in the supply systems we have considered.

Figure 8.6: Activity costs for animal slurry supply systems

Figure Not Available Electronically

Handling costs (the time taken and hence terminal time cost of filling slurry into the road tankers on the farms and then discharging it to the digester upon arrival at the plant) are the only other significant activity cost category in slurry systems. This ranges between approximately 30% (systems A and B) and 50% (system D) of delivered costs per wet tonne.

The cost of storing the slurry on farm prior to collection by road tanker can be seen to be negligible in comparison to the transport and handling costs (storage accounts for 1% to 2% of delivered costs per wet tonne in the systems modelled). This is based on the assumption that the on-farm slurry store is capable of holding approximately one week of slurry. If the storage period was longer than this, the storage tank would have to be larger and this would increase storage costs.

Detailed road transport analysis

Table 8.3 shows the results of the detailed transport analysis of the animal slurry supply systems we have modelled.

Table 8.3: Road transport analysis of animal slurry supply systems

Table Not Available Electronically

Terminal times can be seen to increase with vehicle size as the filling and discharging times for larger vehicles are greater than for smaller vehicles. This, together with the greater operating costs of larger road tankers explains the reason for system D having the highest terminal costs per vehicle load.

Given that the same transport distance and speed assumptions have been used in all supply systems, the trip time is the same for each supply system. Again, the higher operating costs of larger road tankers explain the trip costs per vehicle load in each of the systems (these are highest in system D and lowest in system A).

Therefore, given the higher trip and terminal costs per vehicle load of the larger and hence more expensive road transport equipment, the total transport cost per vehicle load (this includes the return journey of the tanker to the next farm for the collection of a further slurry load) is lowest in system A (approximately £27 per vehicle load) and highest in system D (approximately £55).

However, given the greater payloads of the larger transport vehicles modelled in the systems, the total transport cost per wet tonne will be lower when using a vehicle with a 23 tonne payload (system D -

£2.38 per wet tonne) than when using a vehicle with a 9 tonne payload (systems A and B - approximately £3 per wet tonne).

The relatively short transport distances that are likely to exist in centralised anaerobic digestion schemes (a 10 kilometre one-way distance has been assumed in the base cases) together with the relatively slow fill and discharge times to and from road tankers will result in the road tanker spending a significant proportion of its working day at either the trip origin (on farm filling the road tanker) or destination (the anaerobic digester being weighed and sampled and discharging its slurry load). In the systems modelled, terminal time accounts for between 47% and 64% of the total transport time (i.e. trip time plus terminal time).

The load moving cost for slurry (i.e. the total transport cost of per kilometre per wet tonne) has been calculated to range between £0.12 and £0.16 in the systems modelled.

Logistics costs for centralised anaerobic digestion schemes

Table 8.4 shows the typical annual slurry requirements for a 1 MWe digester (WS Atkins, 1995).

Table 8.4: Annual slurry requirements of a 1 MWe centralised anaerobic digester

Waste Source	Volume (m^3/day)	Wet solids* (tonnes/year)
Pig slurry at 8% dry solids (DS)	238	86,870
Dairy Slurry at 10% DS	45	16,425
Industrial Organic Waste at 20% DS	67	24,455
Total waste at 10.5% DS	350	127,750

N.B. * assuming 1 m^3 = 1 wet tonne and 365 days operation

The cost of hauling 103,295 wet tonnes of animal slurry per annum (86,870 tonnes of pig slurry and 16,425 tonnes of dairy slurry) will give the annual delivered costs of animal slurry supply for the different systems modelled shown in table 8.5.

Table 8.5: Total annual delivered costs of slurry for a 1 MWe digester for the supply systems modelled

	System A	System B	System C	System D
Animal slurry delivery costs	£320,000	£330,000	£300,000	£250,000
Organic industrial waste costs	£75,000	£75,000	£75,000	£75,000
Total slurry delivery costs	£395,000	£405,000	£375,000	£325,000

Assuming that the industrial organic waste is supplied using maximum size articulated road tankers (as in supply system E), and that the average one way distance for this transport movement is 20 kilometres (i.e. 40 kilometres round trip distance), this is likely to cost approximately £3 per wet tonne delivered (this cost has been derived from the delivered cost of an articulated road tanker transport animal slurry over this distance in our modelling). Therefore the annual delivered costs of industrial organic waste would be approximately £75,000.

The total annual delivered cost of slurry for a digester of this size are therefore likely to be in the range of £325,000 to £405,000 depending upon the slurry supply system used for transporting animal slurries. These costs are shown in Table 8.5. (It should be noted that this annual delivered cost does not include the cost of transporting the liquid digestate back to farms for spreading on the land).

8.4 Sensitivity analysis for animal slurry

<u>Road transport distance</u>

In the base case supply systems modelled for animal slurry (see section 8.2) the road transport distance from farm to centralised anaerobic digester was assumed to be 10 kilometres (i.e. a 20 kilometres round trip). Whilst 10 kilometres may represent the average distance that slurry will be hauled, in reality the transport distance will vary significantly dependent upon farm proximity to the digester. The models were therefore rerun for the following alternative transport distances scenarios:

- 5 kilometres one way transport distance (i.e. 10 kilometres round trip) - half the road transport distance in the base cases.

- 20 kilometres one way transport distance (i.e. 40 kilometres round trip) - double the road transport distance in the base cases.

The 20 kilometres one-way scenario is intended to represent the greatest distance over which animal slurry is likely to be hauled in anaerobic digestion schemes.

In modelling these alternative transport scenarios it has been assumed that as the distance over which animal slurry is transported increases there is greater opportunity to use better quality and hence faster roads (e.g. single A and B roads). Additionally, as haul length increases the proportion of the total journey spent on relatively slow farm tracks and minor roads becomes less significant, this also has the effect of increasing the average speed for the journey. As transport distance falls the converse is true. (The transport distance assumptions made for the alternative transport scenarios for animal slurry can be found in appendix 5).

The delivered cost per dry tonne resulting from these different road transport distances are shown in Figure 8.7.

At a transport distance of 5 kilometres the delivered cost per wet tonne is 15% to 25% lower in the supply systems modelled than at a distance of 10 kilometres (approximately £0.35 to £0.70 per wet tonne). If the transport distance is 20 kilometres the delivered cost is 20% to 30% greater than at 10 kilometres (approximately £0.45 to £0.90 per wet tonne).

Delivered costs are therefore more sensitive to transport distance in animal slurry supply systems than for the other biomass fuels studied in this project. This is to be expected given the importance of transport costs when expressed as a proportion of delivered cost.

Figure 8.7: **Effect of road transport distance on delivered costs**

Figure Not Available Electronically

Diesel fuel and labour costs

As for other biomass types the model was run with 40% higher fuel costs (i.e. diesel) to explore the impact of increases in fuel prices on the delivered costs of animal slurry. This resulted in delivered costs of animal slurry increasing by between 3% and 10% for the four supply systems compared with the base case costings.

The combined effect of an increase in fuel cost of 40% together with a 25% increase in labour rates was also modelled. This has the net effect of increasing the delivered cost of slurry by between 13% and 19% compared with the base case costings.

Returning the liquid digestate to the farms

As previously explained it is likely that farmers supplying slurry to the centralised anaerobic digester will want to use the liquid digestate that is produced during the separation process after digestion for spreading on their land. This will help to reduce or even eliminate the money that they currently have to spend on inorganic fertiliser.

The liquid digestate could either be transported back to farms or local storage points accessible to farmers by the transport vehicles collecting the animal slurry, so that they are running full in both directions during the year. Alternatively the liquid digestate could be stored at the digester plant and then distributed to farms when farmers require the digestate for spreading. Given that farmers are all likely to want the digestate during the growing season, this operation would have to be undertaken by different road tankers to those collecting the slurry from farms. In order to consider the costs of both of these liquid digestate operations we have modelled both possibilities using the Supply Chain Option model.

Backhaul of the liquid digestate

If the digestate is transported back to farms by the same transport vehicles collecting the slurry this utilises the transport equipment in both directions (and is therefore more efficient use of transport equipment than in the transportation of other biomass fuels considered in this work, in which vehicles always run empty when returning from the power station to the farm or forest). However the tanks, in which the slurry is transported on the vehicles, would have to be disinfected at the digester plant to prevent contamination of the liquid digestate by pathogenic microorganisms in the undigested slurry. Therefore tank cleaning equipment would have to be installed at the digester plant. This system would result in greater terminal time than in the base cases modelled as the road tankers would have to be disinfected, they would then have to be filled with liquid digestate and this would have to be emptied into a separate storage tank at the farm before the road tanker could be filled with animal slurry. The effect of this increased terminal time is that road transport vehicles would be capable of making fewer round trips between farms and the digester each day and therefore a greater number of transport vehicles would have to be used to achieve the same daily supply of slurry to the centralised anaerobic digester. This would obviously increase the annual logistics costs for the system and thereby the delivered cost of animal slurry.

By rerunning the model with these additional terminal times for tank cleaning and filling and discharging the liquid digestate, it was calculated that the system costs would be likely to increase by between 40% and 70% (depending on the supply system) in comparison with the base case costings (this calculation did not include the cost of providing suitable storage facilities on farm/at local storage points for the digestate or the cost of installing tank cleaning equipment, it is solely based on the additional transport requirements of the system).

Centralised storage of the digestate
If the digestate is stored at the digester until the growing season and then returned to farms by separate transport vehicles from those used to collect animal slurry, the vehicles used are likely to be maximum sized tankers in order to minimise the unit costs of transport. Therefore assuming a vehicle size that is the same as that used in supply system D for supplying animal slurry (i.e. 38 tonne tanker with a 23 m^3 tank) then the costs of this operation will not be dissimilar to that incurred when supplying slurry to the digester using this same vehicle (i.e. the supply system D cost of £2.40 per wet tonne in the base case). Therefore if returning the digestate as a separate transport operation, the transport and logistics costs will be approximately double that previously calculated for animal slurry delivery.

<u>Summary of sensitivity analysis results</u>

To conclude this chapter the sensitivity tests conducted and their effect on the delivered cost of animal slurry are summarised in Table 8.6. The table should be read in conjunction with the full text on each sensitivity test which precede this section as we have examined plausible and likely assumptions for each particular test rather than applying a standard change in input values for all tests. Discussion and comparison of sensitivity analyses for the different biomass fuels is contained in Chapter 9.

Table 8.6: Summary of sensitivity analysis results for animal slurry systems

Sensitivity test	**Effect on delivered cost**
Road transport distance	**
Returning liquid digestate to farms (extent to which this is more expensive than just supplying slurry to the CAD)	**
Diesel fuel and labour costs	**

N.B. Effect of the different sensitivity tests on delivered cost are shown by the following:
* less than 15% change in delivered cost
** more than 15% change in delivered cost

9. DISCUSSION OF SUPPLY CHAIN MODEL FINDINGS FOR ALL BIOMASS FUELS

9.1 Comparison of base case supply systems modelled

<u>Forest fuel, coppice, straw and miscanthus</u>

Our Supply Chain Option modelling suggests that the total delivered costs and the breakdown of these costs between activity cost categories are, as would be expected, significantly different from one biomass fuel to another. The range of delivered costs produced by the supply systems modelled for each biomass fuel are shown in Figure 9.1.

Figure 9.1: The range of delivered cost for biomass supply systems modelled

Figure Not Available Electronically

N.B. Forest fuel supply system D, which involves the supply of unchipped forest fuel to the power station, has not been included in the above diagram as the cost we have calculated for this system (£27 per tonne of dry matter) does not include the cost of centralised chipping and is not, therefore, a final delivered cost.

The modelling shows that the delivered cost per tonne of dry matter for large rectangular Hesston bale straw systems are lower than the costs of other biomass fuel supply systems. This is due to the fact that there are no growing costs for straw (as it is a waste by-product) and that such straw supply systems already exist commercially, serving markets such as the animal feed and bedding and the mushroom composting industry. Therefore these supply systems have been subject to a long period of supply chain planning and machinery developments in order to make them as efficient as possible. The same is not true (or at least not to the same degree) of the supply chains for other biomass fuels.

Forest fuel supply systems provide the next lowest delivered costs per tonne of dry matter at the power station in our modelling. The supply of unchipped forest fuel (system D) has been calculated to have the potential to achieve a similar delivered cost to large rectangular Hesston bales. However these residues would have to be processed and the cost of centralised chipping at the power station would result in higher final delivered costs than those in the straw systems. As this supply system does not include the cost of centralised chipping it has not been included in Figure 9.1.

Whether the delivered costs of unchipped fuel will be lower than material that is delivered ready chipped will depend upon the cost of centralised chipping. In the systems we have modelled, centralised chipping would have to cost less than approximately £5 per dry tonne for the delivery of unchipped fuel to have a lower delivered cost than the cheapest chip delivery system modelled. Centralised chipping does have other advantages to the power station operator that may make it an attractive biomass supply system; it gives them greater control over the chipping process. The quality of the fuel that is fed into the boiler may, depending upon the conversion technology used, be critical to generation efficiency and the smooth running of the power station.

The delivered costs for the short rotation coppice supply systems that we have modelled are, on average, approximately 50% greater than the delivered costs of forest fuel supply systems (approximately £33 per tonne of dry matter in forest fuel systems compared with £50 in coppice systems). This cost difference is due to a number of factors, but the main difference between these two fuels is that coppice has to be grown specifically for biomass supply and therefore the costs of this are all attributable to the biomass supply system, whereas forestry material is a waste by-product and the costs of growing this material are not attributable to the biomass industry. In the modelling we have assumed that farmers will have to be paid £20 per dry tonne to grow coppice on their land (this represents the physical costs of growing coppice such as ground preparation, cuttings, weed control, treatment plus a financial incentive to make growing coppice attractive compared with other food crops). If the price that farmers have to be paid to encourage them to grow coppice was less than this (maybe due to falling crop prices etc) then the difference in supply cost between forest fuel and coppice supply systems would be lessened. Of course, if farmers require payments of more than £20 per dry tonne to grow coppice, this would result in even higher delivered costs for coppice than those derived in the modelling.

Direct cut and chip and stick harvesting supply systems for short rotation coppice have produced similar delivered costs per dry tonne in the modelling exercise. However a system in which whole sticks are delivered to the power station is likely to prove more expensive than chip delivery systems even before the cost of centralised chipping is taken into account unless the road transport of sticks can be made more efficient (i.e. a greater tonnage can be loaded onto the lorry).

The miscanthus systems modelled indicate that delivered costs are likely to be as high as, if not higher than, short rotation coppice. Again a major cost component is likely to be the money that will have to be paid to farmers to encourage them to grow miscanthus on their land. From the modelling it would appear that a baled miscanthus supply system is likely to produce lower delivered costs than a direct cut and chop system.

The delivered cost of the miscanthus large rectangular Hesston bale system (system B) is higher than the system modelled for straw. This is because of three key factors: the price that will have to paid to encourage farmers to grow miscanthus (whereas straw is a by-product), the lower dry matter content at harvest and the harvesting system that will be necessary. Miscanthus is likely to have to be first cut and left in a swath and then baled at a later date; this will result in losses during baling as material in a swath will be difficult to pick up. (The need for separate cutting and baling for miscanthus is due to the lower dry matter content it will have at harvest in comparison with straw which would result in rotting if baled immediately and stored long term).

For all biomass fuels in which the use of intermediate storage systems have been modelled, this supply system, in which the fuel will have to be transported twice by road transport vehicle (first from farm/forest to intermediate store) and then after storage from store to power station), is likely to result in a higher delivered cost than a system in which there is only one road transport movement (direct from farm/forest store to power station). Use of an intermediate store will add in the region of 10% to 20% to delivered costs, as a result of the additional transport and handling costs incurred.

It is important to note that in devising a supply strategy for a power station, the fuel supplier is likely to have to operate a range of different systems in order to ensure that biomass supply can be maintained all year round. For example, a fuel supplier supplying straw will probably have to make use of an intermediate store supply system as well a farm store supply system. Although according to our work the farm store system would be preferable to intermediate storage in terms of delivered cost, it is unlikely that farm stores could be accessed by road transport vehicles during certain periods of the year and therefore intermediate stores would also have to be available. Therefore whilst delivered cost comparisons between different supply systems are important, it must be borne in mind that in reality a fuel supplier is likely to have to adopt a number of supply systems to be able to ensure a balanced fuel supply strategy in which the delivery of biomass on a regular year round basis is essential to the functioning of the power station.

Animal slurry

Direct comparisons between the delivered costs of animal slurry systems that we have modelled and other biomass fuels are not advisable due to the different energy content and the extremely low dry solids content of the slurry compared with other fuel types. In addition, the animal slurry systems modelled are based on one-way transport distances of 10 kilometres compared with 40 kilometres for each of the other biomass fuels. Clearly the cost per wet tonne delivered is far lower than for other biomass fuels but this is due to the low dry solids content.

The major cost in animal slurry supply systems is the transportation and handling cost. Minimising transport distance in slurry systems will be critical in achieving lowest delivered costs possible. By using the largest road transport tankers legally permissible transport costs can be minimised per tonne of slurry delivered. However the largest vehicles may have difficulty operating on small roads connecting cattle and pig farms to the centralised digester in some locations. In such situations the use of road transport tankers with smaller payloads or Fastracs hauling agricultural tankers would be necessary.

An additional advantage of the use of animal slurry to produce electricity at a centralised digester over other biomass fuels is that these systems perform an important environmental role and this is the main driver behind their introduction (i.e. the anaerobic digestion of animal slurry at a centralised digester removes the environmental impacts that could arise from leaving animal wastes on farms such as polluting local water sources).

Animal slurry is the only biomass system in which the road transport vehicles could be utilised in both directions (i.e. from farm to anaerobic digester and from digester back to farm). This is possible in the case of slurry if the liquid digestate is transported to farms or local storage points accessible to farmers all year round. However this would increase the overall cost of the operation as the terminal time would increase (due to tank cleaning, and the filling and discharging of the liquid digestate) and hence more transport vehicles would be required to perform the same number of daily deliveries to the centralised digester.

9.2 Discussion of sensitivity analysis

<u>Road transport distance</u>

Delivered costs are relatively insensitive to transport distance for most of the biomass fuels studied in this project; this is true of forest fuel, short rotation coppice, straw and miscanthus. This suggests that for these biomass types the fuel can be transported relatively long distances (in biomass scheme terms) without delivered costs increasing appreciably.

The results of the modelling carried out in this project show that a transport distance from farm/forest to power station of 80 kilometres (i.e. a round trip distance of 160 kilometres) will produce delivered costs that are only 5% to 15% greater than for a transport distance of 40 kilometres (round trip distance of 80 kilometres).

Several factors explain the limited effect of increased transport distances on the delivered cost of most biomass fuels. These include:

- the proportion of delivered cost accounted for by transport (trip and terminal) costs (these account for between 15% and 40% of delivered costs in all supply systems modelled other than animal slurry);

- average trip speed is likely to increase as transport distance increases (since a greater proportion of the journey will be conducted on higher quality road categories) and therefore any increase in distance will result in a less than proportionate increase in trip time and hence trip costs. Conversely, as transport distance decreases, average speed over the journey will fall and therefore trip time and hence trip costs will fall by a less than proportional amount;

- terminal costs will remain the same even when transport distance changes;

Many of the costs associated with handling and transporting these fuels (such loading and unloading the vehicle, sheeting the vehicle, dropping empty and coupling up full trailers, weighing the vehicle and sampling the fuel at the power station) will remain the same regardless of the transport distance and therefore once these have been taken into account the biomass can be transported relatively long distances (for a biomass scheme) without substantial increases in delivered costs.

The delivered cost of animal slurry is more sensitive to transport distance than for the other biomass fuels studied. In these supply systems a transport distance of 20 kilometres is likely to result in delivered costs of between 30% and 65% higher than when transporting the slurry 5 kilometres (depending upon the supply system used). This is explained by the proportion of delivered cost accounted for by transport activities in these supply systems (i.e. transport and handling are by far the most important costs in these systems, to a far greater extent than in supply systems for other biomass fuels).

However, although the modelling work undertaken suggests that delivered cost is relatively insensitive to the distance the biomass is transported for most fuel types, in order for biomass schemes to prove economic they must strive to produce the lowest delivered costs possible. Therefore by sourcing fuel from closer rather than more distant locations, cost savings can be achieved and these may prove to be crucial to the financial viability of generating electricity from biomass fuel.

Transporting loads which cannot make full use of vehicle payload

When transporting biomass fuels with low bulk densities (such as unchipped forest residues, coppice sticks, chopped miscanthus and straw and miscanthus bales) it is important to use vehicles with as large a vehicle body or bed area as possible. This will ensure that the weight of the load carried can be maximised.

In the case of unchipped forest residues, compaction can be applied to the residues by the head of the crane loading them into the transport vehicle in order to improve bulk density. It may be possible to improve the loading of coppice sticks onto transport vehicles (bundled or unbundled) or to cut the stick bundles so as to improve their size in relation to the dimensions of the bed of the vehicle used. Compaction of coppice sticks may also be a possibility. In the case of chopped miscanthus and straw and miscanthus bale transport it would appear that little can be done to improve the weight of the load carried without significantly increasing total delivered cost (e.g. straw wafering machines and similar equipment could be used to improve bulk density but the bulk density benefits of doing so would be outweighed by the costs of the processing).

Transport vehicle size

It is essential that use is made of the largest vehicles possible (i.e. in terms of payload and also volume in the case of biomass with low bulk densities) when transporting biomass. Although the operating costs of larger articulated vehicles are higher than smaller rigid vehicles, the unit costs of transport per tonne carried are significantly lower when using the former. This has been demonstrated in several of the supply systems modelled.

Maximum gross vehicle weight limits will increase from 38 tonnes to 40 tonnes in the UK in 1999. This will be of benefit in the transportation of biomass fuels which have relatively high bulk densities and therefore reach the weight limit of the road transport vehicle before the volume limits. This is true of animal slurry and wood chips with relatively high moisture contents.

The new weight limits would allow an additional 2 wet tonnes of slurry to be carried by the largest permissable road tanker (i.e. a load weight of 25 wet tonnes rather than 23 wet tonnes as modelled in base case supply system D). The model was rerun to examine the effect of this greater load weight on the trip costs and total delivered costs of animal slurry. The results suggest that trip costs would be approximately 8% lower than achievable with the largest vehicle currently allowed and that delivered costs would be approximately 3.5% lower. The new weight limits will therefore help to reduce the delivered costs of biomass fuels with sufficient bulk densities to make use of them.

When transporting straw, miscanthus, coppice sticks and unchipped forest fuel which have relatively low bulk densities, the volume limits of the road transport vehicle are reached before the weight limits. Therefore the increase in weight limits would not be of use when transporting these biomass fuels.

Dry matter losses of wood chips during storage

In supply systems in which biomass fuel is harvested in a form that is likely to deteriorate significantly during storage (i.e. direct cut and chip coppice harvesting, terrain-based forestry harvesting and cut and chop miscanthus harvesting) dry matter losses during storage are likely to have a significant effect upon delivered cost. If these dry matter losses can be limited this will help to substantially reduce delivered costs in these supply systems. However the use of expensive storage and drying systems to achieve this end are unlikely to be affordable in biomass schemes.

Instead it would be sensible for fuel produced by these harvesting systems to be delivered to the power station as soon as practicable. Biomass from alternative harvesting systems which is less likely to be subject to dry matter losses during storage (such as unprocessed forest fuel and coppice stick harvesting) is more suitable for storage and later delivery over the remainder of the year.

If technologically feasible it would therefore be sensible to consider establishing biomass power stations capable of using the full range of biomass fuels (i.e. forest fuel, coppice, straw and miscanthus) so that each could be used at the power station shortly after harvesting. This would remove the cost of storage facilities and the loss of useful energy that occurs when biomass decomposes during storage.

Mobile chipper productivity

If the productivity of mobile chippers used in forest fuel and coppice supply systems could be increased this would reduce the amount of time that vehicle loading takes and hence reduce the cost of the loading operation. It is also probable that, although a more powerful chipper with a higher productivity rate than that modelled would have higher operating costs, it would reduce the cost of mobile chipping per tonne of dry matter produced as the cost of feeding the chipper would also be reduced. However it is important that chip quality is maintained as productivity increases; research has suggested that chipping machine size (i.e. productivity) tends to affect the proportion of oversized chips produced (Forest Industry Group, 1996).

Purchase/growing costs of biomass fuels

In the case of coppice and miscanthus the cost of purchasing the biomass is likely to represent an extremely important proportion of total delivered cost. This will effect the cost effectiveness of these fuel types in comparison with fuels that are far cheaper to acquire (i.e. forest fuel and straw, both of which are by-products of other products and are therefore essentially waste as far as producers of them are concerned). If the purchase costs of these biomass fuels grown specifically for supply could be reduced to levels similar to those occurring in the case of forestry and straw they would be able to achieve delivered costs not dissimilar to these fuel types.

9.3 Importance of activity cost categories

The proportion of total delivered cost accounted for by each of the different activity costs components considered in this report (purchase costs, harvesting, handling, storage and transport) differ from one biomass fuel to another and from one supply system to another for the same fuel. This is illustrated in Figure 9.2 which shows the relative importance of the different activity costs for the lowest delivered cost supply system for each biomass fuel. The supply chains for each of these systems are shown below Figure 9.2.

Figure 9.2: Proportion of delivered cost accounted for by activity cost categories for the lowest cost supply system for each biomass fuel

Figure Not Available Electronically

N.B. Forest fuel system A has been shown above rather than system D. This is because the delivered cost we have calculated for system D does not include the cost of centralised chipping, which is not currently known. Each of the supply systems referred to in Figure 9.2 are shown below for information.

Forest fuel supply system A

Short rotation coppice system A

Figures Not Available Electronically

Straw supply system D

Miscanthus supply system B

Animal slurry supply system D (Articulated tanker with carrying capacity of 23 m^3)

However from the analysis it is clear that the cost of transporting and handling biomass fuel from its point of availability (in the field in the case of straw, miscanthus and coppice, in the forest for forest fuel and in a farm slurry storage tank for animal slurries) to its point of utilisation (at a power station/centralised anaerobic digester) are activity cost categories that are of great importance in all biomass fuel supply systems. These two activity costs represent about 50% or more of delivered straw costs, approximately 50% of delivered cost in forest fuel supply, 35% or more of delivered costs for coppice, 20% to 40% of delivered cost in miscanthus supply systems and almost all the delivered costs of animal slurry supply. It is therefore extremely important that the transport and handling operations (i.e. the logistics elements of the supply system) are conducted in an efficient and well co-ordinated manner if desirable delivered costs are to be achieved.

In short rotation coppice and miscanthus supply systems the major cost component is likely to be the purchase/growing cost of the fuel (this can account for up to approximately 50% of delivered cost per dry tonne). There may be relatively little scope to alter this cost and it is therefore essential that attention is focused on activities such as transport and handling (together with harvesting technology and operation) if delivered costs are to be reduced in the future.

10. ROAD TRANSPORT OPERATIONS AND POWER STATION REQUIREMENTS

10.1 Discussion

The Supply Chain Option modelling considers one tonne of biomass flowing through the supply system from the point of production to the power station and all the activities required to facilitate this. However it is also important to think about the supply of biomass fuel from the perspective of the power station, as decisions made by those managing the power station will have implications for activities within the biomass supply chain. Power station requirements will influence factors such as the total quantity of fuel needed annually, moisture content of the fuel, the size of chips and bale sizes.

The end result of all biomass supply chain activity is the delivery of the fuel to the power station by road transport vehicles in the correct quantity, at the correct quality, schedule and cost to meet the hourly, daily and seasonal demands of power station operation. The operating conditions implemented by the power station managers and imposed on the station by the local planning authority will determine the delivery window at the power station (i.e. the number of days a week and hours per day when transport vehicles are allowed to deliver to the power station). This in turn will have implications for the total vehicle fleet needed to supply the biomass when required.

In order to think about the effect of decisions and requirements at the power station on the transport and logistics supply system we have collected details of planning applications from a number of proposed and established biomass schemes. From these planning applications we have managed to obtain a significant degree of insight into the fuel requirements of such schemes and have therefore been able to analyse the implications that this would have for the transport planning and operations for biomass supply. Key transport and logistics points to emerge from our study of biomass planning applications are discussed below.

Biomass storage

Few proposed power stations would have facilities to store more than a few days of biomass fuel at the power station. This is due to the size of the storage facilities that would be required and the cost of such storage facilities. Instead biomass will have to be stored at farm/forest stores and at intermediate stores.

Transport delivery frequency

Most of the proposed schemes will require biomass to be supplied on a constant basis throughout the entire year. Therefore the power station will receive the same number of vehicle deliveries every day that it is open for deliveries. Although a few of the schemes suggest deliveries either five or seven days a week, the majority of schemes propose transport deliveries on six days a week (every day except Sunday and public holidays). Many planning authorities in considering applications for such power stations have imposed limits on the times between which daily deliveries could be made. On average a ten hour delivery period (typically from 8 a.m. to 6 p.m.) has been insisted upon. However such delivery restrictions are clearly dependent upon the location of the power station and its surrounding environment. Occasionally a small number of vehicle movements will be permitted on Sundays but more often than not this will be for the removal of residual ash during the operational life of the power station. Adherence to the agreed delivery times will often form a part of the conditions of acceptance of the planning application and will be agreed on in writing. It is unlikely that fuel suppliers and transport operators would want to deliver biomass over a longer working day as this would mean collecting fuel from farms and forests at times when natural daylight was not always available. Such systems would therefore require artificial lighting at loading points and the lack of daylight would make handling and transport less safe in certain circumstances and environments.

Wherever possible maximum gross vehicle weight lorries will be used for the transportation of biomass to the power station.

Table 10.1 shows the transport delivery systems proposed in a number of biomass power station applications made in the UK in recent years.

Routing of fuel delivery vehicles

The routing of fuel delivery vehicles will usually be agreed on by the local council and the operator of the power station during the course of the planning application procedure. Routing agreements often form a part of the conditions of acceptance of the planning application.

Operators are required to submit to the local council the specific details of the routes to be used by the fuel delivery vehicles. Once agreed upon these routes must be strictly adhered to and any future changes which the operator might wish to make to the routing plans must also be submitted to the local council for approval. Local councils may prohibit the use of certain roads and efforts will be made to ensure that vehicles are routed away from centres of local population. It is likely that haulage contractors will have the agreed routes written into their contracts and failure to adhere to these specified routes would put them in breach of contract.

Identification of vehicles

Most planning authorities will insist upon fuel delivery vehicles being clearly badged and identifiable. They will usually be required to carry both the name of the haulier and also the name of the operator of the power station. These details are submitted in writing to the local council and will probably be agreed on before the power station becomes operational.

The vehicles will also be required to be fully sheeted at all times during the transport of the fuel. This is particularly important in the transport operations for chicken litter fuelled power stations (not considered in this report) because of the odour problems and risk of infection associated with this type of biomass. However, it is usual for local councils to require the sheeting of all fuel delivery vehicles transporting biomass to power stations.

Access roads

It will often be necessary for additional access roads to be constructed to allow traffic to gain access to the power station from the main approach roads, which in a majority of cases, are "A" class roads. Modifications to existing infrastructure will also be necessary to allow fuel delivery vehicles, and other HGVs access to the site. These modifications may include additional roundabouts or road widening at junctions.

Vehicle movements during construction

During construction there will be a large number of car movements generated by construction workers and others involved with the development of the site. In a vast majority of cases the numbers of car movements generated by personnel during construction of a given site will greatly exceed the number generated during the operational life of the power station. In some cases car movements associated with construction may be up to 6 times greater than during operation.

Table 10.1: Details taken from UK planning applications for biomass fuelled power stations

	Type of fuel used	Size of the plant	Fuel required per annum	Lorry loads of fuel delivered per annum	Lorry loads of fuel delivered per day	Fuel delivery times	Distance over which fuel would be sourced
Power Station No. 1	Straw-fired (Also able to co-fire on wood chip.)	20 MW	N/A	N/A	32	7 days a week between the hours of 0800 and 1800.	From within a 70 km radius of the site.
Power Station No. 2	Straw-fired	20 MW	153,300 tonnes	7665 approx.	25 on average.	6 days a week (not Sundays). Between 0800 and 2200 Monday to Friday and between 0800 and 1700 on Saturdays.	From with an approximate radius of 100 km.
Power Station No. 3	Chicken litter	10 MW	100,000 tonnes	4000 to 5000	16-20 on average.	6 days a week(not Sundays or Public Holidays). Between 0730 and 1800 Monday to Friday and between 0730 and 1300 on Saturdays.	From within a 50 km radius of the site.

Power Station No. 4	80% Chicken litter (20% forestry waste and coppice wood.)	20 MW	240,000 tonnes (195,000 chicken litter and 45,000 other.)	10435 approx.	35 on average.	6 days a week (not Sundays or Public Holidays) during normal working hours.	From within a 50 km radius of the site.
Power Station No. 5	Chicken litter (Also 20,000 tonnes of coppice wood.)	35 MW	N/A	N/A	70 vehicle movements.	6 days a week between 0730 and 1900. A maximum of 4 vehicle movements on occasional Sundays.	N/A
Power Station No. 6	Coppice	2.5 MW	18,000 (dry) tonnes	1250	5-6	During normal working hours.	From within a 50 km radius of the site.
Power Station No. 7	Straw-fired	31 MW	225,000 straw	15,000	60-65	6 days a week (not Sundays). Between 0800 and 1800 Monday to Friday and between 0700 and 1300 on Saturdays.	N/A

There will also be a number of abnormal loads occurring during construction of the power station which will be required to bring specific items to the site such as boilers, turbines, stacks, cranes etc. This probably amount to no more than 4 to 6 abnormal loads associated with the construction of a single site. These abnormal load movements need to be agreed with the relevant police authorities and also need to be accompanied by local police en route.

10.2 Factors influencing transport distance

The catchment area for the biomass resource and hence the transport distance over which biomass will have to be moved between storage locations and power stations will depend upon a number of key factors. These include the:

- size of the power station and the conversion technology used;
- crop yield that is achieved;
- proportion of land around the power station planted with biomass energy crops (i.e. coppice and miscanthus), or crops that have biomass as a byproduct (i.e. straw) or density of forestry in the case of forest fuel;
- availability of the material for biomass resource (e.g. straw has competing uses and therefore only a proportion of the total produced will be available for use in biomass schemes).

In the case of straw, forest fuel and animal slurry, the resource already exists, it is more a question of how much will be available at the price that a biomass scheme can afford and the extent to which owners of the resource are prepared to supply the material for this use (e.g. farmers may prefer to reincorporate the straw into the land and then plough and replant rather than have the inconvenience of waiting for agricultural contractors to bale and remove it from their land).

For straw-fired power stations the key factors determining the catchment area from which fuel will have to be sourced are: the size of the power station (and its annual straw requirement), and the availability of straw in the surrounding area (which is determined by the proportion of land planted with straw yielding crops and the predisposition of farmers owning these crops towards supplying this straw to biomass schemes).

Taking the former point about power station size, Figure 10.1 shows the effect of power station size on the catchment area required for a wheat straw-fired power station. Clearly, all other things being equal, a large power station (i.e. one with a large annual fuel requirement) will have to source fuel over a greater distance than a smaller one.

The latter point about straw available within the surrounding area is also very important. Figure 10.2 shows how the catchment area varies for a 40 MW straw-fired power station using wheat straw depending upon the proportion of land planted with straw with wheat and its availability for biomass schemes.

Figure 10.1: The effect of power station size on straw catchment area

Figure Not Available Electronically

Figure 10.2: The effect of straw availability on catchment area
(for a 40 MW power station)

Figure Not Available Electronically

Figure 10.1 and 10.2 are based on the following assumptions:

- a 10 MW straw fired power station requires 65000 dry tonnes of wheat fuel, compared with 260,000 dry tonnes at a 40 MW plant.
- the wheat straw supplied has a crop yield of 3.5 dry tonnes per hectare.
- In Figure 10.1 wheat is planted on 30% of all land surrounding the power stations. One third of this straw is made available to the power stations.

For coppice and miscanthus it is presently unclear how receptive farmers will be to growing these fuels (or to allowing others to grow them on their land). This will depend upon the money they are offered and the opportunity cost of the land. The crop yields for these energy crops are also somewhat uncertain; yields achieved in the UK are still substantially below the theoretical yield and are very uncertain on a sustained annual basis.
Taking the first of these points, Figure 10.3 illustrates the effect of the proportion of land planted with coppice around a 10 MW coppice-fuelled power station on its catchment area.

The second point about the influence of crop yield on transport distance is depicted in Figure 10.4 for the same 10 MW power station.

Figure 10.3: The effect of the proportion of land planted with coppice on catchment area
(for a 10 MW power station)

Figure Not Available Electronically

Figure 10.4: **The effect of coppice crop yield on catchment area**
(for a 10 MW power station)

Figure Not Available Electronically

Figures 10.3 and 10.4 are based on the following assumptions:

- a 10 MW coppice fired power station requires 65,000 dry tonnes of coppice per annum.
- In Figure 10.3 the coppice crop yield is 10 dry tonnes per hectare per year.
- In Figure 10.4, 1% of land around the power station is planted with coppice.

All the factors discussed above are of primary importance in determining the catchment area of any biomass power station and hence the distance over which fuel will have to be transported. The Supply Chain Option modelling has shown that the delivered cost of most biomass fuels is not hugely sensitive to change in road transport distance. But, given that transport is a key cost and that there is a link between transport cost and distance, it is worth focusing management attention on power station location and the range over which biomass needs to be sourced.

The distribution of the biomass fuel within the catchment area and the existing road network will also be important factors in determining the transport and handling costs in biomass supply. If the catchment area consists of a few large plantations with direct access to trunk roads then the transport and handling costs would be lower than if the catchment was made up of a few small roads with poor access to the biomass resource. In the latter case, lots of lengthy empty return journeys from the power station would occur and in-field/forest transport distances would be greater. The latter would have higher delivered costs and transport and handling would represent a greater proportion of delivered cost than in the former (as all other supply costs such as purchase of the fuel and harvesting would remain the same). This could prove to be a crucial factor in the viability of a particular power station project: high handling and transport costs will mean that fuel purchase costs have to be forced down by the fuel supplier in order to achieve the target delivered cost; this will in turn potentially stop the farmer from growing the biomass crop.

10.3 Modelling the transport systems to serve power station requirements

Using the information obtained from planning applications and our knowledge of biomass transport from the Supply Chain Option modelling, we have analysed the ways in which decisions made by the power station managers and the local planning authority will affect the transport system needed to serve straw, coppice and animal slurry fuelled power stations.

The transport system requirements for these biomass power stations have been modelled in terms of:

- vehicle deliveries to the power station (per day and per year)
- maximum number of round trips per vehicle per day
- road transport vehicles and drivers required
- vehicle kilometres travelled (per day and per year)

The modelling simply considers the transport of biomass from the store to the power station (i.e. it does not include in-field/forest transport and supply systems which involve road transport from the field/forest to an intermediate store). The results for straw fuelled power stations are given in section 10.4, for coppice in section 10.5 and for animal slurry in section 10.6.

10.4 Results for straw-fired power stations

In the case of straw fired power stations the following factors and their impact upon the transport system required for the power station in terms of vehicle and driver requirements, total vehicle movements and total kilometres performed in supplying fuel to the power station were considered:

- power station size (i.e. megawatt capacity)
- delivery window at the power station
- round trip distance from store to power station

The results are shown in Table 10.2 and assumptions used in the modelling are given below the table. The first two columns of the table show the road transport requirements for power stations of 20 MW and 40 MW (scenario 1 is the 20 MW station and scenario 2 the 40 MW station). The results show that, using the assumptions defined above, a 20 MW power station would require 40 vehicle deliveries per day, compared with 80 deliveries for a 40 MW station. Given that one vehicle could only make a maximum of four round trips per day, the 20 MW station would require a fleet of 10 vehicles and drivers, while the 40 MW station would require 20 vehicles and drivers. The total number of deliveries during the year would be 10,000 in the case of the 20 MW station and 20,000 for the 40 MW station. Given a round trip distance of 80 kilometres, a total of 800,000 kilometres would be performed each year in supplying the 20 MW plant in comparison with 1.6 million kilometres in the case of the 40 MW plant.

Table 10.2: Transport system requirements for straw-fired power stations

Table Not Available Electronically

Assumptions made in the straw transport system modelling are:

- annual fuel requirement of 150,000 wet tonnes of straw at a 20 MW plant and 300,000 wet tonnes at a 40 MW plant (at 85% dry matter content);
- large rectangular Hesston straw bales have a bale density of 138 kg/m^3 at 85% dry matter content;
- straw is delivered to the station 50 weeks a year; in the initial run it is delivered 5 days a week and 10 hours per day;
- terminal time of 70 minutes per vehicle load for straw transport;
- transport distance from store to power station in the initial run assumed to be 40 kilometres one way (i.e. 80 km per round trip);
- average trip speed for an 80 km round trip is 40 km/hour;
- road transport vehicle is a 35 tonne (GVW) articulated flatbed capable of carrying 30 large rectangular Hesston straw bales.

We then considered the effects of relaxing the delivery window at the 20 MW power station by changing the delivery window from 5 days a week and 10 hours a day, to 7 days a week and 24 hours a day. The results are shown in the next two columns in the table. Scenario 1 shows the base case (i.e. delivery window maintained with original assumptions) while scenario 2 has the relaxed delivery window. The results show that with no restrictions on deliveries (i.e. on hours per day or days per week), a transport vehicle would now be capable of making 8 round trips per day (compared with only 4 when the delivery window restrictions exist) and this reduces the fleet size required to 4 vehicles and 10 drivers. Driver requirements are greater than vehicle requirements as by law drivers' working hours are restricted to a maximum of 90 hours per fortnight. Obviously this system would involve practical problems such as loading vehicles at stores during the night. However this effectively illustrates how operating restrictions imposed on the supply system result in the need for more capital intensive equipment.

We then examined the impact of different transport distances on the number of round trips each vehicle could make per day and the transport fleet requirements for a 20 MW power station; these results are shown in the last three columns of the table (scenario 1: 20 km one way (therefore 40 km round trip), scenario 2: 40 km one way (therefore 80 km round trip - this is the base case), scenario 3: 80 km one way (therefore 160 km round trip). As explained in section 6.4 the average speed for the journey is likely to increase as transport distance increases and this has been assumed in the modelling.

The results show that in a system with a trip distance of 20 km (one way), each vehicle would be capable of making 5 round trips per day from the store to the power station. Therefore the total vehicle requirement for this system would be 8 transport vehicles. In a system with a one way trip distance of 40 km, the vehicles can only achieve 4 round trips per day and therefore 10 vehicles are needed to supply the power station with its daily fuel requirement. At a one way trip distance of 80 km each vehicle would only be capable of making 3 round trips per day and therefore fleet requirements would increase to 14 vehicles and 15 drivers. The table also shows the impact that this increase in round trip distance would have upon the total vehicle kilometres performed per year in each system. Therefore the larger the catchment area from which fuel is sourced, the greater the road transport vehicle requirements to supply straw in that system.

10.5 Results for coppice-fired power stations

A similar analysis to that conducted for straw transport was undertaken for coppice; the results of this are shown in Table 10.3. This took into consideration the effect of power station size, the delivery window and the trip distance on the vehicle and driver requirements, total vehicle movements and total annual kilometres performed in supplying fuel to the power station.

For coppice systems we examined the transport requirements for a 5 MW (scenario 1) and a 10 MW (scenario 2) power station supplied with chipped material using the assumptions previously described; the results are shown in the first two columns of Table 10.3. The 5 MW power station would require 12 vehicle deliveries per day, while the 10 MW power station would need 24 deliveries. In both systems each transport vehicle would be capable of making 4 round trips per day and therefore the 5 MW station would need a transport fleet of 3 vehicles and drivers while the 10 MW plant would need 6 vehicles and drivers. Over an entire year the 5 MW station would receive 3,000 vehicle deliveries compared with 6,000 vehicle deliveries at the 10 MW station.

The next two columns in the table show the effects of extending the delivery window at the 10 MW power station so that vehicles can now deliver 7 days a week and 24 hours a day (scenario 2). Scenario 1 shows the base case assumptions of 5 days a week and 10 hours a day. With the extended delivery window one vehicle would now be capable of making 9 round trips from the store to the power station per day (assuming a one way trip distance of 40 kilometres) and this reduces the vehicle fleet requirements to 2 vehicles and 6 drivers.

We also considered the effects of different round trip transport distances on the transport requirements for a 10 MW power station (scenario 1: 20 km one way (therefore 40 km round trip), scenario 2: 40 km one way (therefore 80km round trip - this is the base case), scenario 3: 80 km one way (therefore 160 km round trip). As explained in section 5.4 the average speed for the journey is likely to increase as transport distance increases and this has been assumed in the modelling. From the table it can be seen that in a system with a trip distance of 20 km from store to power station each of the transport vehicles would be capable of making 6 round trips per day from the store to the power station and this system would therefore need a total of 4 transport vehicles in order to meet the daily fuel requirements of the power station. If the trip distance was 40 km, the maximum number of round trips per vehicle per day would be 4 and this system would require a total of 6 road transport vehicles. For a trip distance of 80 kilometres, each vehicle could only achieve 3 round trips per day and therefore 8 vehicles would be needed to supply the station with its daily fuel requirement.

Table 10.3: Transport system requirements for coppice-fired power stations

Table Not Available Electronically

Assumptions made in the coppice transport system modelling are:

- annual fuel requirement of 67,500 wet tonnes of coppice at a 5 MW plant and 135,000 wet tonnes at a 10 MW plant (at 50% dry matter content);
- coppice chip has a bulk density of 330 kg/m^3 at 50% dry matter content;
- coppice is delivered to the station 50 weeks a year; in the initial run it is delivered 5 days a week and 10 hours per day;
- terminal time of 45 minutes per vehicle load for coppice transport;
- transport distance from store to power station in the initial run assumed to be 40 kilometres one way (i.e. 80 km per round trip);
- average trip speed for an 80 km round trip is 40 km/hour;
- road transport vehicle for coppice chips is a 38 tonne (GVW) articulated tipping vehicle with a 90 m^3 body.

The last two columns of Table 10.3 show a comparison between the transport of chipped coppice and unchipped coppice sticks for a 10 MW power station (scenario 1 is the base case chip transport system and scenario 2 is stick transport). Given the relatively low load weight that can be achieved when transporting sticks (in this example 10 wet tonnes) there would have to be 54 vehicle deliveries of sticks per day compared with only 24 deliveries of chips to meet the power stations fuel requirements. In the case of stick transport a vehicle fleet of 14 transport vehicles would be required compared with only 6 vehicles in the chip transport system. The vehicle kilometres performed per year would be 2.25 times greater in the stick transport system than in the chip delivery system.

The difference in the vehicle deliveries required per day when comparing chipped and unchipped material is also true of forest fuel. Given the lower bulk density of the latter in comparison to wood chips, there would have to be a higher number of daily vehicle deliveries and hence vehicle fleet requirements would be greater.

10.6 Results for animal slurry delivered to a digester

For animal slurry the effect of the size of the centralised anaerobic digester, the delivery window at the digester, the trip distance and the size of vehicle used on the transport system requirements were examined.

Table 10.4 shows the results of this analysis. The first two columns of the table show the impact of the digester size on the transport requirements. For a 0.1 MW digester (scenario 1) given the assumptions outlined below the table, two vehicles deliveries would be required per day if using a 23 m^3 road tanker. Therefore only one transport vehicle would be required in this system. In comparison, a 1 MW digester would require 18 vehicle deliveries per day by a vehicle of this size and, as each vehicle is capable of making 5 round trips per day, a total of 4 such vehicles would be required.

The trip distance from farms to the digester will obviously effect the number of round trips a vehicle is capable of making per day and hence the total number of transport vehicles required for the system. The next three columns of Table 10.4 illustrate this point, showing that if the trip distance doubled (from a round trip of 20 km to 40 km) then each transport vehicle would only be able to achieve 4 round trips per day and hence the fleet requirement would increase from 4 vehicles to 5 vehicles.

The final three columns of Table 10.4 show how the size of the transport vehicle used will affect the number of daily deliveries necessary. The first column (scenario 1) shows a 23 m^3 road tanker, which as already discussed can make 4 round trips per day in the specified system and results in a total fleet requirement of four vehicles. Scenario 2 is for a 16 m^3 road tanker, and shows that whilst this vehicle is able to make more round trips per day than the 23 m^3 vehicle (due to the shorter time taken to fill and empty a smaller vehicle), the smaller load carried results in the need for 26 daily deliveries and hence a fleet of 5 such vehicles. Scenario 3 considers the use of a 9 m^3 road tanker (this could be hauled by a Fastrac). This vehicle can make 7 round trips per day but, given the lower carrying capacity of the vehicle, 46 deliveries would be required per day, meaning that 7 such transport vehicles would be required.

Using smaller vehicles to deliver slurry would significantly increase the total annual deliveries and kilometres performed in supplying the digester. If a 23 m^3 road tanker is used 4,500 vehicle deliveries and 90,000 kilometres would be performed per year; whilst if a 9 m^3 road tanker were used this would rise to 11,500 deliveries and 230,000 kilometres.

Table 10.4: Transport system requirements for animal slurry transported to a digester

Table Not Available Electronically

Assumptions made in the animal slurry transport system modelling are:

- annual requirement of 10,330 wet tonnes of animal slurry at a 0.1 MW digester and 103,300 wet tonnes at a 1 MW digester;
- animal slurry has a wet bulk density of 1000 kg/m^3;
- animal slurry is delivered to the station 50 weeks a year; in the initial run it is delivered 5 days a week and 10 hours per day;
- terminal time of 80 minutes per vehicle load for animal slurry (when using a 23 m^3 tanker);
- transport distance from farm store to centralised anaerobic digester in the initial run assumed to be 10 kilometres one way (i.e. 20 km per round trip);
- average trip speed for a 20 km round trip is 25 km/hour;
- road vehicle used for animal slurry transport in the initial run is a 38 tonne (GVW) articulated road tanker with a 23 m^3 tank;
- it has been assumed that the vehicles do not backhaul liquid digestate.

11. ENVIRONMENTAL IMPLICATIONS OF BIOMASS SCHEMES

11.1 Positive environmental impacts

There are a number of positive environmental impacts associated with the use of biomass fuel for electricity generation that make it an attractive energy source. Firstly, it is a more sustainable form of fuel than fossil fuel, as resources can be replenished in relatively short periods of time (such as in the case of short rotation coppice for example) or are available on a continual basis (such as animal wastes). In the case of some biomass fuels (such as straw, forestry residues and animal wastes), the use of these materials to produce energy represents the recovery of energy from waste.

Secondly, the increased use of biomass fuels (together with reductions in the use of fossil fuels) will help to reduce emissions of pollutant gases. Both acid rain levels, carbon dioxide and other greenhouse gas emissions can be reduced thereby ensuring UK compliance with the United Nations Convention on Climate Change. Biomass fuels have a neutral carbon balance; although carbon dioxide is released in the use of these fuels, as long as crops and trees are replanted as fast as they are used much of this carbon dioxide will be re-absorbed. These fuels also have very low levels of sulphur in comparison with fossil fuels thereby reducing acid rain (DTI, 1994).

Thirdly, the use of biomass fuels will help to ensure the security of fuel supply in the UK. By producing fuel in the UK, dependence on fuel imports will be reduced thereby giving the country more control over fuel supply (DTI, 1994).

Other benefits of biomass fuel include the social benefits of employment creation (both in constructing and operating power stations and also the related activities of growing, storing and transporting the fuel) and the role that planting new crops and trees can play in encouraging wildlife (Sage, 1994).

When legislation makes it necessary for a waste material to be treated, there can be environmental benefits from society's perspective if government issue clear regulations and guidelines as to how this will be achieved rather than leaving these decisions to the individual producing the waste. This approach helps to ensure that waste treatment is conducted in the required manner and that specified treatment quality standards are achieved. Therefore in the case of animal slurries, which can pose a significant health risk if allowed to enter water sources, there are environmental benefits associated with central processing of this waste, thereby removing the burden of waste treatment from the individual farmer.

Many of these benefits are identified by the UK Government in their Planning Policy Guidance 22 (PPG 22) which sets out the Government's advice on the issues to be taken into account in considering planning applications for renewable energy projects in England and Wales (and the equivalent document NPPG 6 for Scotland - SOED, 1994). In this publication it is stated that " renewable energy sources offer the hope of increasing the diversity and security of energy supplies, and of reducing harmful emissions to the environment. Technologies involving the conversion of waste to energy may help alleviate the problems associated with waste treatment and disposal" (DOE, 1993). In the annexes to PPG 22 the government state that "renewable energy sources can provide significant benefits for the rural economy" (DOE, 1994).

11.2 Negative environmental impacts

The use of biomass fuel for electricity generation could result in several negative environmental impacts. These impacts need to be considered in assessing the relative merits of any specific biomass scheme that has been proposed. In PPG 22 the government recognises that renewable energy sources may have negative environmental impacts, "sites proposed for the development of renewable energy sources will often be in rural areas or on the coast, and such development will almost always have some local environmental effects. The Government's policies for developing renewable energy sources must be weighted carefully with its continuing commitment to protecting the environment" (DOE, 1993).

PPG 22 outlines some of the negative impacts that local planning authorities should address in considering an application. These include instances in which proposed developments will:

- affect archaeological remains, listed buildings and conservation areas;
- affect agricultural land quality, water resources and nature conservation;
- create significant noise;
- result in the release of harmful substances to the environment;
- have traffic implications for the surrounding area.

In specifically addressing schemes involving energy from waste combustion (this includes straw, wood fuel and anaerobic digestion) the policy guidance document highlights the following important points and recommendations (DOE, 1994):

- In terms of power station siting issues the relevant planning considerations are mainly the same as for other industrial schemes. However the siting of the power station should be close to the source of the fuel to minimise the adverse environmental effects of transport. As schemes will require sizeable buildings, sites such as industrial or trading estates, close to settlements may in many cases provide the most suitable development location. The most acceptable location for centralised anaerobic digesters will be beside existing industrial estates or waste water treatment works. Site access issues and visual impacts in connecting to the electricity grid should also be considered.

- The power station will add a prominent feature to the landscape, so a high standard of design and landscaping should be used to minimise visual impact.

- Local planning authorities should not duplicate the functions of Her Majesty's Inspectorate for Pollution (HMIP), and therefore if the power station gains HMIP acceptance with respect to air pollution levels then planning authorities should accept this. However a proposed scheme which complies with HMIP licence requirements could still give rise to odours. This could emanate from the chimney or vents, open air storage, handling or transport of the fuel. Consideration should therefore be given to the effects of odour on housing and other odour sensitive land uses close to the site. Odour consideration is especially relevant in the case of animal wastes.

- Dust could be created during processing and ash handling. This is best controlled by minimising open air storage, water sprinkling, and covering transport vehicles.

- Water may be affected by certain liquid effluents created by particular processes. Main sources of effluent will be cooling water and surface run off.

- Landscape considerations should be taken into account in the case of coppice and other fuel sources grown specifically for energy generation. Careful design can ensure that the fuel is in keeping with the surrounding landscape.

- ➢ Noise associated with waste wood collection will be comparable to, or less than that associated with existing agricultural practices. Coppice offers noise reduction benefits over other arable crops as it is only harvested every 3 to 5 years. Chipping of forest residues is a noisy operation and planning authorities could therefore impose working hour restrictions on this.

The production and supply systems for biomass fuels have a number of additional negative environmental impacts which need to be taken into account. These include factors such as the:

- fuel consumed in mechanically harvesting, processing, handling and transporting the fuels from farms and forests to power stations;
- fire risks associated with large stores of highly combustible materials;
- effluent run-off from stores;
- health risks associated with mould growth during storage;
- environmental impacts associated with transport movements including vehicle pollutant emissions, vehicle noise and the addition to existing traffic levels that a biomass scheme will result in, and hence the increased potential for road traffic accidents.

Many of the negative environmental impacts discussed above will manifest themselves at a local scale. Negative local environmental impacts of any biomass scheme will be dependent upon the specific location and scale of that scheme. The physical and human geography of the site and its surrounding area (in terms of its natural physical features such as the topography, geology and ecology, the population density, existing land use patterns, road infrastructure and traffic flows) will determine the significance of this impact. Therefore such negative impacts must be considered in relation to a specific site and catchment area over which the biomass fuel will be sourced.

11.3 Environmental impacts of transport and logistics activities

11.3.1 Methodology

There are a variety of techniques available that can be used to help in considering the environmental impacts of human activities. Many of the detrimental environmental effects of a project usually originate "on site". Good design, operating procedures and mitigating techniques can often reduce their impact on the local environment.

Shopley and Fuggle (1984) suggest it is possible to distinguish eight categories of environmental impact analysis:

1) ad hoc approaches
2) checklists
3) matrices
4) networks
5) overlays
6) modelling procedures
7) evaluation techniques
8) adaptive methods

We have adopted a system that takes elements from the checklist and matrix approach in order to produce an essentially qualitative review of environmental impacts.

We have identified the following categories of impact:

- Noise
- Fossil fuel use and emissions

- Health and safety issues (i) for workers (ii) for the public
- Visual intrusion
- Water pollution
- Traffic generation

For each potential impact we have considered the following aspects:

- Importance
- Probability
- Time of occurrence
- Duration

11.3.2 Forest fuel

Using forest residues and thinnings for producing energy will mainly involve the further development of existing supply chains designed to extract wood from forested areas.

Noise

The main sources of noise within the forest supply chain are:

i) cutting/harvesting operations
ii) forwarder and skidder operation
iii) chipping at forest landing OR
iv) chipping at intermediate store or power station
v) transport operations

Activities i,ii and iii all take place in the forest and cannot be regarded as a significant addition or change to current forestry operations. These activities will take place throughout the year although there are periods during the year when activity is reduced (e.g. as a result of weather and/or ground conditions). Chipping at an intermediate store or the power station would produce noise and whether this matters depends largely on whether the location is near where people live or work.

Fossil fuel use and emissions

Most use of fossil fuel and the resulting emissions occur through the use of:

- harvesting and forwarding within the forest
- chipping
- lorries collecting/delivering chips or residues

Health and safety issues

For workers: The main risks arising for workers arise from the hazardous nature of forestry operations. these risks are independent of the final use of the forest residues so using residues for energy production cannot be said to give rise to any additional risk.

It is not clear whether chips can give rise to health hazards through spore production and therefore the precautionary principle is likely to be adopted and it will be necessary to ensure adequate protection of workers.

For the public: The forestry activities themselves give rise to hazards for members of the public using forest tracks (e.g. walking and riding). Signs are erected to advise the public that harvesting and extraction are in progress and there are no major differences between the supply system that would apply for wood being used to produce energy and that which prevails at present. Spores could also affect the public as well as forestry workers.

Visual intrusion

The main impacts will arise from storage facilities and the power station. The visual intrusion caused by storage is influenced by the height of the pile. Current thinking and experiments suggest this will not be a major problem as wood chip piles will not be any higher than three to five metres.

Concerning the power station, it is the type and size that will have the main impact. For example, if the power station is a gasification plant then there will be no need for a high chimney and therefore visual impact is likely to be less than in the case of a thermal power station.

Water pollution

Water pollution could occur from run-off from the stored chips. The likelihood and the significance of this type of damage still need further exploration.

Traffic generation

Large vehicles are already used to haul timber from forests to the point of use. There would be no major differences with the extraction and subsequent transport of forest residues. It would represent an additional volume of traffic and in some cases this could be traffic on roads that are subject to pressure from seasonal traffic or present travel difficulties in winter. However, the main implication of this is for planning of the supply chain system rather than in the environmental impact of the additional vehicle movements.

The concentrated nature of the production and the sparse road network means that the traffic flows will be over a relatively small number of roads.

11.3.3 Short rotation coppice

Noise

For the purposes of this study our interest in short rotation coppice begins at the time of harvesting. Before, during and after planting there will be activities that give rise to noise. There is no evidence that the activities will be exceptionally noisy or take place at such a time or be of such duration that they will be significantly different to any other noises caused by agricultural activities.

Harvesting the coppice is a noisy activity and harvesting will typically take place during the winter months. It is possible to distinguish two scenarios regarding the duration of higher noise emissions:

i) the grower owns the equipment and fits in harvesting activities around other tasks and in such a way as to take advantage of firmer ground conditions. In this case the harvesting activity may be spread out over a period of two months and occur for a short period on any one day.

ii) the capital cost of the harvesting equipment may encourage a cooperative strategy and/or the use of contractors. Where this is the case then the harvesting operation will be of greater intensity and the noise from harvesting will be for only one or two days at a particular site.

The duration and nature of noise will vary depending whether coppice is harvested using a direct cut and chip machine or a stick harvester.

If the coppice is harvested as sticks it may then be chipped at:

- the farm store
- an intermediate store
- the power station

In each case there will be noise impacts from the chipping activity but the degree of importance, the duration of operations and the number of people that may be affected will be different for each strategy. Given that coppice harvesting is a winter activity, unlike forage and combine harvesting which take place in summer and autumn, this may lessen the noise impact because people are more likely to be indoors with windows closed in winter.

Fossil fuel use and emissions

Most use of fossil fuel and the resulting emissions occur through the use of:

- harvesting machinery
- tractors, trailers and loaders
- lorries delivering the chips or sticks to the power station
- chipping machinery
- drying or ventilating (if used)

Unlike straw, coppice will be grown specifically for energy use and the activities associated with its supply are therefore an addition rather than a replacement of other activities. It is worth noting that harvesting only takes place every three to five years compared with other agricultural activities many of which have an annual cycle. There are however, no special features of the supply chain for coppice that give rise to an exceptional use of fossil fuel or that result in significant emissions; it is simply another agricultural activity.

Health and safety issues

For workers: Main implications are from the use of machinery in harvesting and from transport operations. Unloading can lead to risks associated with tipper lorry stability and this means that unloading areas will need to be correctly designed, built and maintained.

There may also be risks associated with dust from the chips and potentially hazardous spores that could develop during storage.

For the public: Concern about health and safety means that all tipper lorries carrying chips will need to be sheeted. Where coppice is transported on public roads as sticks then sheeting and/or covering may not be practicable and this will need to be considered when planning the supply system.

Visual intrusion

The main impacts will arise from storage facilities and the power station. The visual intrusion caused by storage is influenced by the height of the pile. Current thinking and experiments suggest this will not be a major problem as wood chip piles will not be any higher than three to five metres. If covered buildings are used for storage then these are likely to be buildings that already exist as it would be too expensive to construct new buildings specifically for storage of chips.

Concerning the power station, it is the type and size that will have the main impact.

Water pollution

Water pollution could occur from run-off from the stored chips. The likelihood and the significance of this type of impact require further study.

Traffic generation

It has been estimated that a power station large enough to supply Tiverton with electricity (12,000 inhabitants, 8 MW power station requiring 100,000 tonnes of fuel a year) will require 14 inbound lorry movements each day to fuel the power station (ATB Landbase, 1995).

But the type of road network is going to be important. Coppice will be grown across a wide area of the country and in some cases harvesting will take place in relatively inaccessible areas. The systems will require the use of large vehicles and often the economics are such that wherever possible the largest vehicle possible should be used. In some instances this will mean that additional 38 tonne lorries are operating on small country roads (this size of lorry is already using such roads for other farm transport such as beet and feed). This may lead to seasonal problems. For example, in the south west there may be difficulties during hard winter conditions but probably of greater significance will be the increased level of summer traffic in certain areas and this may affect the productivity of transport within the system.

11.3.4 Straw

Noise

Noise within the straw supply chain will be associated mainly with the activities of processing (baling), loading and unloading, and transport. Much of the noise happens already since there are already established supply chains involving straw and these activities form a normal part of the rural environment. Baling, in-field transport, loading/unloading, and transport to a store take place during a relatively short period in late August or September (depending on weather and region). Contractors try to complete the work as rapidly as possible and this means long working hours (sometimes beyond sunset).

The duration of noise from transport operations will be rather different. Transport from a farm store or an intermediate store to the power station will take place throughout the year in most systems and therefore the noise from vehicles will also occur throughout the year. However, hours of operation are likely to be restricted and the numbers of vehicles will vary depending on the size of the scheme (see examples in section 10.4).

Emissions and fossil fuel use

The main consumption of fossil fuel and the main source of emissions will be caused by the use of:

- tractors: for baling, in-field transport, transport to local store
- handling equipment: in field and at farm and intermediate store
- lorries: transport from farm store to intermediate store and from store to power station

Levels of emissions will be no higher than for other farm and transport activities. The nett effect is probably to leave total fossil fuel use and emissions largely unchanged given the scale of operations we are discussing.

Health and safety issues

For workers: Main risks for health and safety come from the machinery used to bale and collect the straw and the need to stack the bales up to nine high for optimum storage arrangements. We are not aware that there is any evidence of a greater number of accidents arising from the supply chains that would be encountered in supplying straw for generating electricity than in the case of supplying straw for other uses. Nevertheless there are important health and safety considerations that need to be addressed especially in roping and (possibly covering) the high loads associated with straw carrying vehicles.

There may be a risk associated with dust from the various processing tasks and also with mouldy straw from deterioration in storage.

For the public: Main risks are those associated with vehicle accidents, but since most of the straw would have been used somewhere in any case this cannot really be seen as an additional risk. There may be some, as yet unidentified, risks to the public associated with the storage of straw but we are not aware of any.

During storage of straw there will be a fire risk. Unintended fires lead to particulate/smoke emissions. This is true of forest fuel, coppice and miscanthus as well as straw stacks.

Visual intrusion

Operating an efficient supply chain demands that straw is stored in very large stacks. These could be considered unsightly. The power station itself will give rise to some degree of visual intrusion - the extent will depend upon the size, type and detailed design.

Water pollution

Risk and environmental impact associated with water pollution seems minimal.

Traffic generation

The straw supply systems described and documented earlier in this report will all give rise to traffic movements involving heavy goods vehicles. A 20 MW power station will require about 150,000 tonnes of straw a year; this would require 40 full vehicle loads a day (assuming 250 working delivery days - see section 10.4). As a proportion of existing traffic flows this additional volume is unlikely to be judged to be significant. Nevertheless we have to bear in mind the types of road being used and the rural nature of the area in which straw fired power stations will be sited and that people do live along these roads.

Traffic counts and studies from planning applications (see section 11.4) suggest that the impact of additional vehicles is limited and that in most cases maximum size lorries are already used extensively for grain collection and other agricultural activities in the areas where we are likely to see straw fired power stations used. It is worth noting that the place where the lorries are kept will need to be specified as an Operating Centre and covered by an Operators licence.

The Transport Act 1968 created a system of licensing ('quality licensing') with the potential to hold operators to high safety and environmental standards. Anyone operating HGVs is required to hold an operator's licence (O-licence), granted by the Traffic Commissioners to those of good repute. Since 1984 Local Authorities have had the right to object to O-licences if a depot is, or would be, damaging to the local environment. In addition, members of the public living in the vicinity of an Operating Centre (the site specified on the O-licence as being where the vehicles are kept) has the right to make representations to the Traffic Commissioners. These representations could apply to the grant/issue of a new O-licence or the renewal of an existing one. Representations could be made on the environmental grounds such as concern about noise and emissions. As a result of the representations the Traffic Commissioner may decide not to grant an O-licence or the licence may be granted but with restrictions (for example, limits to the hours of use of the site).

11.3.5 Animal slurries

Materials originating from agricultural premises are not classed as controlled waste in the Waste Management Licensing Regulations. Therefore animal wastes are not controlled wastes, the plant does not require a waste disposal licence and the transporter (or supplier) of fuel would not need to be a licensed carrier. However, industrial waste will be a controlled waste and therefore a licence may be required for moving and spreading treated waste from the CAD plant (WS Atkins, 1995).

Noise

The main sources of noise will arise from transport operations. Other activities such as loading and discharge of the material are unlikely to generate significant noise levels.

Fossil fuel use and emissions

Animal waste will be transported by road in heavy goods vehicles and a compromise will be necessary between the economies of scale of using the largest vehicles and the problems of accessibility and manoeuvrability that may be encountered in operating large vehicles in rural areas with narrow lanes.

Health and safety issues

There is a risk of contamination from the vehicles carrying the wastes as they contain odorous substances and pathogenic microorganisms. There is also a risk of release to the atmosphere in the case of an accident.

No releases are likely from enclosed tankers. However, tankers will require washing to remove external slurry and tanker drivers will need to be trained about the hazards from slurry and suitable protective clothing issued.

If the vehicles are not washed then there will be an unacceptable level of dust and dirt deposited along the routes taken by the lorries.

Unloading tankers can cause odour release, dust and aerosol formation. Use of a dedicated reception building maintained under negative pressure will help prevent release of odour, aerosol, dust and ammonia (WS Atkins, 1995).

Visual intrusion

The CAD plant will give rise to some degree of visual intrusion. This will, as in the case of power stations, depend on its size together with its design and siting.

Storage tanks will be required on farms to hold the waste. In some cases these will be present already, while in others they will need to be built. In many cases increasingly stringent controls designed to prevent accidental discharge of slurry mean that storage facilities on farms would, in any event, have had to be developed and improved whether or not the material is to be used in a CAD.

Water pollution

Water pollution could occur if there is a leak of waste from the storage point on the farm or from the vehicle (e.g. if there were an accident). Rain water could also cause run-off and this could lead to contamination of water courses. However, the risk of water pollution arising from accidental discharge from slurry lagoons and tanks exists at present. Any additional risks arise as a result of the additional transport of the wastes to and from a CAD plant.

Traffic generation

Given the low energy content of one tonne of animal waste even a small CAD plant will give rise to a large number of vehicle loads of waste. A 1 MW CAD plant will require about 18 to 20 deliveries per day (assuming a five day delivery week and a 23 m^3 road tanker - see section 10.6). This scale of operation will in many cases lead to some opposition at the planning stage for a CAD plant.

Waste that originates from dairy farms in the west of Britain will need to be transported along small roads and lanes. In some cases these roads are congested in the peak summer months and in the winter there may be problems arising from the weather.

However, it is important to keep the scale of increase in proportion. In many cases dairy farms already have a tanker calling every one to two days to collect milk. Slurry collection from the farm would take place less frequently than this.

11.4 Energy analysis and the logistics energy ratio

An important consideration in the use of biomass fuel to generate electricity is the amount of fossil fuel (i.e. non-renewable fuel) that is consumed in the supply of the biomass to the power station. Clearly if the energy value of the fossil fuel used is greater than the energy value of the biomass then there would be no benefit in using biomass fuels in this manner (there would in fact be a net energy loss if this was the case). Research has already been conducted into the total energy ratio for coppice, which has considered the following forms of energy consumption that occur in the supply of this fuel (Matthews et al, 1994):

- direct energy costs due to fuel consumption (i.e. fuel use by machines and equipment supplying the biomass);

- indirect costs due to materials consumption (i.e. energy used in producing materials used in producing biomass such as pesticides, fertilisers, twine, supply and production of diesel etc);

- indirect costs due to consumption implied by the use of machinery with a finite life span (i.e. the energy required to manufacture the machines and equipment used in supplying biomass such as tractors and road transport vehicles).

It is beyond the scope of our work to consider the latter two forms of energy consumption in supplying biomass fuel. However the Supply Chain Option model produces output from which it is possible to calculate the direct energy costs of the biomass supply system due to diesel fuel consumption by vehicles and equipment used to harvest, handle and transport the fuel to the power station.

In the sections presented below for each biomass fuel, the direct energy used in all the activities required in the supply of biomass from the point of harvest through to the point of delivery at the power station has been calculated for the lowest delivered cost base case supply system for each biomass fuel. We have referred to this as the "logistics energy ratio". It is important to note that these calculations do not take account of direct fuel consumption in growing the biomass or at the power station post-delivery of the biomass.

In the calculations the following assumptions have been made:

- for agricultural and forestry equipment, a diesel engine will consume 0.3 litres of diesel fuel per kilowatt per hour and this equipment will typically work at 60% of its maximum rated power;

- the road transport vehicle used in straw transport will consume diesel fuel at a rate of 0.35 litres per kilometre;

- the road transport vehicle used in coppice, forestry and animal slurry transport will consume diesel fuel at a rate of 0.39 litres per kilometre;

- road transport distance is 40 kilometres from farm/forest to power station (i.e. 80 km round trip) as in the base case supply systems defined in chapters 4 to 8;

- when using their engines but not actually driving to the power station (i.e. during the coupling of trailers, discharging loads and filling and discharging slurry from vacuum tanks) road transport vehicles consume 14 litres of fuel per hour;

- oil consumption is not included in the calculations.

In reality the fuel consumption of a road transport vehicle will depend upon a number of factors including the weight of the load carried, the gradient of the roads travelled on, the speed at which the vehicle travels and the evenness of the journey (i.e. the extent to which the vehicle has to stop and start due to other traffic, junctions, traffic lights etc). However it has been necessary to make the simplifying assumptions given above for the purposes of this work.

Tables 11.1 and 11.2 show the hourly fuel consumption of the various equipment used in supplying biomass fuels from farm/forest to power station.

Table 11.1: Agricultural and forestry equipment fuel consumption

Equipment	Power rating (kW)	Fuel consumption (litres/hour)
Agricultural tractor	85	15.3
Agricultural tractor	110	19.8
Front end loader	75	13.5
Forage harvester	250	45.0
Rape swather	50	9.0
Forwarder	80	14.4
Grapple crane*	80	14.4

NB * taken from Mitchell et al, undated.

Table 11.2: Road transport vehicle fuel consumption

Road transport vehicle	Fuel consumption when on the road (litres/km)	Fuel consumption when working off road (litres/hour)
Articulated flatbed	0.35	14.0
Articulated tipper	0.39	14.0
Articulated tanker	0.39	14.0

Forest fuel - supply system D

It is important to note that, as the Supply Chain Option model does not concern itself with the harvesting and extraction systems for forest fuel supply, the energy analysis for forest fuel is from the point at which the fuel is at the forest landing through to delivery to the power station. In forest fuel supply system D it would also be necessary to process the forest fuel in a centralised chipper at the power station; the fuel consumption of such a chipper has not been included in the fuel consumption calculations given below.

Activities other than road transport

Activity	Machine used	Litres used per hour (per km for road transport)	Hours per tonne of dry matter	Litres per tonne of dry matter
Loading residues to articulated trailer	Grapple crane	14.4	0.0926	1.33
Coupling up the trailer	Articulated road tipper	14.0	0.0171	0.24
Unloading residues from articulated trailer*	Grapple crane	14.4	0.0329	0.49

* Assumes use of small independent grapple crane but in reality this is likely to be undertaken by a large fixed crane at the power station.

Road transport activities

Activity	Vehicle	Round trip distance (km)	Litres per kilometre	Load carried (t DM)	Litres per tonne of dry matter
Road transport to the power station	Articulated road tipper	80	0.39	9.7	3.20

Therefore by adding the fuel consumption of the all the activities together we derive a diesel fuel use in supplying one tonne of dry matter of forest fuel to a power station of 5.3 litres.

Short rotation coppice - supply system A

Activities other than road transport

Activity	Machine used	Litres used per hour	Hours per tonne of dry matter	Litres per tonne of dry matter
Harvesting	Forage harvester	45.0	0.0412	1.85
Collecting chips in tractor and trailer	Agric.tractor and trailer (85 kW)	15.3	0.0412	0.63
Transport to farm store	Agric.tractor and trailer (85 kW)	15.3	0.0842	1.29
Unloading at farm store	Agric.tractor and trailer (85 kW)	15.3	0.0337	0.52
Stacking chips at the store	Loader (75 kW)	13.5	0.0253	0.34
Loading road transport tipper	Loader (75 kW)	13.5	0.0253	0.34
Self unloading tipper at power station	Articulated tipper	14.0	0.0072	0.10

Road transport activities

Activity	Vehicle	Round trip distance (km)	Litres per kilometre	Load carried (tonnes DM)	Litres per tonne DM
Road transport to the power station	Articulated road tipper	80	0.39	11.6	2.70

By adding the fuel consumption of the all the activities involved in supplying coppice together we derive a total diesel fuel use of 7.8 litres per tonne of dry matter.

Straw - supply system D

Activities other than road transport

Activity	Machine used	Litres used per hour	Hours per tonne of dry matter	Litres per tonne of dry matter
Baling	Tractor and baler (110 kW)	19.8	0.0588	1.16
Collecting bales in the field	Agric.tractor and bale collector (110 kW)	19.8	0.0196	0.39
Transport bales to farm store	Agric.tractor and bale collector (110 kW)	19.8	0.0599	1.19
Unloading bales at farm store	Agric.tractor and bale collector (110 kW)	19.8	0.0078	0.15
Stacking bales at the store	Loader (75 kW)	13.5	0.0235	0.32
Loading road transport flatbed	Loader (75 kW)	13.5	0.0235	0.32
Unloading road transport flatbed at power station	Loader (75 kW)	13.5	0.0196	0.26

Road transport activities

Activity	Vehicle	Round trip distance (km)	Litres per kilometre	Load carried (tonnes DM)	Litres per tonne DM
Road transport to the power station	Articulated flatbed vehicle	80	0.35	11.0	2.55

By adding together the fuel consumption of the all the activities involved in the above straw supply system we derive a total diesel fuel use of 6.3 litres per tonne of dry matter delivered to the power station.

Miscanthus - supply system B

The data given in the tables below is for the system in which miscanthus is cut and then later baled.

Activities other than road transport

Activity	Machine used	Litres used per hour	Hours per tonne of dry matter	Litres per tonne of dry matter
Cutting	Rape swather	9.0	0.0250	0.23
Baling	Tractor and baler (110 kW)	19.8	0.0588	1.16
Collecting bales in the field	Agric.tractor and bale collector (110 kW)	19.8	0.0196	0.39
Transport bales to farm store	Agric.tractor and bale collector (110 kW)	19.8	0.0403	0.80
Unloading bales at farm store	Agric.tractor and bale collector (110 kW)	19.8	0.0078	0.15
Stacking bales at the store	Loader (75 kW)	13.5	0.0235	0.32
Loading road transport flatbed	Loader (75 kW)	13.5	0.0235	0.32
Unloading road transport flatbed at power station	Loader (75 kW)	13.5	0.0196	0.26

Road transport activities

Activity	Vehicle	Round trip distance (km)	Litres per kilometre	Load carried (tonnes DM)	Litres per tonne DM
Road transport to the power station	Articulated flatbed vehicle	80	0.35	12.8	2.20

By adding together the fuel consumption of the all the activities involved in the above miscanthus supply system we derive a total diesel fuel use of 5.8 litres per tonne of dry matter delivered to the power station.

Animal slurry - supply system D

Activities other than road transport

Activity	Machine used	Litres used per hour	Hours per wet tonne	Litres per wet tonne
Filling road tanker at farm	Articulated road tanker	14.0	0.0333	0.46
Discharging at anaerobic digester	Articulated road tanker	14.0	0.0167	0.24

Road transport activities

Activity	Vehicle	Round trip distance (km)	Litres per kilometre	Load carried (wet tonnes)	Litres per wet tonne
Road transport to the power station	Articulated road tanker	20	0.39	23	0.34

By adding together the fuel consumption of the filling/discharging and trip to the digester we derive a total diesel fuel use of 1.0 litre per wet tonne of animal slurry delivered.

Discussion of the logistics energy ratio

From the fuel consumption analysis for the activities that occur in supplying biomass fuels to power stations it is possible to calculate the logistics energy ratio (i.e. the comparison between the fuel inputs used in supplying the biomass fuel and the energy value of the biomass fuel).

Table 11.3 shows the logistics energy ratio for forest fuel, coppice, straw, miscanthus and animal slurry. This shows that the energy ratio of the energy benefit of biomass compared with the energy cost in the logistics of supplying fuel is extremely positive. Any result of greater than one indicates that from an energy perspective the biomass system would be worth operating.

The road transport distance over which the biomass fuel is supplied will have an important effect on the logistics energy ratio. As distance increases, fuel consumption per tonne delivered also increases thereby reducing the logistics energy ratio. For example in the case of the straw system a doubling of transport distance to 80 kilometres (i.e. 160 km round trip) would reduce the energy ratio to 51 (from 73).

Whilst transport distances will vary significantly from one source (i.e. farm or forest) to another and from one biomass scheme to another, the other activities and the manner in which they are performed is unlikely to change greatly and therefore the energy use associated with each of these activities will remain relatively stable.

Table 11.3: Logistics energy ratios for biomass systems modelled

Biomass Fuel Type	Total Energy Benefit (net calorific value in GJ per delivered tonne of dry matter)**	Logistics Energy Cost (i.e. diesel fuel consumption in GJ per delivered tonne of dry matter)***	Logistics Energy Ratio
Forest fuel (system D)	17.4	0.19****	91
Coppice (system A)	16.6	0.28	59
Straw (system D)	16.6	0.23	73
Miscanthus (system B)	16.0	0.24	65
Animal slurry (system D)*	0.6	0.04	17

N.B. * Calculations for animal slurry are based on cow slurry and "Total Energy Benefit" and "Logistics Energy Cost" figures are per wet tonne of slurry delivered (not per tonne of dry matter as for the other biomass fuels - see Appendix 9 for further details).

** Whilst straw and miscanthus have a net calorific value of approximately 17 GJ per dry tonne and forest fuel and coppice have a value of approximately 19 GJ per dry tonne, although our systems are based on a tonne of dry matter delivered to the power station, this fuel is wet and the final net calorific value as shown in the table is lower than this due to some of the energy released during combustion being dissipated in evaporating excess moisture (see Appendix 9 for further details).

*** Assuming that 1 litre of diesel fuel has a net calorific value of 36 MJ (i.e. 0.036 GJ).

**** This figure does not include the fuel consumption associated with forest fuel harvesting and extraction systems, nor the fuel required for centralised chipping at the power station. It is therefore an underestimate of the total energy used in supplying forest fuel.

The energy cost shown in Table 11.3 only refers to the direct energy use in supplying fuel from the point of harvesting through to delivery at the power station, and that the supply systems examined in this report do not use covered stores or electricity to dry the fuel during storage. Nor does it include direct fuel consumption in growing the biomass or at the power station after delivery of the biomass. Additionally it does not take account of the indirect energy costs due to materials consumption or indirect energy costs due to consumption implied by the use of machinery with a finite life span.

Research undertaken into the total energy ratio for short rotation coppice indicates an energy ratio of significantly greater than 1 and, typically, values near to 30 (Matthews et al, 1994). In this work it was shown that the indirect inputs of energy due to the consumption of materials account for almost 60% of total energy costs.

11.5 Environmental impacts: insight from planning applications

As already discussed in section 10.1, we have collected planning applications from a number of proposed biomass schemes in order to obtain a greater understanding of the transport and logistics supply systems planned by station developers. From these planning applications we have also obtained further information about the likely environmental impact of biomass schemes.

This section contains information taken from planning applications on the following two considerations:

- environmental objections by individuals and interest groups to biomass schemes

- environmental assessment of predicted traffic-related impacts for a proposed biomass power station

The information about environmental objections to a proposed scheme is taken from one particular application, whilst the environmental statement is taken from a different biomass proposal.

11.5.1 Environmental objections and reservations

In the case of one planning application made to a local authority for a straw-fired power stations a large number of objections were raised to the proposal. These objections were raised by a very wide range of concerned groups such as parish councils, environmental groups, local community organisations and pressure groups. Below are listed some of these objections raised at the time the proposal was being considered; we have divided these into two types of objection: objections to the power station and objections to the logistics and transport supply system for the biomass fuel.

Whilst objectors to this particular scheme did not generally attempt to quantify the environmental impact associated with their objection (and in many cases the impact may have been negligible) it is interesting to note the diversity of concerns held by the public and interest groups. This reflects that, although the public may support the use of electricity generation from biomass fuel at a national level, they have a wide range of reservations when the development of such schemes will result in them being personally affected at a local level (see section 11.6 for further discussion of public perception of biomass).

Power station related objections and reservations

- Noise from the power station;
- Stack emissions;
- The water requirements of the power station would reduce local availability;
- The visual impact of the buildings;
- The proposed landscaping would be ineffective;
- Possible presence of silica in the fly-ash and its health effects;
- The chosen location for the power station was not sufficiently remote from local housing;
- The power station would be a low employment generator compared with other types of development;
- The power station would affect the possibility of attracting other employers to the area;
- Unknown health risks associated with long term pollution hazards.

Logistics and Transport related objections and reservations

- The number of lorry movements spread over six working days per week;
- The number of lorry movements through local centres of population;
- The increased risk of traffic accidents;
- CO_2 emissions from long term, long distance haulage;
- Approach roads to the power station would be through some local towns and villages and would be unsuitable for lorry movements;
- Pollution, noise and vibration would be suffered by settlements located along the lorry routes;
- The traffic generated by the scheme would affect holiday traffic in the summer months;
- Pollution problems from the storage of straw bales at farms and at the power station;
- Risk of vermin at straw bale stacks;
- Risk of fire at straw bale stacks.

Despite these objections the proposal was granted planning permission with certain conditions attached. These conditions were concerned with:

- Vehicle routing agreements;
- Construction of a roundabout near the power station for lorry access;
- Landscaping of the power station.

11.5.2 Assessment of predicted traffic-related impacts for a proposed power station

In the case of this planning application proposal for a biomass power station, the outcome of the evaluation undertaken on behalf of the applicant predicted that there would be no significant traffic-related impacts associated with the operational stage of the development. Below is a brief summary of the stages of the environmental assessment procedure and the findings of that assessment.

Generated operational traffic and traffic related impacts

It was calculated that the operation of the biomass power station would generate 32 car movements and 64 HGV movements per day. Therefore the increase in traffic flows resulting from the scheme were not considered to be significant (normally an increase in traffic flow of at least 50% would be necessary to warrant concern from the planning authorities).

From the calculations of traffic-related impacts resulting from these traffic levels, the proposal was shown to not significantly increase road traffic noise (i.e. the noise increase did not exceed the accepted threshold). The generated traffic levels were also found not to result in air pollution concentrations generally taken to be significant when assessing planning applications.

These operational traffic levels were not "predicted to have any significant traffic-related impacts in terms of noise, air pollution, HGV annoyance or vehicular, pedestrian or cyclist conflicts." Further details of the calculations undertaken can be found in appendix 14.

Discussion

This case study helps to illustrate that, although biomass power stations will increase traffic levels in the surrounding areas in which they are located, this increase is not likely to be considered significant. Therefore the environmental impacts resulting from this increase in vehicle traffic is also not likely to be considered significant.

The traffic flows generated by the proposed scheme in the case study are not dissimilar to those associated with other schemes which we have studied (see section 10.1). Therefore, although such biomass schemes do generate traffic and its associated environmental impacts, this is generally speaking unlikely to be considered significant by the local planning authority assessing an application. However the environmental impacts resulting from the transport of biomass will differ from scheme to scheme according to the specific location of the power station and its catchment area and each scheme must therefore be assessed on its own merits.

11.6 Public perception

As already discussed, although the use of biomass fuel to produce electricity is being promoted on environmental grounds (such as its renewable nature and its neutral carbon balance - see section 11.1), environmental impacts are caused by its production and supply to power stations. Public perception of these impacts is likely to prove to be an extremely important factor in the acceptability and development of biomass fuel.

In the initial phase of renewable energy development it appeared that these forms of electricity generation might avoid the difficulties encountered by fossil fuel and nuclear technologies in obtaining public support. Renewable technologies were not to be built on the same scale as these existing facilities and did not involve the same degree of environmental impact or risk. In addition, environmental pressure groups were supportive of renewable technologies and the role that they could play in reducing dependence on finite, and significantly more environmentally damaging, sources of electricity. However as renewable schemes have been proposed and established around the world it has become apparent that public opposition to such schemes does exist and can prove conflictual (Walker, 1995a).

Research has indicated that the consideration of the public's perception of biomass is also likely to be an important factor if the biomass industry is to gain the widespread support of the general population of the UK (Sadler, 1994). Whilst the public are likely to be supportive of biomass and other renewable energies at the national and global level, they are less enthusiastic at a local level, and that support can be eroded when specific proposals are unveiled. This is borne out by the public opposition in the UK to certain renewable schemes that have been proposed. Sadler's work has illustrated that one of the major concerns of the public about biomass fuel is the physical scale of biomass to electricity schemes and the effect that this will have on the "look of the landscape" (Sadler, 1994). Therefore the environmental impact of the biomass fuel itself is likely to be a major concern to many people. This work suggests that people also expect the fuel supply system to have detrimental environmental impacts. These include factors such as the visual impact caused by large storage facilities, the increase in freight traffic on minor roads, the noise involved in processing operations such as chipping, the energy used in supplying the biomass to power stations and the pollution occurring at the power station itself.

The environmental impacts associated with biomass schemes may lead to a conflict between the public's view of national interests and their perception of how they will personally be affected at the local level. Whilst research tends to suggest that the public are supportive of renewable energy and believe that it has an important role to play in national energy policy given the environmental benefits associated with its use in comparison with fossil fuels, it also indicates that they do not welcome the environmental impacts that they may experience in the course of their lives as a result of its implementation (Walker, 1995a).

Clearly it is important that the environmental impacts of using biomass fuel (both positive and negative) are carefully considered in any planning applications for such schemes. This should also occur at a strategic level in determining the role that biomass should play in future energy policy.

Public involvement in the planning and design of any scheme is also of importance. As one commentator has noted, "It is now widely recognised that the decision-making procedures employed in the siting of any kind of land use that has negative impacts on the local area are crucial in obtaining public consent. The `decide-announce-defend' approach to siting with minimal public involvement has been shown to repeatedly antagonise and create public mistrust, concern and ultimately conflict" (Walker, 1995a). A number of measures can be used to help facilitate public involvement. These include:

- involving the public in early consultation and discussion
- providing full and detailed information to the public
- establishing contacts and local committees
- joint Environmental Impact Assessment
- negotiated impact management agreements

It has been suggested that as renewable energy schemes increase in number and scale, the tensions between the attractions of this source of energy and the negative impacts associated with it could become significant blockages to further development (Walker, 1995b). It is important that the public are involved at an early stage in the biomass planning process and that schemes are carefully chosen and planned to minimise environmental impacts and disruption to local life.

12. CONCLUDING REMARKS AND RECOMMENDATIONS

There are substantial and significant attractions to the use of biomass as a fuel and these have been noted in many recent reports. But there is a striking problem to do with its use in a commercial and market driven context - it is very low value, bulky and expensive to handle and transport. As a result one of the key determinants for the success of biomass in the renewable energy programme will be whether those involved in fuel supply are able to efficiently manage the supply chain from the point at which the resource is grown or originates through to the power station.

By investigating the supply chains for different biomass fuels in considerable detail we have been able to demonstrate:

- the importance of logistics management to the supply chain cost;
- the need to think very carefully about the way in which transport is organised and the size and type of vehicle used;
- the interdependence of many of the activities within biomass supply chains.

An important benefit of investigating a range of different biomass resources has been that it becomes possible to see the way in which as an industry matures so the systems supporting the logistics and supply chains within the industry also mature. Thus it is clear that in the case of straw supply there are robust supply chain strategies already in existence and the scope for significant reductions in the delivered costs of straw will not really come from further development of these supply chain strategies but are more likely to come about because of external factors such as a change in the market demand for straw. By contrast where the industry is immature - as it is in the case of short rotation coppice - then there remains significant scope to reduce costs by improving and modifying the way the supply chain is operated and managed.

So while there may be very different equipment and players involved in the different biomass sectors there are some valuable lessons to be learnt by bringing the work together as we have done in response to the ETSU Project Brief.

12.1 Key decisions about activities in the supply chain and implications for costs

It has not been our aim at any point in the research to say that one biomass resource is "better" than another - although clearly there are significant differences in the delivered cost of each. In the same way it is necessary to be careful not to try to identify the single "right" way to organise the supply chain. What our work shows clearly is that there are some major cost differences that will result from organising the supply chain in different ways and anyone concerned with supplying or using biomass as an energy source needs to be aware of these differences.

All the supply systems modelled in this report are plausible and have the potential to be used in providing fuel for power stations. It is critical that a balanced fuel supply strategy is adopted that is capable of supplying the quantity of biomass required by the power station at the right time, at the right quality all year round. Therefore several different fuel supply systems are likely to have to be operated in providing fuel to the power station to ensure this security of supply. What is therefore important is not attempting to find the single lowest cost system, but instead determining the necessary systems to guarantee supply at all times and then attempting to minimise delivered costs for each of these systems.

The results in the report have indicated that the cheapest supply systems will often not be capable of supplying fuel all year round. The lowest cost options tend to involve on-farm or in-forest storage and there will be periods during the year that these stores will not be accessible due to weather and track surface conditions and other activities taking place on the farm or in the forest. Therefore use of intermediate stores with good quality access at all times will be necessary; supply systems involving intermediate storage will have higher delivered costs than on-farm/in-forest storage due to the double handling and road transport that they entail. However, given that they are necessary, what is important is how to operate and manage these systems to produce the lowest possible delivered cost.

Some supply systems are cost-effective from a harvesting perspective but these benefits will be lost during long-term storage due to significant rates of decomposition (e.g. direct cut and chip coppice harvesting). The use of expensive storage and drying systems to prevent/limit decomposition are extremely unlikely to be affordable for such a low value product. Instead of losing these benefits through dry matter losses during storage, it would be sensible for fuel produced from these harvesting systems to be delivered to the power station as soon as possible after harvest. Biomass harvested using other, more expensive approaches but which are better suited to long term storage (such as coppice stick harvesting systems) could be used to provide supply over the remainder of the year. In this way it is possible to maximise the benefits of each supply system.

If technologically feasible it would be worthwhile to consider establishing biomass power stations capable of using a range of different biomass fuels so that each could be used at the power station shortly after harvesting. This would remove the cost of storage facilities and the loss of useful energy that occurs when biomass decomposes.

In addition, it is also clear from the research that there is still much uncertainty over what amounts to "best practice" in the supply chains that have yet to form and develop. It is simply inappropriate to say that we can define best practice in the supply of miscanthus since there are still so many uncertainties connected to successfully growing it, its crop yield etc. But we can say that different supply chain configurations will have an important influence on these costs and we can and have illustrated the order of magnitude of the likely differences.

Decisions about appropriate techniques and approaches to activities such as harvesting, handling, storage and transport should not be made in isolation; it is essential to see the activity in the context of the entire supply chain if efficient operations are to be achieved. Optimising a single activity within the chain may have detrimental effects on the rest of the supply chain.

Delivered costs have been found to be relatively insensitive to transport distance for most of the biomass fuels studied in this project; this is true of forest fuel, short rotation coppice, straw and miscanthus. The results of the modelling show that a transport distance from farm/forest to power station of 80 kilometres (ie a round trip distance of 160 kilometres) will produce delivered costs that are only 5% to 15% greater than for a transport distance of 40 kilometres (round trip distance of 80 kilometres).

The delivered cost of animal slurry is more sensitive to transport distance than for the other biomass fuels studied. In these supply systems a transport distance of 20 kilometres is likely to result in delivered costs between 30% and 65% higher than when transporting the slurry 5 kilometres (depending upon the supply system used). This is explained by the proportion of delivered cost accounted for by transport activities in these supply systems (i.e. transport and handling are by far the most important costs in these systems, to a far greater extent than in supply systems for other biomass fuels).

However, although the modelling work undertaken suggests that delivered cost is relatively insensitive to the distance the biomass is transported for most fuel types, in order for biomass schemes to prove economic they must strive to produce the lowest delivered costs possible. Therefore by sourcing fuel from closer rather than more distant locations, cost savings can be achieved and these may prove to be crucial to the financial viability of generating electricity from biomass fuel.

Transport and handling activities account for a significant proportion of total delivered costs in the biomass supply chain (these two activities represent about 50% of delivered straw costs, 50% of delivered costs in forest fuel supply, 35% or more in coppice supply, 20% to 40% in miscanthus supply and almost all the delivered costs in animal slurry supply). It is therefore essential that transport and handling activities are operated and managed in an efficient manner. Achieving this will help in controlling delivered costs.

12.2 Environmental impacts

Using biomass to generate electricity leads to some positive environmental impacts and many of these benefits are listed in PPG 22 (NPPG 6 in Scotland). However there are also some negative impacts and these are concerned not just with the construction and siting of a power station but occur during the supply of the resource. The main impacts are:

- fuel consumed in harvesting, processing, handling, and transporting the biomass from farms and forests to the power station

- risks of fire associated with storage

- possible effluent run off

- health risks (mainly to workers) from mould growth during storage

- environmental impacts associated with transport movements including vehicle pollutant emissions, vehicle noise and the addition to existing traffic levels that result from a biomass scheme.

It is important to keep the transport implications (that lead to much of the negative impact) in perspective. The following table shows the likely traffic generation from different scales and types of power station development together with annual vehicle kilometres performed and fleet requirements.

Table 12.1: Road transport requirements for biomass power stations

Type and size of power station	Vehicle deliveries per day	Total annual vehicle kilometres supplying fuel to the power station	No.of road transport vehicles required
20 MW straw-fired	40	800,000	10
10 MW coppice-fired	24	480,000	6
1 MW anaerobic digester	18	90,000	4

But the precise details of the environmental impact will vary from scheme to scheme and will be influenced by the catchment area from which the biomass is sourced. This local level of impact assessment has been beyond the scope of the present study - what we can do based on the research is to note the implications both for the commercial success of schemes and for the environmental considerations. Catchments with a few large plantations (in the cases of SRC) or where the resource is available in large quantities from a small number of sites and where there is direct access to trunk roads, will have lower trip and hence delivered costs than catchments with poor access to the road network and small roads. This will also have implications for the environmental impact of a given supply network. The highest number of trips per day will occur near to the power station since this will be the focal point of the catchment area. However, greatest sensitivity to transport movements may occur near farms or forests where small roads are being used by large vehicles. Detailed questions of location and access will have major implications both for the commercial viability of schemes and also for their likely acceptability to local residents.

Our work has also demonstrated that the fossil fuel directly consumed in supplying biomass from the point of production to the power station will be significantly lower than the energy benefit of the biomass (we have calculated "logistics energy ratios" of between approximately 60 and 90 for forest fuel, coppice, straw and miscanthus - i.e. the energy value of the biomass is between 60 and 90 times greater than the fossil fuel directly consumed in harvesting, handling, processing and transport it to the power station).

12.3 Limitations and areas for further research

Given the differences in the supply chain requirements for each biomass fuel, it is not possible to develop a research and development strategy spanning all of them. Hence we cannot say that by concentrating on one aspect we will be able through R&D to drive down delivered costs for all biomass types. But by comparing the biomass resources in the manner we have it is possible to identify the way in which the relative maturity in different supply chain systems can help to reduce the costs incurred throughout the supply chain.

A further strength of the present study is the way in which it incorporates an entire supply chain perspective from the point of harvest through to delivery at the power station. By doing this it is possible to consider the interrelationship between all the activities necessary in order to deliver fuel in an efficient way to a power station and it is this need for a co-ordinated approach that will influence the operational and commercial viability of biomass fuelled power generation.

Despite the comprehensive nature of the research there are a number of areas that could be benefit from further work:

Planning and public participation - further work should be undertaken to help present and convey the positive and negative environmental impacts of biomass in a manner that is both understandable and helpful to the public. This is especially important in relation to transport and logistics impacts which, as this report has shown, are not likely to be very harmful but which are often perceived as severe by the public. Methods by which public involvement can be incorporated into the design and development of biomass projects should also be considered.

Management of the supply chain - this report has shown that an integrated approach is necessary in order to achieve supply chain efficiency. However further research needs to be conducted to establish who is best suited to take the lead in organising and managing the supply chain. Approaches to assisting the various supply chain parties (i.e. fuel suppliers, farmers, agricultural, forestry and transport contractors and power station operators) to reach consensus about supply chain issues would also be of merit. Given the lack of maturity of the biomass industry it is essential that all parties work closely together to generate ideas and appropriate working practices if it is to succeed. Partnerships and working alliances need to be established and encouraged; supply chain efficiency requires the active involvement and efforts of all parties.

Operational issues - there are several outstanding transport and logistics problems and hurdles that need to be overcome. Solving these problems will help to increase supply chain efficiency and reduce delivered costs:

- miscanthus harvesting and transport data (trials needed);
- dry matter losses during storage;
- mobile chipper productivity and the capital and running costs of large scale mobile chippers;
- productivity rates and operating costs of centralised chipping at the power station;
- transport and handling initiatives to allow for the efficient loading and movement of coppice sticks;

- Straw sheeting methods (important not in order to make the chain more cost effective but because at present covering loads is not a general requirement and if it were to become one, which seems likely when local authorities decide on planning applications, then it would significantly affect terminal time and would drive up the costs of what is at present an efficient system).

This report has shown that transport and logistics represent a significant proportion of total delivered cost in biomass supply and that costs of these activities can be reduced in a way which cannot necessarily be achieved in other cost areas (e.g. purchasing and harvesting costs). Mature supply systems such as those already operated in straw supply have proved that organising and managing the supply chain efficiently can result in low delivered costs. Therefore efforts should be placed on trying to achieve similar efficiency in transport and logistics activities in other less established biomass supply chains.

However transport and logistics efficiency should not be seen as the single key to achieving acceptable delivered costs. In the longer term, cost convergence with fossil fuel is important if biomass is to play a significant role in the renewable energy programme in the UK. But there must be some concern about how further cost reductions in mature supply systems such as straw can be achieved. Ensuring an efficient supply chain will not by itself be sufficient to achieve cost convergence.

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APPENDIX 1 LOGISTICS AND OTHER PARAMETERS/INPUTS USED IN FOREST FUEL SUPPLY

a. Price paid to producer

We have set the price paid to producer (in this case the forest owner) for residues/thinnings at £2.00 per tonne. This represents the money that will have to be paid for him to allow use of forestry material for biomass fuel. This payment will help the forest owner to cover the cost of forest road repair and compensate him for the loss of nutrients and matting that the material provided. It does not however include the cost of harvesting and extraction.

b. Harvesting and extraction costs

Harvesting and extraction costs used in our work are being taken from research already carried out for ETSU by Aberdeen University and from discussions with experts in the forestry industry. For the base cases, in systems A to D, we have used input costs of £10 per tonne of dry matter for the cost of harvesting and extracting the material to the forest landing. In system E, the terrain chipping system, we have also used an input cost of £10 per tonne of dry matter to represent the costs of harvesting, terrain chipping and forwarding chips to containers (see section on harvesting costs later in this Appendix for further details of these costs and the extent to which they may vary when using different harvesting systems).

In the sensitivity analysis we have explored the effect of alternative costs for different forestry harvesting and extraction systems on total delivered cost at the power station (see section k of this appendix for further details).

c. Storage at the forest landing

In systems in which forest storage is used the store has been assumed to be a heaped stack on the forest floor at a forest landing point.

Intermediate stores are assumed to have hard standing surfaces. Such stores could have concreted surfaced, being facilities which were originally built for another purpose (e.g. ex-airfield, factory site etc).

Given that forestry material will be used at the power station on a year round basis, significant quantities will have to be stored. We have assumed that the average storage period will be six months.

In the calculations it is assumed that unchipped material stored in the forest will not be subject to dry matter losses. It has also been assumed that the unchipped material will dry during storage (we have assumed that the moisture content of 50% at harvest will fall to 40% during storage - i.e. dry matter content will change from 50% to 60%).

All chip storage considered in the supply systems occurs at an intermediate store with hard standing. We have assumed that chips will decompose at a rate of 4% per month during storage. We have also assumed that the moisture content of chips will remain unchanged during storage (i.e. they will come out of store with the same dry matter content as when they went in).

d. Chipping of forest fuel prior to transport

Based on conversations with experts and data taken from the Forestry Authority work for ETSU we have assumed that a trailer mounted mobile chipper will chip forest fuel at a rate of approximately 15 wet tonnes (45 m^3/hour). In the model, residue is fed into the chipper by a small forwarder. It is assumed that chipping losses of 2% will occur. Operating costs for the trailer mounted chipper have been taken from research by Aberdeen University for ETSU (Mitchell and Hankin, 1993).

e. Road transport

Chip transport involving the loading of ready chipped material from a heap will make use of either a 38 tonne (GVW) articulated tipping vehicle or a 32 tonne (GVW) rigid tipping lorry.

Chip transport involving the chipping of forest fuel directly into an articulated trailer will require a trailer with a roof/hood or a conveyor to ensure that the chips are retained in the vehicle body. We have assumed that terrain chipping systems could involve the use of two 30 m^3 containers on a 38 tonne (GVW) articulated vehicle. The vehicle chassis would be fitted with lifting equipment so that the containers could be loaded and unloaded from the vehicle.

The transportation of unchipped material would be undertaken with an articulated tipping vehicle (this could be fitted with an on-board grapple but it is more likely that an independent grapple crane would be used to load the vehicle and this is what we have assumed in the system we have set up).

Road transport vehicle body volume will be as large as possible in order to ensure that as much forestry material is carried as possible in order to achieve as low unit costs for transport as possible. We have assumed that articulated vehicles will have bodies of up to 90 m^3 and that rigid tippers will have bodies of up to 65 m^3. However, whilst vehicles with bodies of 90 m^3 could be operated in forests with flat terrain and good quality forest roads without any difficulties, such body sizes may prove problematic in less flat forests such as Kielder and Scottish forests. In such cases it would be necessary to either use vehicles with lower deck heights to lower the centre of gravity, thereby improving vehicle stability or to use vehicles with smaller body sizes. Clearly using smaller body sizes will increase the unit costs of transporting forest fuel if the bulk density of the material is such that the vehicle payload cannot be reached.

By using the largest vehicle allowed it is possible to minimise trip costs, and therefore when purchasing vehicles specifically for biomass operations hauliers are likely to order the largest vehicles available that can operate in the manner required (i.e taking into account any physical constraints). However if a haulier already has an existing fleet of smaller vehicles (either in terms of gross vehicle weight or internal body volume), they may well choose to use these vehicles for biomass operations if they are not fully utilised in their existing activities.

f. Transport distance scenarios

In the base cases it has been assumed that the transport distance by road from the forest to the power station is 40 kilometres (one way trip distance). This distance has been modelled as, from discussions and interviews with prospective fuel suppliers, it would appear to represent the typical trip length in a biomass scheme. In addition the forest fuel will be have to be extracted from stump to forest landing/roadside. The cost of this forest extraction is represented by the harvesting and extraction costs used in the modelling. The extraction distance is typically 100 to 250 metres.

In supply systems A, B and D, the forest fuel is transported direct from the forest landing to the power station. In the case of supply system C the forestry chips are transported from forest landing to an intermediate store and then from the intermediate store to the power station and in system E the residues are chipped at stump and then transported directly from the forest to an intermediate store and then on to the power station after storage. These systems have all been assumed to take place in a forest such as Kielder with relatively long distances having to be covered on forest roads by road transport vehicles to get in and out of the forest.

The transport distances for the road transport stages of the forest fuel supply systems are shown in Table A.1.1.

Table A.1.1 Transport distance scenario for 40 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B and D	Supply system C and E
From forest landing (road transport)	Track	0.50	1.00
	Uncl.+ urban	29.50*	19.00*
	Single A/B	10.00	
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	10.00
	Single A/B	N/A	9.50
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		40.00	40.00

NB * 10 km on forest roads, the rest on minor public roads.

For the transport distance scenario of 20 kilometres from forest to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.1.2.

Table A.1.2 Transport distance scenario for 20 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B and D	Supply system C and E
From forest landing (road	Track	0.50	1.00

transport)			
	Uncl.+ urban	19.50*	14.00*
	Single A/B		
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	4.50
	Single A/B	N/A	
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		20.00	20.00

NB * 10 km on forest roads, the rest on minor public roads.

For the transport distance scenario of 80 kilometres from forest to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.1.3.

Table A.1.3 Transport distance scenario for 80 km trip (all figures are one-way distances in kilometres)

Stage	**Surface**	**Supply system A, B and D**	**Supply system C and E**
From forest landing (road transport)	Track	0.50	1.00
	Uncl.+ urban	29.50*	19.00*
	Single A/B	10.00	
	Dual A	40.00	20.00
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	10.00
	Single A/B	N/A	9.50
	Dual A	N/A	20.00
	M-way	N/A	

Total road transport distance (one way)		80.00	80.00

NB * 10 km on forest roads, the rest on minor public roads.

g. Loading and unloading road transport vehicles and securing the load

In systems A and C, in which the forest fuel is chipped directly to the articulated tipper trailer by a trailer mounted chipper, the trailer is filled with chips at a rate of 45 m^3/hour (with chipping losses of 2% of dry matter). We have assumed that it takes 10 minutes to drop off an empty trailer and couple up the road tractor and the full trailer awaiting removal, and a further 5 minutes to sheet the load. Unsheeting the load at the destination has been estimated to take 5 minutes and unloading the chips 5 minutes (achieved by tipping the vehicle or using a walking floor type system).

In system E, 30 m^3 containers are used to transport chips. The containers are left in the forest and filled by forwarders, extracting chips from stump. We have assumed it then takes 5 minutes to sheet the load and 20 minutes to load the containers onto the vehicle. Unsheeting the containers at the destination has been estimated to take 5 minutes and unloading the chips from the containers 20 minutes (assuming they are tipped by the vehicle one at a time).

When using a 32 tonne (GVW) rigid tipper to transport chips (system B), the chips are chipped to a heap before the arrival of the vehicle. The chips are loaded from the chip heap to the vehicle by a loader a rate of 240 m^3/hour (½ minutes per 2 m^3 bucketful). We have assumed it then takes a further 5 minutes to sheet the load. Unsheeting the load at the destination has been estimated to take 5 minutes and unloading the chips 5 minutes (achieved by tipping the vehicle or using a walking floor type system).

When transporting unchipped material (system D) we have assumed that the articulated tipper trailer used will be loaded by a grapple crane. We have assumed a loading rate for the grapple of 100 m^3/hour (i.e. it will fill and compact the load carried on a 90 m^3 vehicle in approximately one hour). The head of the grapple crane is used to compact the residue in the trailer thereby increasing the load size carried. We have assumed that it takes 10 minutes to drop off an empty trailer and couple up the road tractor and the full trailer awaiting removal, and a further 5 minutes to sheet the load. We have estimated that unsheeting also takes 5 minutes. We have assumed that unloading the vehicle at the power station with a grapple crane at the point of delivery will take 20 minutes.

At the power station the vehicles will have to be weighed and the fuel quality sampled while still on the vehicle. We have assumed that this will take 15 minutes per vehicle.

h. Chipping of forest fuel at the power station

In supply system D forest fuel is chipped at the power station in a centralised chipper. This cost is not included in the Supply Chain Option modelling.

i. Insurance of the fuel

Forestry fuel suppliers are likely to insure the material to financially protect themselves against losses due to fire in storage etc. We have used an insurance cost of £0.50 per tonne of dry matter per year. Therefore for a storage period of six months, insurance would cost £0.25 per dry tonne.

j. Forestry fuel bulk density and dry matter content

We have assumed that all the forestry fuel is harvested at 50% moisture content. If stored at the forest landing as unchipped residues, we have assumed that the moisture content will fall to 40% (i.e. 60% dry matter content) after 6 months storage. If the material is chipped and then stored at an intermediate store on hard standing, we have assumed that the proportion of dry matter will remain constant (50%) during storage.

We have made the assumption that no decomposition will occur with unchipped material residue during the six month storage period. In the case of chip piles stored on hard standing, uncovered for six months we have assumed that they will decompose at a rate of 4% per month (i.e. 24% over a six month period).

We have assumed that forestry chips have a dry matter bulk density of 165 kg/m^3. Therefore at harvest with 50% dry matter content the bulk density of the chips will be 330 kg/m^3.

Residues that are chipped after six months of storage (with a dry matter content of 60%) are therefore taken to have a bulk density of 275 kg/m^3.

Unchipped forestry residues have been assumed to have a dry matter content of 50% and a bulk density of 100 kg/m^3 at harvest.

We have taken the bulk density of forestry residues compacted by a grapple crane to be 180 kg/m^3 when loaded onto transport vehicles at 60% dry matter content.

k. Harvesting costs for different systems from research at Aberdeen University and the Forest Industry Group

<u>Residue harvesting systems</u>
Forest residue harvesting systems have no felling costs as the wood energy in this system comprises tops and branches left behind in the forest during conventional forestry operations. There are two residue harvesting systems and both are discussed below.

Landing-based systems - Work by the Forest Industry Group has shown extraction costs to roadside/landing for unchipped residues in residue harvesting systems of between £3.38 per wet tonne and £5.87 per wet tonne at 50% dry matter content (i.e. £6.76 to £11.74 per tonne of dry matter - Forest Industry Group et al, 1996).

Terrain chipping systems - Aberdeen University trialled the following residue terrain chipping system in which residues are chipped at the stump and the chips then forwarded to containers at the landing/roadside. Forwarder mounted chipper: pick up residue, chip to bunk, travel to landing, discharge to demountable container, return to stump. They calculated costs of £22.34 to £23.34 per dry tonne for this system (Mitchell & Hankin, 1993). These relatively high costs are related to the sparse and dispersed nature of the residue.

<u>Integrated harvesting systems</u>
In an integrated harvesting system, whole trees are felled and extracted to a forest road or landing where roundwood and residue are separated during processing. This system can be used for both thinnings and clearfell. In costing such systems, Aberdeen University split the costs of felling and extraction equally between roundwood and energy products (based on the quantity of each produced), delimbing costs are all attributed to roundwood and chipping costs are all attributed to residue.

In trials work, Aberdeen University (Mitchell et al, 1993) studied the use of integrated harvesting for both thinnings and clearfell. In the case of early thinnings they calculated costs of £8.41 per wet tonne to £13.94 per wet tonne for felling, extraction and chipping (with a dry matter content of 48% this represents a cost per dry tonne of approximately £17 to £28). Comminution costs represent approximately £8 per dry tonne to £15 per dry tonne of this total.

In the case of clearfell operations, Aberdeen calculated costs of £5.51 per wet tonne to £13.37 per wet tonne systems for felling, extraction and comminution (approximately £11 per dry tonne to £27 per dry tonne).

<u>Whole tree harvesting systems</u>
In whole tree harvesting systems, wood for fuel is the sole product of the harvesting operation. Processing can occurs at stump or at landing; the system is mostly used for early thinnings but can also be used for premature clearfell.

In the case of early thinnings work conducted by Aberdeen University (Mitchell et al, 1993) has shown that for terrain chipping (i.e. at stump) of hardwoods costs of £3.14 per wet tonne to £8.34/wet tonne (approx.£6.40 per dry tonne to £16.80 per dry tonne) can be achieved. For conifers, costs of £5.14 per wet tonne to £10.34 per wet tonne (approx.£10.40 per dry tonne to £20.70 per dry tonne) are given.

Research (Mitchell et al, 1990) has also shown that whole tree harvesting systems to a forest landing for conifers can cost between £8.85 per wet tonne and £12.53 per wet tonne for felling and extraction (approximately £19.50 per dry tonne to £28.50 per dry tonne). If comminution costs are included whole tree comminution system costs are likely to be between £26 per dry tonne and £45 per dry tonne (Mitchell et al, 1990).

<u>Harvesting cost inputs used in the sensitivity analysis</u>
Therefore we are using a cost of £10 per tonne of dry matter to represent felling and extraction costs in our forestry supply base cases for both landing and terrain-based systems.

For systems in which forestry wood fuel is stored at landing (our supply systems A, B, C and D) costs to landing could be as low as approximately £7 per dry tonne in a landing-based forestry residue system and as high as £20 per dry tonne in a whole tree system. Therefore sensitivity analysis has been undertaken using this range of harvesting and extraction costs.

In the case of terrain-based chipping systems (our supply system E) costs to roadside could be as low as about £7 per dry tonne for a hardwood whole tree harvesting system and as high as approximately £20 per dry tonne for a residue harvesting system in a forest in which fuel is widely dispersed. Therefore, similarly, these alternative harvesting costs have been explored in the sensitivity analysis.

APPENDIX 2 LOGISTICS AND OTHER PARAMETERS/INPUTS USED IN COPPICE SUPPLY

a. Price paid to producer

We have set the price paid to the farmer for coppice at £20 per tonne of dry matter. This input value represents the money farmers would have to be paid to grow coppice on their land (it therefore incorporates the cost of preparing the land, planting and treatment during growth as well as the financial incentive necessary to encourage farmers to use their land for this purpose). It does not include harvesting costs.

b. Harvesting productivity rates and hourly operating costs of harvesters

In establishing harvesting productivity rates we have assumed the following values:

Crop yield - coppice assumed to have a crop yield of 27 tonnes of dry matter/hectare at the end of a three year rotation (i.e. 9 tonnes of dry matter per hectare per annum).

Direct cut and chip harvesting (using a large, self-propelled Claas Jaguar harvester with coppice header) - using data from Forestry Authority trials, the Claas forage harvester has been assumed to operate at a work rate of 0.9 hectares per hour (Forestry Authority work rate of 0.64 hectares per standard hour multiplied by conversion factor of 1.403 gives the actual work rate of 0.9 hectares per hour whilst being used productively). Given the above crop yield of 27 tonnes of dry matter per hectare, this equals a productivity rate of 24.3 tonnes of dry matter per hour.

Stick harvesting (using the Segerslatt Empire 2000 harvester) - using data from Forestry Authority trials, the Empire has been assumed to operate at a work rate of 0.74 hectares per hour (Forestry Authority work rate of 0.53 hectares per standard hour multiplied by conversion factor of 1.403 gives the actual work rate of 0.74 hectares per hour whilst being used productively). Given the above crop yield of 27 tonnes of dry matter per hectare, this equals a productivity rate of 20 tonnes of dry matter per hour.

These harvester productivity rates and crop yields assume two way working, with a row length of 200 metres and twin row spacing of 1.5 m + 0.75 m.

Capital costs for these harvesting machines have been taken from Forestry Authority work (Forestry Authority, 1995).

c. Transport from field

In direct cut and chip systems we have set up systems in which the chips are blown into an agricultural tractor and bulk tipping trailer (of 15 m^3) which runs alongside the harvester. The unloading time for the tipper at the farm store has been set at 5 minutes. The chips are stacked by a loader at a rate of 240 m^3/hour (i.e. ½ minute per 2 m^3 bucketful).

In the stick harvesting systems that we have set up the sticks are bundled and left on the headland by the harvester. The bundles are then loaded onto an agricultural tractor and trailer (15 m^3) by a front end loader with suitable attachment at a rate of 75 m^3/hour - ie one bundle is loaded to the trailer approximately every minute; this loading rate is relatively slow as the vehicles are having to move around the field to pick up bundles). They are taken to the farm store where they are unloaded. The unloading time at the farm store has been set at 5 minutes. The bundles are built into a stack by the loader at a rate of 150 m^3/hour (i.e. about two bundles every minute).

d. Storage at farm and intermediate store

All coppice chips stored at the farm store are stored on hard standing in the systems (the cost of laying concrete would be too high to justify). The chips are not covered and are not subject to forced ventilation. Coppice chips stored at an intermediate store are also assumed to be stored on hard standing; the chips are not covered or ventilated.

We have assumed that bundled coppice sticks stored on-farm would be stacked in a field adjacent to point where the road transport vehicle will be able to access to collect them.

Given that coppice will be used at the power station on a year round basis and that it is harvested at a particular time of year, significant quantities of coppice will have to be stored. We have assumed that the average storage period will be six months.

In the calculations it is assumed that chips will decompose during storage at a rate of 4% per month. It is assumed that chip moisture content will remain constant during storage (i.e. the dry matter content of the chips at harvest of 50% will remain the same during being storage).

In the case of stick bundles it has been assumed that no decomposition will occur during storage. The moisture content of the sticks is likely to fall during storage; in the model it has been assumed that the moisture content will fall from 50% at harvest to 40% after six months of storage (i.e.dry matter content of 60% after storage).

e. Chipping of sticks prior to transport

We have assumed that a large mobile chipper will chip stick bundles at a rate of approximately 45 m^3 per hour (15 wet tonnes). In the model, bundles are fed into the chipper by a front end loader with suitable attachments. It is assumed that chipping losses of 2% of dry matter will occur. Operating costs for such a chipper have also been taken from Forestry Authority research.

f. Road transport

For coppice chip transport, the most suitable road transport vehicle is likely to be a 38 tonne (GVW) articulated HGV tipping vehicle (with a 90 m^3 body). Although the vehicle is assumed to have a 90 m^3 body, it will only be possible to utilise all of this volume if the bulk density is sufficiently low.

For bundled stick transport the most suitable transport vehicle is likely to be a flatbed or timber trailer. Given that the load carried will not require the use of the maximum gross vehicle weight allowed, we have assumed that a 35 tonne articulated vehicle will be used for this operation. We have assumed, based on Forestry Authority findings (Forestry Authority 1995), that given the low bulk density of stick bundles a maximum load of approximately 10 tonnes of fresh wet sticks could be carried on a road transport vehicle.

g. Transport distance scenarios

In the base cases for each of the coppice supply systems it has been assumed that the total road HGV transport distance from the farm to the power station is 40 kilometres (one way trip distance). This distance has been modelled as, from discussions and interviews with prospective fuel suppliers, it would appear to represent the typical trip length in a biomass scheme.

In addition the coppice has to be transported from the point of harvest in the field to the farm steading or farm store. It has been assumed that this involves a transport distance of 0.50 km in field and 0.50 km on farm tracks (i.e. 1 km in total), and will be undertaken by agricultural tractors and trailers in all supply systems.

In supply systems A, C, D and E, the coppice is, after storage on the farm, transported by road directly from farm store to power station. Therefore exactly the same distance and road category assumption have been assumed for the road transport stage in these systems. In the case of supply system B the coppice chips are transported from field directly to an intermediate store and then, after storage, from the intermediate store to the power station. Therefore it has been necessary to allocate the 40 kilometre distance over two road transport stages in this supply system. The transport distances for the road transport stages of the coppice movement for a 40 kilometre (one way) trip length are shown in Table A.2.1.

Table A.2.1 Transport distance scenarios for 40 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, C, D and E	Supply system B
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	30.00	9.50
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	
	Single A/B	N/A	19.50
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		40.00	40.00

For the transport distance scenario of 20 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.2.2.

Table A.2.2 Transport distance scenarios for 20 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, C, D and E	Supply system B
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	10.00	4.50
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	
	Single A/B	N/A	4.50
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		20.00	20.00

For the transport distance scenario of 80 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.2.3.

Table A.2.3 Transport distance scenarios for 80 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, C, D and E	Supply system B
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	30.00	9.50
	Dual A	40.00	20.00
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	
	Single A/B	N/A	19.50
	Dual A	N/A	20.00

	M-way	N/A	
Total road transport distance (one way)		80.00	80.00

h. Loading and unloading transport vehicles

In the direct cut and chip harvesting systems we have set up (systems A and B) and stick harvesting system D, the road transport vehicles are loaded by a front end loader with loading shovel (which loads the lorries from a chip pile). The loading rate we have used is 240 m^3/hour (i.e. ½ minute per 2 m^3 bucketful).

In system C, in which sticks are chipped directly into trailers we have used a chipper productivity rate of 45 m^3/hour (with chipping losses of 2%). The road tractor then arrives drops off an empty trailer and couples up the full trailer awaiting removal; this is assumed to take 10 minutes.

In system E, in which stick bundles are transported on a road transport vehicle, we have assumed that the vehicles are loaded by a front end loader with suitable attachment at a rate of 150 m^3/hour (i.e. approximately 2 bundles placed on the trailer every minute).

Tipper vehicles are self unloading (this could either occur by tipping or by the use of a walking floor type system). We have estimated an unloading time of 5 minutes for a 38 tonne (GVW) articulated tipper.

In the case of stick bundle transport (system E), these vehicles would have to be unloaded by a grapple or loader at the power station. We have assumed that this would occur at a rate of 150 m^3/hour.

i. Securing the load and vehicle weighing/sampling

We have assumed that it will be necessary to sheet vehicles carrying coppice chips. A sheeting time of 5 minutes has been built into the model. An unsheeting time of 5 minutes at the destination has also been included.

Where tipper trailers are loaded with chips direct from the chipper and then the driver arrives with the tractor and another empty trailer, we have assumed a trailer coupling time of 10 minutes.

The road vehicles carrying stick bundles are likely to require strapping and possibly sheeting; we have assumed that this takes 10 minutes. The vehicle will then require unstrapping and unsheeting at its destination and we have estimated that this will take 5 minutes.

At the power station the vehicles will have to be weighed and the coppice chip/stick quality sampled while still on the vehicle. We have assumed that this will take 15 minutes per vehicle.

j. Chipping of sticks at the power station

In supply system E coppice sticks are chipped at the power station in a centralised chipper. The costs of centralised chipping are not included in the Supply Chain Option modelling and are not therefore reflected in the delivered cost of this system.

k. Insurance of the fuel

Coppice suppliers are likely to insure the coppice to financially protect themselves against losses due to fire in storage etc. We have used an insurance cost of £0.50 per tonne of dry matter per year. Therefore for a storage period of six months, insurance would cost £0.25 per dry tonne.

l. Coppice density and dry matter content

We have assumed that the coppice used in all supply systems is harvested at 50% moisture content. If stored as chips, we have assumed that the moisture content will remain the same (50%) during storage. However, if stored as bundled sticks we have assumed that the moisture content will fall to 40% after 6 months storage (i.e. 60% dry matter content).

We have made the assumption that chip piles stored on hard standing, uncovered for six months will decompose at a rate of 4% per month (i.e. 24% over a six month period). In the case of sticks we have assumed that no dry matter losses will occur during the six month storage period.
We have assumed that coppice chips have a dry matter bulk density of 165 kg/m^3. Therefore at harvest with 50% dry matter content the bulk density of the chips will be 330 kg/m^3.

Coppice chips that are produced after six months of storage (with a dry matter content of 60%) are therefore taken to have a bulk density of 275 kg/m^3.

We have taken the bulk density of coppice stick bundles to be 200 kg/m^3 at harvest (i.e. at 50% dry matter content).

APPENDIX 3 LOGISTICS AND OTHER PARAMETERS/INPUTS USED IN STRAW SYSTEMS

a. Price paid to farmer

We have set the cost paid to the producer (i.e. the farmer) at £7.00 per tonne of dry matter for straw. This represents the cost that farmers would have to be paid for fuel suppliers to use their straw lying in the swath; it does not include baling and other processing costs.

b. Baling rates we are using:

Small rectangular baler - 350 bales per hour
Large roll baler- 40 bales per hour
Large rectangular baler - 40 bales per hour

c. Cost of twine is set to £1.50 per tonne of dry matter for small rectangular bales, £1.00 for roll bales, and £1.20 for large Hesston bales.

d. Building heaps

Small rectangular bales - Flat 8 heaps of 56 bales built in 7 minutes using a loader and grab.

Roll bales - these are left individually in the field for collection by a tractor with trailer and loader.

Large Hesston bales - built into heaps of 10 in 7 minutes using a loader with grab in system C. In systems D and E the bales are left individually in the field for collection by a trailed self-loading carrier.

e. Transport from field

Small rectangular bales are moved from field heap to farm store by a farm tractor and self loading carrier which can carry 56 bales (one heap) at a time (wet weight of one tonne and volume of 7.9 m^3). Using this equipment bales are picked up at a rate of 3360 bales per hour (1 minute per set of 56) and are self-unloaded at the same rate at farm store.

Roll bales are loaded onto a farm tractor and agricultural flatbed trailer by a loader with grab at a rate of 50 bales per hour. 18 bales are carried in each load (with a wet weight of 4.3 tonnes).

Large Hesston bales are either:

- collected from heaps of 10 in field by a self-propelled bale carrier (referred to as a Transtacker) at a rate of 400 bales per hour (1½ minutes per set of 10 bales - (this refers to the time it takes to actually pick up and off-load bales; the transport from field to farm store is calculated separately). 10 bales are carried in each load (with a wet weight of 5 tonnes and a volume of 36.3 m^3). This approach is used in system C.

or:

- collected individually from field by a Fastrac and self loading bale carrier (carrying 10 bales at a time). The loading rate is 120 bales per hour and the unloading rate is 300 bales per hour (this refers to the time it takes to actually pick up and off-load bales; the transport from field to farm store is calculated separately). The 10 bales carried in each load have a wet weight of 5 tonnes and a volume of 36.3 m^3. This approach is used in system D and E.

f. Storage at farm and intermediate store

On-farm storage of straw bales occurs in the systems A to D that we have set up. In each case, on-farm storage involves bales being stored in a stack in a field. It is assumed that bales are not sheeted or covered, and therefore a proportion of the stack will be lost due to exposure to the weather (this is discussed below).

System E involves storage of straw bales at an intermediate store. This is a store that is not located on-farm and requires transport of the bales on a road transport vehicle to deliver them to the store. It is located between the point of production and the power station. At the intermediate store we have assumed that the bales are stacked on hard standing. As with farm stores, it is assumed that bales are not sheeted or covered, and therefore a proportion of the stack will be lost due to exposure to the weather (see below).

Given that straw will be used at the power station on a year round basis and that it is harvested at a particular time of year, significant quantities of straw will have to be stored. We have assumed that the average storage period for straw bales will be six months.

In the calculations it is assumed that the entire top layer of the bales will be of no use in biomass supply due to water absorption. Therefore storage losses are dependent upon the number of bales high to which the storage stack is built. In the case of small rectangular bales the stack is assumed to be 12 bales high and therefore storage losses are 8%. For roll bales stacks are 5 bales high and therefore storage losses are 20%. For large Hesston bales the stack height is assumed to be 9 bales and therefore storage losses are 11%.

g. Road transport

The most suitable type of road transport vehicle body for the distribution of straw bales is the flatbed. In the case of straw bales transport it is not necessary to operate vehicles with the maximum gross vehicle weights allowed in the UK (38 tonnes) as the weight of the straw bales does not require such a large payload as this would permit.

Table A.3.1 shows the road transport vehicle and number of bales that can be carried in one load for each bale type.

Table A.3.1: Road transport vehicles for straw bales

Bale type	Vehicle used	Bales carried
Small rectangular	35 tonne (GVW) articulated flatbed	720
Roll	35 tonne (GVW) articulated flatbed	45
Large Hesston: either	35 tonne (GVW) drawbar flatbed	39
or	35 tonne (GVW) articulated flatbed	30

The articulated vehicles used to carry large Hesston bales need to be built with lower than normal body heights in order to ensure that a load three bales high can be carried (without this lower body height it is only possible to carry 20 large Hesston bales on an articulated flatbed vehicle - ie a load stacked two bales high).

h. Transport distance scenarios

In each of the straw supply systems the total distance that the straw transported by road (i.e. by HGV) from the farm store/steading to the power station has been assumed to be 40 kilometres (one way trip distance) in the base case supply systems.

In addition the straw has to be transported by farm equipment from the point at which the bale is produced in the field to the farm store or steading. This distance has been assumed to be 2 km in total (made up of 0.5 km in field, 0.5 km on farm track and 1 km on public roads).

In supply systems A to D, the bales are transported directly by HGV after storage from the farm store to the power station. Therefore exactly the same distances have been assumed for road categories travelled on by HGVs in these systems. In the case of supply system E the bales are transported from field directly to an intermediate store and then from the intermediate store to the power station. Therefore it has been necessary to spread the distance travelled over both of the two road transport stages in this supply system whilst maintaining the total road transport distance by HGVs to 40 km. The transport distances for each stage of the bale movement are shown in Table A.3.2.

Table A.3.2: Transport distance scenarios for 40 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D	Supply system E
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	30.00	9.50
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	
	Single A/B	N/A	19.50
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		40.00	40.00

For the straw transport distance scenario of 20 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.3.3.

Table A.3.3: Transport distance scenarios for 20 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D	Supply system E
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	10.00	4.50
	Dual A		
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	
	Single A/B	N/A	4.50
	Dual A	N/A	
	M-way	N/A	
Total road transport distance (one way)		20.00	20.00

For the straw transport distance scenario of 80 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.4.4.

Table A.3.4: Transport distance scenarios for 80 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D	Supply system E
From farm store (road transport)	Track	0.50	1.00
	Uncl.+ urban	9.50	9.50
	Single A/B	30.00	9.50
	Dual A	40.00	20.00
	M-way		
From intermediate store (road transport)	Track	N/A	0.50
	Uncl.+ urban	N/A	

	Single A/B	N/A	19.50
	Dual A	N/A	20.00
	M-way	N/A	
Total road transport distance (one way)		80.00	80.00

i. Loading and unloading transport vehicles

Straw bales are loaded onto, and unloaded from, road transport vehicles by using a loader with appropriate grab for small rectangular, roll and large Hesston bales.

In the case of small rectangular bales, the loader loads and unloads bales to and from the road transport vehicle at a rate of 640 bales per hour (0.75 minutes per flat 8).

For roll bales the loader loads bales onto the road transport vehicle at a rate of 40 bales per hour and unloads from the vehicle at a rate of 100 bales per hour.

For large Hesston bales the loader loads bales onto the road transport vehicle at a rate of 100 bales per hour and unloads vehicles at a rate of 120 bales per hour.

j. Securing the load and vehicle weighing/sampling

The road vehicles carrying straw bales will require strapping and sheeting before the vehicle leaves the storage area; we have assumed that this takes 10 minutes. The vehicle will require unstrapping and unsheeting at its destination and have we have estimated that this will take 5 minutes.

At the power station the vehicles will have to be weighed and the straw quality sampled while still on the vehicle. We have assumed that this will take 15 minutes per vehicle.

k. Insurance of the fuel

Straw suppliers are likely to insure the straw to financially protect themselves against losses due to fire in storage etc. We have used an insurance cost of £0.50 per of tonne dry matter per year. Therefore for a storage period of six months, insurance would cost £0.25 per dry tonne.

l. Bale volume, density, and dry matter content

Table A.3.5 shows the bale volume for the different types of bales which we have considered in the supply systems. It also contains details of dry matter bale density, dry matter content and bale density at harvest.

We have assumed that the small rectangular bales have a wet bale weight of 18 kg each, the roll bales have a wet weight of 240 kg each and the large rectangular Hesston bales have a wet weight of 500 kg each at harvest.

Table A.3.5: Straw bales volume, density and dry matter content

	Bale volume (m^3)	Dry matter bale density (kg/m^3)	Dry matter content (%)	Bale density at harvest (kg/m^3)
Small rectangular bales	0.14	108	85	127
Roll bales	2.16	95	85	111
Large Hesston bales	3.63	117	85	138

We have assumed that the straw used in all supply systems is harvested and baled at 85% dry matter content and that the dry matter content will remain at 85% during storage.

APPENDIX 4 LOGISTICS AND OTHER PARAMETERS/INPUTS USED IN MISCANTHUS SUPPLY

a. Price paid to producer

We have set the price paid to the farmer for miscanthus at £20.00 per tonne of dry matter. This input value represents the money farmers would have to be paid to grow miscanthus on their land (it therefore incorporates the cost of preparing the land, planting and treatment during growth as well as the financial incentive necessary to encourage farmers to use their land for this purpose). It does not include harvesting costs.

b. Harvesting productivity rates and hourly operating costs of harvesting equipment

In costing the harvesting systems for miscanthus, we have based input values on those used in coppice harvesting and straw harvesting. We have also calculated a cost for cutting miscanthus prior to baling. We have assumed a crop yield of 20 dry tonnes per hectare.

Direct cut and chop harvesting (using the Claas harvester) - 18 dry tonnes per hour (this assumes a productivity rate of 0.9 hectares per hour and a crop yield of 20 dry tonnes per hectare). We have also assumed that wastage of 5% of dry matter will occur during direct cut and chop harvesting as some of the miscanthus is likely to blow away from the spout of the harvester rather than be deposited in the trailer running alongside.

In the baled system we have assumed a work rate for the swather of 40 tonnes of dry matter per hour (this assumes a crop yield of 20 dry tonnes per hectare and a swather rate of 2 hectares per hour). We have also assumed that the baler will produce large rectangular Hesston bales at a rate of 40 bales per hour. The cost of twine for the bales is set to £1.20 per tonne of dry matter. In the baled system we have also assumed that, as the mowing and baling are separate processes, in the baling process 20% of the material will not be picked up by the baler due to the difficulty that is likely to be experienced when baling a brittle crop.

c. Transport from field

For the cut and chop system, the chopped material is blown into an agricultural tractor and bulk tipping trailer (of 15 m^3) which runs alongside the harvester. The unloading time for the tipping trailer at the farm store has been set at 5 minutes.

Large Hesston bales are collected from the field by a Fastrac and self loading bale carrier. The bale carrier picks each bale up individually and is able to carry 10 bales at a time. The loading rate is 120 bales per hour and the unloading rate is 300 bales per hour (this refers to the time it takes to actually pick up and off-load bales; the transport from field to farm store is calculated separately). The 10 bales carried in each load have a weight of 5 tonnes and a volume of 36.3 m^3.

d. Storage at farm store

In the cut and chop system the chopped material is stored on hard standing at the farm for 6 months. It is stacked at a rate of 240 m^3/hour by a front end loader with bucket attachment.

Miscanthus bales are stored in a field for farm storage. It is assumed that bales are not sheeted or covered, and therefore a proportion of the stack will be lost due to exposure to the weather. It is assumed that the top layer of bales are not suitable for supply to the power station and therefore represent a storage loss (of 11%). Bales are stacked by a loader at a rate of 100 bales/hour.

e. Road transport

The chopped material is transported by an articulated tipping vehicle with an internal body size of up to 90 m^3 to maximise possible load weight.
The bales are transported on road by a 35 tonne (GVW) articulated flatbed vehicle which can carry 30 large Hesston bales in one load.

f. Transport distance scenarios

In both miscanthus supply systems (chopping and baling) it has been assumed, as in other biomass fuel supply systems, that the miscanthus is transported a distance of 40 kilometres by HGV from farm to power station (one way trip distance) in the base case supply systems.

In addition the miscanthus will have to be transported from point of harvest in the field to the farm store by agricultural tractors and trailers. The farm transport distance for miscanthus has been assumed to be the same as that for coppice (i.e. 0.5 kilometres in field and 0.5 kilometres on farm track).

In both supply systems the miscanthus is, after storage, transported directly by HGV from farm store to power station. Therefore exactly the same distances have been assumed for road transport stages in both systems. The transport distances used are exactly the same as those used in coppice systems A, C, D and E as the supply system is identical. The spread of the transport distance over different road categories for the supply of miscanthus from farm to the power station when the trip length is 40 km is shown in Table A.4.1.

Table A.4.1: Transport distance scenario of 40 km trip length (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A and B
From farm store to power station (road transport)	Track	0.50
	Uncl.+ urban	9.50
	Single A/B	30.00
	Dual A	
	M-way	
Total road transport distance (one way)		40.00

For the miscanthus transport distance scenario of 20 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.4.2.

Table A.4.2: Transport distance scenario of 20 km trip length (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A and B
From farm store to power station (road transport)	Track	0.50
	Uncl.+ urban	9.50
	Single A/B	10.00
	Dual A	
	M-way	
Total road transport distance (one way)		20.00

For the miscanthus transport distance scenario of 80 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.4.3.

Table A.4.3: Transport distance scenario of 80 km trip length (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A and B
From farm store to power station (road transport)	Track	0.50
	Uncl.+ urban	9.50
	Single A/B	30.00
	Dual A	40.00
	M-way	
Total road transport distance (one way)		80.00

g. Loading and unloading transport vehicles

Chopped miscanthus will be loaded onto articulated tipping vehicles by a front end loader with loading shovel (which loads the lorries from the pile). The loading rate we have used is 240 m^3/hour (i.e. ½ minute per 2 m^3 bucketful). These vehicles are self-unloading (this can either occur by tipping or by the use of a walking floor type system). We have estimated an unloading time of 5 minutes for a 38 tonne (GVW).

Miscanthus bales are loaded onto, and unloaded from, road transport vehicles by using front end loader with grab. The loader is assumed to load large Hesston bales at a rate of 100 bales per hour and unloads vehicles at a rate of 120 bales per hour.

h. Securing the vehicle load

Tipping vehicles carrying chopped miscanthus will require sheeting and we have estimated that it takes 5 minutes to sheet the vehicle and 5 minutes to unsheet it.

We have assumed that all road vehicles carrying miscanthus bales require strapping and sheeting and have estimated that this takes 10 minutes. Loads will also require unstrapping and unsheeting at the destination and have assumed a time of 5 minutes for this activity.

At the power station the vehicles will have to be weighed and the miscanthus quality sampled while still on the vehicle. We have assumed that this will take 15 minutes per vehicle.

i. Insurance of the fuel

Miscanthus suppliers are likely to insure the fuel to financially protect themselves against losses due to fire in storage etc. We have used an insurance cost of £0.50 per tonne of dry matter per year. Therefore for a storage period of six months, insurance would cost £0.25 per dry tonne.

j. Miscanthus density and dry matter content

We have assumed that the miscanthus used in both supply systems is harvested at 40% moisture content (i.e. 60% dry matter content). If stored in a chopped form we have assumed that the moisture content will remain the same during storage. We have made the assumption that chopped piles of miscanthus stored on hard standing, uncovered for six months will decompose at a rate of 4% per month (i.e. 24% over a six month period).

In the case of miscanthus bales we have assumed that the stems will be allowed to dry to 30% moisture content (i.e. 70% dry matter content) before baling occurs. It is assumed that the bales will maintain the same dry matter content during storage (i.e. 70% dry matter). We have also assumed that the top layer of the bale stack will absorb too much water to be supplied to the power station and will therefore have to be discarded (i.e. given a stack height of nine bales, 11% of the miscanthus bales will be damaged).

We have assumed that chopped miscanthus has a dry matter bulk density of 70 kg/m^3. Therefore at harvest with 60% dry matter content, the bulk density of the chopped material will be 116 kg/m^3.

Miscanthus bales are assumed to have the same dry matter content of straw bales of the same volume (425 kg per bale). Therefore at 70% dry matter content the bales will have a weight of 607 kg. This gives a bale density of 175 kg/m^3.

APPENDIX 5 LOGISTICS AND OTHER PARAMETERS/INPUTS USED IN SLURRY SUPPLY

a. Price paid to farmer

We have assumed that farmers will provide their animal slurry to fuel suppliers free of charge in return for the fuel supplier removing and becoming responsible for its safe treatment.

b. Storage at farm

All cattle and pig slurry is assumed to be stored on-farm for a period of one week in a slurry storage tank before being collected.

c. Road transport

We have set up four different types of road transport vehicle for transport cattle and pig slurry from farm to digester:

- Fastrac tractor and agricultural slurry tank trailer (9 m^3 tank capacity)
- 17 tonne (GVW) rigid road tanker (9 m^3 and 9 tonne tank capacity)
- 26 tonne (GVW) rigid road tanker (13.6 m^3 and 13.6 tonne tank capacity)
- 38 tonne (GVW) articulated road tanker (23 m^3 and 23 tonne tank capacity)

All vehicles are assumed to be vacuum tankers.

d. Transport distance scenarios

In the base cases for all of the slurry supply systems it has been assumed that the total transport distance from the slurry storage tank on farm to the anaerobic digester will be 10 kilometres (one way trip distance). This one way transport distance is in accordance with the CAD concept (i.e. it involves relatively short transport distances). Unlike the transport supply systems for other biomass fuels, only a one stage transport system is required for slurry. The slurry is collected from farm slurry storage tank and transported directly to the anaerobic digester. The transport distances for the animal slurry are shown in Table A.5.1.

Table A.5.1: Transport distance scenario for 10 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D
From farm slurry store to digester (road transport)	Track	0.50
	Uncl.+ urban	7.50
	Single A/B	2.00
	Dual A	
	M-way	

Total road transport distance (one way)		10.00

For the animal slurry transport distance scenario of 5 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.5.2.

Table A.5.2: Transport distance scenario for 5 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D
From farm slurry store to digester (road transport)	Track	0.50
	Uncl.+ urban	4.50
	Single A/B	
	Dual A	
	M-way	
Total road transport distance (one way)		5.00

For the animal slurry transport distance scenario of 20 kilometres from farm to power station (one way distance) modelled in the sensitivity analysis, the journey was spread over the different road categories in the manner shown in Table A.5.3.

Table A.5.3: Transport distance scenario for 20 km trip (all figures are one-way distances in kilometres)

Stage	Surface	Supply system A, B, C and D
From farm slurry store to digester (road transport)	Track	0.50
	Uncl.+ urban	7.50
	Single A/B	12.00
	Dual A	
	M-way	
Total road transport distance (one way)		20.00

e. Loading and unloading road transport vehicles

All tankers are vacuum tankers and are therefore self loading and unloading. We have assumed that the tanker filling rate is 30 m^3 per hour in all systems and that the discharge rate for all tankers is 60 m^3 per hour.

At the power station the tankers will have to be weighed and the slurry quality sampled while still on the vehicle. We have assumed that this will take 15 minutes per vehicle.

f. Insurance of the fuel

We have assumed that slurry suppliers are unlikely to insure the fuel to financially protect themselves against losses as the chance of loss is extremely small given the storage system and storage period involved.

g. Slurry density and dry solids content

We have assumed that the wet bulk density of animal slurry is 1000 kg/m^3. Cattle slurry is likely to contain 5-10% dry solids, depending on dilution. Pig slurry is likely to contain 2% to 5% dry solids, depending on dilution.

APPENDIX 6 ROAD CATEGORIES AND TRANSPORT SPEEDS

There are several potential transport stages in the supply of biomass fuel from its point of production to the power station. In the supply chain modelling work we have specified three distinct transport stages that can occur. These are:

- in-field/forest transport - the transport required to move the biomass from its point of production to the farm store, forest landing or roadside. This is normally undertaken by agricultural and forestry equipment.

- road transport from the farm store/forest landing - the transport required to move the biomass from the on-site store or access point. From here the fuel can either be transported to an intermediate store or to the power station. This stage is normally undertaken by road transport vehicles (i.e. heavy goods vehicles). However it can be undertaken by other equipment such as agricultural tractors hauling trailers.

- road transport from intermediate store - if the biomass is transported to an intermediate storage point it will, when required at the power station, have to be transported from the store to the power station. This stage is normally undertaken by road transport vehicles (i.e. heavy goods vehicles).

There are also several different types of vehicle that will be involved in these various transport stages of the biomass supply chain as indicated above. These vehicles are capable of operating at different transport speeds on the same road surfaces. We have therefore split the transport equipment used in the supply chain modelling into three categories for the purposes of defining vehicles speeds:

- Agricultural and forestry tractors and forwarders
- High speed (Fastrac) agricultural tractors
- Road transport vehicles (HGVs)

The type of road surface over which a vehicle is travelling will affect its operating speed. We have therefore specified seven types of surfaces over which vehicles could be travelling in the transportation of the biomass:

- Field
- Track (farm track or forest road)
- Unclassified public roads
- Single lane A and B roads
- Dual lane A roads
- Motorways
- Urban roads

In order to take account of the different operating speeds of different types of vehicles and the effect that the road surface will have on vehicle speed, we have specified speeds for each vehicle type over each type of surface. This is shown in Table A.6.1.

Table A.6.1: Average speed assumptions for vehicles over different road categories (all figures are in kilometres per hour)

Road category	Agricultural or forestry tractor (km/hour)	Fastrac (km/hour)	Heavy Goods Vehicle (km/hour)
Field	8	10	N/A
Track	12	14	14
Unclassified+urban	16	24	24
Single A/B	20	48	48
Dual A/B	25	64	64
Motorway	N/A	N/A	80

In the supply chain modelling results in the base case supply systems in this report we have assumed that, for all biomass fuels with the exception of animal slurries, the total road transport distance (i.e. for transport stages 2 and 3 as defined above) is 40 kilometres (one-way distance). This represents the total distance from point of production in a field or forest to the power station.

In the case of animal slurry, we have assumed a one-way road transport distance of 10 kilometres in the base case supply systems. This represents the total distance from farm storage tank to anaerobic digester and is in accordance with the typical distance likely in a centralised anaerobic digester scheme.

For each biomass fuel supply system we have specified the distance that the fuel is likely to travel over different surfaces in accordance with the characteristics of the production locations for that particular fuel supply system (see appendices 1 to 5 for explanation of the distance scenarios specified for each fuel supply system). It is important to note that although the distances specified are the one way distance (i.e. they refer to a vehicle travelling from a farm or forest to a power station), the transport costs that we calculate are based on the round trip distance (i.e. they take account of the fact that the vehicle has to travel back in the reverse direction to collect the next load and thereby continue its work). Therefore the round trip distance, on which the transport costs we have calculated are based, is twice the one way distance.

APPENDIX 7 EQUIPMENT OPERATING COSTINGS

The majority of activities taking place in each of the supply systems for biomass fuel involve the use of agricultural, forestry or transport equipment. Therefore in order to calculate the cost of each of these activities it is necessary to derive operating costs for each of the pieces of equipment.

Using existing operating cost data, the project team has developed an equipment operating cost database. The equipment including in this database includes a wide range of farm and forestry equipment and road transport vehicles. In the case of agricultural and road transport equipment, the project team have derived hourly operating costs from the constituent standing and running costs associated with the equipment, taking account of the utilisation of the machine. This equipment costing therefore takes account of all costs components including:

- insurance
- maintenance
- fuel and oil
- tyres
- licences
- depreciation
- interest
- labour
- establishment

The equipment operating cost calculations have been based upon a number of assumptions. These are shown in Table A.7.1 overleaf.

In the case of some of the more specialist coppice harvesting and forestry and equipment it has been necessary to take operating cost data from other reports undertaken for ETSU, such as the work conducted by Aberdeen University on residue and whole tree harvesting (for instance Mitchell and Hankin, 1993 and Mitchell et al, 1993) and the work by the Forestry Authority (Forestry Authority, 1995). Therefore the cost data collected by the project team for these pieces of equipment is more limited, comprising of an hourly operating cost and a productivity rate (i.e. not the detailed breakdown of all the cost components that make up the operating cost).

Farm and forestry equipment for which operating costs have been established include:

- farm tractors (including Fastrac tractors)
- agricultural trailers
- front end loaders
- balers
- bale carriers
- forwarders
- forwarder mounted chippers
- other mobile chippers
- grapple cranes
- coppice harvesters
- swathers

Operating costs have also been established for the following types of transport vehicle in a range of vehicle sizes (gross vehicle weights) and in rigid, articulated and drawbar configuration:

- bulk tipping vehicles
- curtainsided vehicles
- flatbed vehicles
- slurry tankers

- demountable containers for road transport

A full listing of the hourly operating costs that we have calculated for the equipment used in the biomass supply systems is shown in Table A.7.2.

Table A.7.1 Assumptions made in the operating cost calculations

Finance
It is assumed that equipment is purchased using a bank overdraft. Therefore interest is payable on the overdraft. Today, in practice much equipment in both farming and road haulage is acquired through some form of leasing. However the interest payments in our calculations can be taken as the lease payment.

Vehicle cost
Vehicle and machinery purchase costs have been obtained from published sources. They are list prices less a discount to reflect the typical values that companies can negotiate.

Depreciation
Vehicle and machinery values have been decreased by a constant percentage each year to reflect depreciation. In our calculations, vehicles have a residual value at the end of the period over which they are depreciated. In the case of articulated HGV road vehicles, tractor units and trailers have been treated separately for the purposes of depreciation.

Inflation
Inflation is not directly addressed but an estimated "real" interest rate figure is used. Future payments and receipts are considered in terms of today's money.

Licences
Figures for road vehicles incorporate operator licence and vehicle excise duty levels appropriate to each vehicle.

Vehicle insurance
Insurance costs are expressed as a proportion of vehicle purchase price for road vehicles (the percentage varies according to the type of vehicle). For farm equipment the insurance premium is taken as a proportion of current machine value.

Labour costs
A uniform hourly labour charge is used in the calculation for all farm equipment. A different set of labour rates have been used for drivers of road transport vehicles. This cost represents the wage rate and National Insurance.

Vehicle usage
Assumptions are made about the number of weeks per year, day per hour and hours per day the equipment is used for. The annual usage obviously affects standing cost and varies greatly between different operations. The total annual cost of agricultural equipment has been spread over the number of hours that it is productively used for during the year (i.e. the hours it is actually harvesting, handling biomass etc). In the case of road transport vehicles, the total annual operating costs have been spread over the entire time that the vehicles will be deployed, whether on the road transporting biomass fuel or at a terminal so that both trip and terminal costs can be calculated. Therefore the annual hours usage over which road transport vehicle operating costs are spread are far higher than for farm equipment. For road vehicles it is also necessary to make assumptions about the annual distance travelled by a vehicle in order to calculate total running costs.

Tyres
Tyre lives and costs for road vehicles are taken from manufacturer's vehicle specification. For farm vehicles, tyre costs are part of maintenance costs.

Fuel and oil costs
Fuel consumption is based on manufacturer's vehicle specification in the case of road vehicles and calculated on the assumption that an engine will be typically operating at 60% of its maximum rated power output in the case of farm equipment. For all equipment, lubricating and hydraulic oil costs are taken as 15% of fuel costs.

Maintenance costs
Maintenance costs for equipment are taken as a percentage of purchase price. For all equipment the percentage is dependent upon the vehicle type.

Establishment
This refers to other costs associated with running a business that are not reflected in vehicle operating costs. These business overheads can include cost items such as administrative staff, rent and rates, telephone and mail, light and heat, company cars etc). Establishment costs have been taken as 10% of operating costs.

Profit
The equipment operating costs are simply that; they do not contain any profit margin for the operator.

Table A.7.2: Hourly operating cost of equipment used in the Supply Chain Option modelling

Table Not Available Electronically

APPENDIX 8 STORAGE SYSTEMS AND SITE RENTAL COSTS

Storage of biomass fuel for significant periods of time is likely to occur in all biomass supply systems (with the exception of animal slurry), as the biomass will be harvested or gathered at a particular time of year (either on-farm or in-forest) and then supplied to the power station on a constant basis throughout the year. The biomass can be stored at a number of different locations in the supply system, this could be either at the point of production (i.e. on-farm or in-forest) or at an intermediate storage point (i.e. a storage location between the point of production and the power station).

In calculating storage costs for biomass, we have considered the following storage cost components:

- stockholding costs - the interest payable on (or opportunity cost of) money tied up in biomass stock;

- insurance of the biomass fuel - the costs of insuring against the loss of, or damage to, the biomass fuel;

- storage site rental - the rental/opportunity cost of using land or structures for the storage of biomass.

Stockholding costs are based on the cost of the biomass into the store, the period of time for which the fuel is stored and the opportunity cost of money.

The insurance cost input values have been explained in the discussion of the parameters and input values used for each biomass fuel (see appendices 1 to 5). This is calculated from the annual insurance cost and the average time period over which the biomass is stored.

The project team have considered relevant factors and made informed judgements on the most likely storage systems for each of the fuels. The storage systems considered for each biomass fuel are explained in detail in the supply system descriptions and input values for each biomass fuel type (see appendices 1 to 5). We have then derived storage site rental costs for each of the storage system options.

The storage site rental cost calculations are based on a number of factors including:

- stack/pile dimensions
- repose angles of stacks/piles
- site cover (ratio of store area to total site/access area)
- land rental costs
- capital costs (of hard standing and slurry tanks)

Site cover refers to the fact that the total storage area required may be considerably larger than the area occupied by the biomass store/stack itself, in order to allow for the access and manoeuvrability of handling and transport vehicles.

The costs we have calculated for each type of storage system (in £/m^3/year) are shown in Table A.8.1 overleaf.

We have not specified the use of covered buildings and drying systems as storage options in the supply systems we have specified for biomass fuel as the costs of such storage techniques will result in extremely large increases in the delivered cost of the fuel. It is even highly improbable that the cost of laying concrete would be economically viable in biomass schemes. Therefore we have not defined the use of such storage options in the biomass supply strategies we have modelled for each fuel.

Table A.8.1: Costs of different storage systems (£/m^3/year)

Table Not Available Electronically

APPENDIX 9 NET CALORIFIC VALUE CALCULATIONS AND DATA USED

In determining the delivered costs of biomass fuel in £/GJ it has been necessary to calculate the net calorific value per tonne of dry matter at the delivered dry matter content.

The following net calorific values (dry) for biomass have been used in the calculations:

Straw - 17 GJ/tonne of dry matter (FEC Consultants, Straw Firing of Industrial Boilers, ETSU Report B 1158, 1988)

Miscanthus - 17 GJ/tonne of dry matter (Alexander.J, Analysis of Miscanthus as a Fuel, ETSU Report B/M5/00488/16, 1995)

Wood - 19 GJ/tonne of dry matter (The Centre of Biomass Technology, Wood Chips for Energy Production, 1993)

This calorific value is based on a dry tonne of biomass with no water present. However in our delivered cost calculations, although we have calculated the cost per tonne of dry matter delivered, this fuel will not be dry upon delivery (i.e. to deliver one tonne of dry matter more than one tonne of wet material is delivered; how much more is dependent upon the dry matter content of the fuel). Therefore in working out the energy value of the biomass it is necessary to adjust the net calorific (dry) values for the water present which has to be burnt off during combustion.

The following equation has been used to make this adjustment (Nellist et al, 1993b):

Net calorific value (wet) = net calorific value (dry) - 2.45 (W/100 - W) GJ/tonne dry matter

Where W = moisture content, % wet basis (i.e. 100% - dry matter content)

Table A.9.1 below shows the net calorific value for a tonne of dry matter of various biomass fuels at dry matter contents assumed in the Supply Chain Option modelling.

Table A.9.1: Net calorific value of biomass fuels at different dry matter contents

Biomass at given dry matter content	Net calorific (dry) value (GJ/tonne of dry matter)
Straw at 85% dry matter	16.6
Miscanthus at 60% dry matter	15.4
Miscanthus at 70% dry matter	16.0
Wood at 50% dry matter	16.6
Wood at 60% dry matter	17.4

The delivered costs of animal slurry have been presented on a wet tonne basis and therefore the above conversion was unnecessary for this fuel. However, in order to calculated the "logistics energy ratio" for animal slurry (see section 11.4) it has been necessary to work out the energy content of a wet tonne of slurry. The following assumptions (based on Baldwin, 1993a and 1993b) were made:

- The logistics energy ratio calculation we have made is for cow slurry.
- Cow slurry has 10% dry solids content.
- Cow slurry has a gas yield of 0.26 m^3/kg.
- Cow slurry has a calorific value of 24 MJ/m^3

Based on these assumptions the following calculations can be made:

1 wet tonne contains 1000 kg * 0.1 = 100 kg of dry solids.

100 kg of dry solids has a gas volume of 100 * 0.26 = 26 m^3.

This volume of gas has a calorific value of 26 * 24 = 624 MJ.

Therefore, based on the given assumptions, one wet tonne of cow slurry has a calorific value of 624 MJ (or 0.624 GJ).

APPENDIX 10 ROAD VEHICLE TYPES AND REGULATIONS

A.10.1 Vehicle definitions (taken from the Road Traffic Act 1988)

Motor vehicle
A motor vehicle is a mechanically propelled vehicle intended or adapted for use on roads.

Articulated vehicle
An articulated vehicle is a motor car or heavy motor car with a trailer superimposed on it so that when the trailer is uniformly loaded not less than 20% of the weight of its load is borne by the drawing vehicle. When coupled up an articulated vehicle (artic) is treated as a motor vehicle and trailer.

Semi-trailer
A semi-trailer is a trailer which is constructed to form part of an articulated vehicle including a vehicle which is not itself a motor vehicle but which has some or all of its wheels driven by the drawing vehicle.

Goods vehicles
A goods vehicle is a motor vehicle or trailer constructed or adapted for the carriage of goods. The carriage of goods includes the haulage of goods.

Unladen weight
The unladen weight (also known as tare weight) of a vehicle is to be taken as its weight, inclusive of the body and all parts necessary to or ordinarily used with the vehicle when working on a road but not including the weight of water, fuel or accumulators used to supply the power for the propulsion of the vehicle, loose tools and loose equipment.

A.10.2 Goods vehicles

There are two types of goods vehicles:

Rigid vehicle - A goods vehicle where the motor unit and the carrying unit are constructed as a single vehicle.

Articulated vehicle - A goods vehicle made up of a power unit plus a semi-trailer.

Goods vehicles sizes
Goods vehicles are produced in a range of sizes. The weights and dimensions set out in the following pages are taken from sources applying to Great Britain. However, all weight and dimension regulations for European Community countries now originate from the Commission. Thus most of the maximum weights and dimensions stipulated in one country will apply to the remainder of states. There may be some differences when different axle configuration are used or if weights and dimensions have been derogated.

The following categories are often used to define goods vehicles of varying sizes:

Small goods vehicles - Maximum permissible weight does not exceed 3.5 tonnes (this is known as the Gross Vehicle Weight - the maximum weight at which a vehicle together with its load is allowed to operate on public roads).

Medium goods vehicles - Goods vehicles with a maximum Gross Vehicle Weight (GVW) exceeding 3.5 tonnes, but not exceeding 7.5 tonnes.

Large goods vehicles - Goods vehicles with a maximum GVW exceeding 7.5 tonnes. All large goods vehicles are often referred to as Heavy Goods Vehicles (HGVs).

Figure A.10.1 shows the axle spacings and plated axle limits that rigid vehicles must comply with in Britain in order to take advantage of the permitted weight limits.

Figure A.10.1: Rigid vehicle weights in Britain

Figure Not Available Electronically

A.10.3 Semi and drawbar trailers

There are two main types of trailer:

Semi-trailer - a type of trailer that forms part of an articulated vehicle. It does not support its own load when uncoupled from the tractor unit. There are a number of designs of semi-trailer including the conventional semi-trailer, the step-trailer and the skeletal trailer (for conveying swap bodies and containers), which are available in numerous shape and size specifications. However all of these designs of semi-trailer, subject to the number of axles they possess, must comply with the same height, width and length regulations in Britain.

The maximum permitted weights for articulated vehicles depends upon the number of axles, axle spacings and overall length. Figure A.10.2 shows the restrictions on the weight and length of semi-trailers in Britain; Table A.10.1 shows the plated gross weight and typical carrying capacity limits for three, four, five and six-axle articulated vehicles.

Table A.10.1: Articulated vehicle characteristics

Vehicle type	Plated gross weight (tonnes)	Typical carrying capacity (tonnes)
3-axle artic	24.39 25.00 26.00[1]	14.6 15.2 16.1
4-axle artic	32.52 35.00 36.00* 38.00*	20.1 22.4 23.3 25.1
5-axle artic (2+3)	38.00 40.00*	24.2 26.1
5-axle artic (3+2)	38.00 40.00*	24.1 26.0
6-axle artic (3+3)	38.00 40.00* 44.00**	23.2 25.1 28.8

1. tractor with 2 axles, which has twin tyred drive axle and road friendly suspension.

* from 1.1.99
** only allowed for combined transport operations (i.e. journey partly by road and partly by rail).

N.B. Typical carrying capacity values based on survey data.

Source: Newton & Frith, 1993 & Croner's, 1996

Figure A.10.2: Restrictions on semi-trailers in Britain

Figure Not Available Electronically

Drawbar trailer - a type of trailer that is attached to a rigid vehicle; it has at least four wheels and supports its load of its own accord. When attached to a rigid vehicle it is commonly referred to as a road train. Figure A.10.3 shows the types of drawbar trailer system available and the effect that they have upon the clearance between the vehicle and trailer. The top diagram is of a conventional turntable trailer, in this system the corner swing arcs of both the vehicle and trailer affect the size of the gap. In the middle diagram, which depicts the extending drawbar system, only the towing vehicle's swing arcs affect the gap. In the bottom diagram of the centre-bogie trailer system the gap is also only influenced by the towing vehicle's corner swing arc.

Figure A.10.3: Drawbar trailer systems

Figure Not Available Electronically

Table A.10.2 shows the plated gross weight and typical carrying capacity limits for four and five-axle drawbars.

Table A.10.2: Drawbar vehicle characteristics

Vehicle type	Plated gross weight (tonnes)	Typical carrying capacity (tonnes)
4-axle drawbar	32.52 35.00*	20.0 22.3
5-axle drawbar	32.52 38.00** 40.00***	19.1 24.1 26.0
6-axle drawbar	32.52 38.00** 40.00*** 44.00****	Carrying capacities within this class of vehicles will be slightly lower than 5 axle vehicles.

* if trailer is fitted with power assisted brakes operational even when the drawing vehicle's engine is not running.

**	if vehicle has * (above) plus twin tyres and road-friendly suspension.
***	to be allowed from 1.1.99.
****	only allowed for combined transport operations (i.e. journey partly by road and partly by rail).

N.B. Typical carrying capacity values based on survey data.

Source: Newton & Frith, 1993 & Lowe, 1996

The maximum gross weight for a road train in Britain, regardless of whether it has four, five or six axles, is 32,520 kg. This can be increased to 38,000 kg when the drive axle/s of the drawing vehicle are fitted with twin tyres and road-friendly suspension and the trailer is fitted with power assisted brakes operational even when the engine of the drawing vehicle is not running.

The length of drawbar trailers are restricted as follows. If the drawbar trailer has four wheels or more and the drawing vehicle has a maximum gross weight in excess of 3500 kg, then the drawbar trailer can be up to 12 metres in length (excluding the length of the drawbar). Other drawbar trailers cannot exceed 7 metres (excluding the length of the drawbar). Road trains with one trailer cannot exceed 18.35 metres.

Suspension - Two types of systems are used on rigid and articulated vehicles and trailers, conventional springs or air derivative suspension (road-friendly). Generally most freight can be transported by vehicles with convention springs. However, freight of a more fragile nature (i.e. computers, furniture, flowers) may require vehicles which provide a smoother ride and therefore need air suspension. Many of the new vehicles and trailers that are used by hauliers have the air systems fitted as standard, however, it should not be assumed a vehicle with the correct suspension would automatically be available.

A.10.4 Vehicle bodies

The type of vehicle body used is dependent upon the operating and load requirements. The majority of body types can be fitted to either a rigid or an articulated vehicle. The body types likely to be considered for the transportation of biomass fuels are described below.

The flat-bed (platform) - this comprises a wooden base above the trailer with a range of heights at sides and rears. It is mainly used for the movement of raw materials and products unaffected by water, as it is uncovered. Loads are normally roped and sheeted. It offers up to a 13.6 m bed length and a 2.55 m width, with a typical carrying capacity of up to 25 tonnes. Some flat-bed trailers are fitted with twist lock couplings in order to carry containers.

The curtain-sided body (tautliner) - these have a rigid roof from which are suspended the sides of the trailer in the form of PVC curtains, which can be drawn back to facilitate side loading. Loading can also take place through the rear doors. This type of trailer is extremely suited to palletised loads which can be rapidly loaded and unloaded via side or rear, and offers a high internal space of up to 75 m^3. Internal dimensions are likely to be approximately 13.5 m (length) x 2.4 m (width) x up to approximately 3 m (height).

The skeletal trailer - this is essentially a naked trailer chassis which is used for transporting containers and swap-bodies. It is equipped with `twist lock' couplings to secure the body to the chassis. These fitting point may be static or adjustable in order to accommodate one or two bodies depending on the size. The trailers come in varying lengths and can be operated up to a GVW of 44 tonne when involved in road-rail intermodal transport.

The tipper - vehicles with the capacity to tip loads. They are used to discharge bulk materials such as sand, gravel, grain etc and can be either covered or uncovered. Tippers are manufactured in a wide range of shapes and sizes depending on the freight to be carried and they are usually hydraulically operated. Popular large capacity vehicles include four axle rigid lorries which typically carry between 12-65 m^3 (maximum 32 tonnes); and artics that operate up to 38 tonnes GVW typically carrying between 40-90 m^3. These vehicle bodies can also be fitted with walking floor or "Ejectaload" systems so that the load can be discharged without having to raise the body (see Appendix 12.4).

The road tanker - the tank body is used to carry liquids, gases and powders. Many products carried by tankers have special requirements in terms of lining for the tanks and their loading and discharging. Many types of hazardous goods are transported by tanker. Tankers are produced to a wide range of weight, length and size specifications, dependent upon the operations that they are required for. The majority of tankers are operated by specialist freight companies.

Demountable systems - vehicles that deposit the load carrying body when it is either loaded or empty. The bodies are "portable" versions of conventional heavy goods vehicle bodies (i.e. curtainsided, tankers, etc). Various systems are available the majority of which are developed for intermodal application. An increasing number of systems are designed specifically for use in the distribution industry, whereby bodies are deposited by trunking vehicles at depots before being picked up by local delivery vehicles. Other systems are used in the waste disposal sector, with large skip like bodies (containers) being left at depots or other points for filling/emptying. Typically these waste containers have a carrying capacity of between 6 and 31 m^3.

On-board handling equipment - a wide range of lifting equipment can be attached to vehicles and used for vehicle loading and unloading. This equipment varies in terms of type, size and capacity.

Use of this type of lifting equipment can replace the need for separate lifting equipment which could be useful in the context of biomass fuel handling. Rather than requiring a vehicle to transport the fuel and, for example, a bucket loader, to load it, if the transport vehicle has a loading bucket fitted to it, it is capable of doing the entire task on its own. This reduces both the total capital cost of equipment and the amount of labour needed (one person can carry out the loading and transport, rather than requiring two people).

There are however several disadvantages associated with the use of lifting equipment which is fitted to the vehicle. These include:

- the equipment is not generally as productive as separate loading and unloading equipment, resulting in longer loading and unloading times and hence the road vehicle is idle for longer periods;
- having the equipment attached to the vehicle adds substantially to the unladen weight of the vehicle and thereby reduces the carrying capacity of the vehicle. This causes transport running costs per tonne mile to rise significantly.

A.10.5 Vehicle length restrictions

In determining the length of a vehicle (either rigid, articulated or road train) it is necessary to take into account `any part of the vehicle and this includes any receptacle which is of a permanent character and accordingly strong enough for repeated use, and fittings on, or attached to the vehicle, subject to the following exceptions:-

- sheeting;
- an empty receptacle which is itself the load;
- a receptacle which contains an indivisible load;
- a receptacle not exceeding 2.5 metres in length or width;
- lifting lugs for multi-modal transport;
- tailboards let down to facilitate carriage but not essential for the support of loads which extend beyond the rearmost point of the vehicle;
- bridging plates on vehicles transporting trailers, used to facilitate loading and unloading of vehicles carried but not to support such vehicles;
- receptacles, other than maritime containers, manufactured before 30 October 1985 (this specifically legalises certain existing demountable bodies);
- cranes etc. which do not increase the carrying capacity of the vehicle and which are a permanent or essentially permanent fixture'(Freight Transport Association, 1993).

Table A.10.3 shows the current length restrictions for all types of road freight vehicles in Britain.

Table A.10.3: Length restrictions in Britain

Length	**Maximum permitted**
Rigid vehicles	12 m
Articulated vehicle	*16.5 m
Articulated vehicles with low-loader semi-trailer manufactured on or after 1 April 1994	18 m
(Note step frame low-loaders are not included)	
Car transport semi-trailer:	
kingpin to rear	12.5 m
kingpin at any point on the front	4.19 m
Other semi-trailers	
kingpin to rear	+12 m
kingpin at any point on the front	+2.04 m
Composite trailer	14.04 m
Drawbar trailers *(excluding length of drawbar)* provided:	
1. trailer has four more wheels;	
2. drawing vehicle has a GVW exceeding 3,000 kg	*12 m
Other drawbar trailers *(excluding length of drawbar)*	
Road trains: one trailer	18 m *(see note 1)*

* No set limit if designed to carry indivisible loads of exceptional length.

\+ These dimensions include thickness of any front or rear wall, if more than one kingpin position measurement is taken from rearmost.

Note 1:

The maximum construction and use regulations have been amended so to allow road trains a maximum length of **18.35 m**. Vehicles operating at this length are subject to two additional dimension criteria: 1. the distance from the foremost point of the loading area behind the cab the rear of the trailer must not exceed 16 m; and 2. the above measurement less the distance between the vehicle and trailer must not exceed 15.5 m. *(This gives, therefore, a maximum load space)*. This requirement does not apply to road trains which are car transporters.

Source: Freight Transport Association, 1993

A.10.6 Vehicle width restrictions

`In calculating the overall width account is to be taken of any part of the vehicle, any receptacle which is of a permanent character and accordingly strong enough for repeated use, and fittings on or attached to the vehicle subject to the exceptions set out relating to overall length. Driving mirrors and direction indicators are not included for construction and use purposes. It should be noted that some traffic regulation orders do not use the same definition and consequently mirrors may have to be included' (Freight Transport Association, 1993).

Table A.10.4 shows current width restrictions for road freight vehicles in Britain. The maximum permitted width for standard vehicles and trailers is 2.55 m.

Table A.10.4: Vehicle width restrictions in Britain

Width	**Maximum permitted**
Motor tractors	2.5 m
Heavy motor cars	2.5 m
Trailers - provided: 1. every wheel is fitted with pneumatic tyres; 2. drawn by a vehicle having a maximum gross vehicle weight exceeding 3,500 kg; 3. every wheel of the towing vehicle is fitted with pneumatic tyre	2.5 m
Any other trailer	2.3 m

Source: Lowe, 1996

In addition to the vehicle width regulations shown above, there are also regulations concerning the width of the load placed on the vehicle. Loads must not project more than 305 mm on either side of the vehicle and the overall width of the vehicle and load must not exceed 2.9 m (Croner's, 1996).

A.10.7 Vehicle height restrictions

There are no legal height restrictions on road freight vehicles or their loads on British roads. However heights are restricted by the heights of bridges on routes on which vehicles are operating.

Regional electricity and national grid companies need to be informed of vehicle movements when vehicle height or load height exceeds 16 feet 6 inches (just over 5 metres), and British Telecom must be informed when vehicle or load height exceeds 17 feet 6 inches (5.33 metres).

When vehicles are carrying containers, engineering equipment or skip loaders and the overall height exceeds 3.66 metres, the overall height of the vehicle must be indicated in the driver's cab.

A.10.8 Other road haulage legislation

In addition to the regulations regarding vehicle weights and dimensions, there are two other important areas of road transport legalisation with respect to road freight that need consideration: drivers' hours regulations and speed limits.

Drivers' hours
The legislation covering the amount of time that the driver of a heavy goods vehicle is allowed to drive for each day is extremely complex. However at its most basic a driver is allowed to drive for 9 hours each day which may be extended to 10 hours not more than twice a week. The "daily driving period" is the period spent at the wheel of the vehicle between any two daily rest periods or between a daily and weekly rest period.

A driver must take a weekly rest period after no more than six daily driving periods.

The total amount of time that a driver can spend driving during a fortnightly period is 90 hours. A driver can drive up to 56 hours in one week but can then only drive 34 hours in another so as not to breach the 90 hour maximum.

After a total of 4½ hours a minimum break of at least 45 minutes must be taken. This break can be divided into shorter periods which must be of at least 15 minutes duration to qualify so that when spread over the driving period the aggregate is at least 45 minutes.

In each period of 24 hours a driver must have a daily rest of at least 11 consecutive hours which may be reduced to 9 consecutive hours on three days a week.

Tachographs are fitted into all vehicles with a gross vehicle weight exceeding 3.5 tonnes. The tachograph automatically records:

- the distance travelled by the vehicle;
- the speed of the vehicle;
- the driving time;
- periods of work of drivers;
- breaks from work and daily rest periods;
- the opening of the case containing the record chart.

By referring to the tachograph it is possible to check whether the driver has operated within the drivers' hours regulations (Croner's, 1996).

Speed limits and limiters
Legislation about speed limiters came into force in August 1992 but it has started to affect a significant number of vehicles during the past year. Speed limiters are now fitted into every new goods vehicle with a gross vehicle weight exceeding 7.5 tonnes and have also been fitted to all vehicles with a gross vehicle weight exceeding 16 tonnes manufactured since January 1988. These limit the speed of the vehicle to 56 miles per hour (approximately 90 km per hour).

The aim of introducing limiters is primarily to play a part in promoting safety but they also play a role in improving fuel efficiency.

Heavy goods vehicles (i.e. greater than 7.5 tonnes gross vehicle weight) without speed limiters (because they were manufactured prior to January 1988) are restricted to a maximum speed of 60 miles per hour (approximately 96 km per hour) on motorways.

All heavy goods vehicles are restricted to a maximum speed of 50 miles per hour (approximately 80 km per hour) on dual carriageways and 40 miles per hour (approximately 64 km per hour) on other roads (providing lower limits are not in force).

Use of high speed agricultural tractors for road haulage operations

In the Supply Chain Option modelling work we have considered the use of high speed agricultural tractors (e.g. the Fastrac) for hauling slurry tankers to anaerobic digesters. These high speed tractors could also be used in road transport operations in other biomass schemes (e.g. straw or wood chip delivery to the power station). They are likely to be most attractive in schemes with relatively short transport distances from storage points to the power station.

However it is important to note that the police are somewhat concerned about the use of agricultural tractors on the public road network. Instances have been reported of hauliers purchasing agricultural tractors to undertake everyday haulage work and thereby enjoy the operational and economic benefits of using these vehicles (vehicle excise duties far below those of haulage vehicles, no plating and testing, no need for tachographs, no drivers' hours regulations, up to 20 tonnes carrying capacity without an LGV licence, drivers of 17 years of age and rebated fuel).

Until relatively recently the use of agricultural tractors for haulage operations was considered to be unviable due to the low speeds of these vehicles. However the advent of agricultural tractors capable of travelling at up to 50 miles per hour (approximately 80 km per hour) has transformed this situation.

This can lead to a number of problems both in terms of road safety and the viability of the haulage industry:

- Unqualified drivers
- Drivers working excessive hours
- Young drivers paid wage rates below the going industry rate
- Pressure on haulage rates for established hauliers

However certain road haulage legislation prevents direct competition between owners of agricultural tractors and road haulage companies. These include:

- Agricultural tractors can only operate to a gross weight of 24.4 tonnes

- Maximum speed on public roads is restricted to 40 miles per hour (approximately 64 km per hour) for agricultural tractors unless lower restrictions exist

- Such agricultural tractors can only be operated up to 15 miles (approximately 24 km) from their holding and can only carry farmers' goods. To use agricultural tractors for distances greater than 15 miles a restricted operators licence is required.

For further details of the use of high speed agricultural tractors for road haulage see:

Hemingway.P, "Agricultural Vehicles" in Commercial Motor, letters page, 20-26 July 1995.

Lambert.P, "Sound Off" in Commercial Motor, 13-19 July 1995, p.41.

Stephens.C, "Farmer or Haulier" in Commercial Motor, letters page, 9-15 November 1995, p28.

APPENDIX 11 SAFETY ISSUES IN HANDLING AND TRANSPORTING BIOMASS

A.11.1 Straw storage

Sheeting of bale stacks is labour intensive, difficult to undertake in windy conditions, and involves considerable hazard to workers. In many situations the most economical method of storage may be to make very high stacks of bales, without sheeting, and to set up a compost making enterprise nearby.

Bulk straw stores are very vulnerable to fires arising from accidental causes or arson. Stacks would need to be isolated from one another.

The Health & Safety Executive (HSE) have issued guidelines for stacking bales, giving recommendations for maximum stack height (HSE, 1992). The HSE document suggests that high density rectangular bales should not be more than six layers high, with bales overlapping to form a stable stack. Roll bales with axes horizontal should be not more than four layers high. The height of roll bales with axes vertical should be not more than three times the bale diameter, which implies a stack only three layers high for most of the standard bale types.

In commercial practice, bales are commonly built into stacks considerably higher than the HSE recommends, in order to minimise rain damage.

A.11.2 Straw loading and transport

Safety is a particular concern during loading and unloading of vehicles and stacks. Nearly all farm loaders have safety cabs to protect the drivers, but bales falling onto pedestrians cause very serious injuries. Bales are very liable to be dislodged while other bales are being added to or removed from a load. The act of fitting ropes or straps onto a high load is risky in itself.

Netting/sheeting of lorry loads is not usual in the UK. Some straw does escape from loads, especially where lorries on rural roads brush against trees. Any handling operation tends to produce some loose pieces of straw, and these often blow away during the first few miles of any journey. Blown straw is unsightly and can lead to numerous complaints, though is seems unlikely to have any long-term environmental effects.

A.11.3 Animal slurry loading

Safety is an important issue in the transportation of animal slurries. Many farm storage tanks in the UK are open-topped and it is therefore likely that drivers will require protective clothing such as overalls, gloves and visors and it may be advisable to carry breathing apparatus. Agitation or mixing of animal slurry releases noxious gases, notably hydrogen sulphide. Deaths due to hydrogen sulphide poisoning have occurred on UK farms. Although the odour is easily recognised, hydrogen sulphide poisoning quickly impairs the sense of smell, probably causing victims to believe that the danger has passed.

A.11.4 General points about loading, unloading and transport

<u>Depots and loading/unloading</u>
In 1994 there were 77 workplace fatalities and 1,363 serious accidents in the UK. These figures do not include those killed or injured on the roads or suffering chronic illness due to workplace conditions. In addition there are approximately 5,000 workplace injuries that cause people to be off work for more than three days. Health and Safety Executive data (HSE, 1994) shows that vehicle accidents are the second biggest cause of workplace death (the biggest being falling from a height, so if a driver were to die or be

injured falling from their vehicle this would be attributed to this category).

According to the Health and Safety Executive, 80% of all workplace accidents are preventable.

Most frequent transport workplace accidents:

- people being hit or run over by moving vehicles
- slipping and/or falling while working on vehicles
- injuries as a result of objects (usually part of the load) falling from the vehicle
- being injured by a toppling vehicle

Employers have a legal duty "so far as is reasonably practicable, to provide and maintain safe systems of work, and to take all reasonably practicable precautions to ensure the health and safety of all workers in the workplace and members of the public who might be affected by their activities" (HSE, 1995).

Regulation 3 of the Management of Health and Safety at Work Regulations (1992) requires employers to assess the risks to employees, and anyone else, who may be affected by the work undertaken. Under this regulation five steps have been identified:

- identify the hazards

- identify who might be harmed and how

- evaluate the risks and assess whether existing precautions are adequate or whether more precautions are needed

- record the significant findings (necessary for employers with five or more employees)

- periodically review the risk assessment as necessary (e.g. when working activities change, new equipment is purchased etc).

Health and Safety Executive practical advice on safety in the transport workplace considers five aspects of workplace safety:

1. A safe workplace
   - design and layout of road systems
   - pedestrians
   - parking areas
   - loading bays
   - construction of roads
   - lighting
   - roadsigns
   - temporary workplaces and unprepared roadways

2. Vehicle safety
   - design of vehicles (e.g. stability, ease of access/exit to and from vehicle, horns, windscreen wipers etc)

3. Maintenance work
   - the workplace (e.g. surface of traffic routes free from obstruction, maintenance of roadways and road markings)
   - vehicles (brakes, tyres, steering, mirrors, signals etc)

4. Selection and training of drivers and other employees

- selection of drivers
- training

5. Contractors, visiting drivers and shared workplaces
- contractors and sub-contractors
- visiting drivers
- shared premises

The Health and Safety Executive have also suggested a number of examples of workplace safety. These include:

- speed limits on site

- providing pedestrian crossing points between workplaces and car parks

- driver training

- physical barriers or designated areas to separate pedestrians and vehicles

- maintenance programmes with adequately equipped and trained workers

On area of particular importance to biomass transport is that of safe working practices for vehicle loading and unloading and sheeting and unsheeting and access onto vehicles. The Health and Safety Executive recommend a number of safe practices that should be considered in the areas of operation discussed below.

Access onto vehicles

Getting onto and off of larger vehicles for activities such as loading and sheeting can result in falls. Access onto vehicles should be restricted to those permitted to do so.

Climbing on top of vehicles should be avoided where possible. Bottom filling and fitting level gauges and controls accessible from the ground help to avoid the need for drivers to climb on top of road tankers.

If access to the top of a road tanker is necessary access should be via a properly constructed ladder on the front or back of the tank. Walkways should be of non-slip material; suitable guard rails may be needed.

Many vehicles do not incorporate these features. Operators may need to consider retro-fitting such features or providing access methods that are not fitted to the vehicle.

Loading and unloading vehicles

Loading/unloading should be carried out in an area away from passing traffic, pedestrians and other people not involved in the process.

Loading/unloading should not take place so near to overhead electric cables that there is a possibility of making contact with them, or of electric arcing between the cables and vehicles and/or loading equipment.

Loading/unloading operations should never be carried out on gradients steep enough to make the operation unsafe. To maintain stability, trailers should be situated on firm ground which is free from pot-holes or debris which could cause vehicles and trailers to overturn.

It may be necessary to safeguard against mechanical hazards from equipment used during loading and unloading operations, for example dock levellers or vehicle tail lifts.

Loading/unloading should be carried out in such a way that, as far as possible, the load is spread evenly. Uneven distribution can result in the vehicle or trailer becoming unstable, especially if it is an articulated or similar type of trailer which has been detached from the power unit.

Ensure the vehicle has its brakes applied and/or is stabilised, as appropriate, to prevent unsafe movements during loading and unloading operations.

Incidents have occurred where drivers have driven away from a loading bay before unloading operations have been completed. It is important that measures are taken to prevent this happening. The use of suitable vehicle/trailer restraints or the installation of traffic lights can be particularly effective.

Tipping of loads

A significant number of tipping vehicles, including rigid body lorries, tipping trailers and tankers, overturn each year with the potential for fatal accidents. The following guidance by the Health and Safety Executive should help avoid such accidents:

- report to site before commencing tipping
- site operator and driver liaise
- tipping on level ground
- suitable tipping faces
- use of wheel stops
- check even distribution of load before tipping. Check load will discharge smoothly.
- driver should not stand or walk behind vehicle, or allow anyone to do so, when body is raised or during tipping.
- driver should never leave vehicle during lowering or raising and should ensure cab doors are closed.
- drivers need to be sufficiently experienced to anticipate loads sticking or "freezing" in the body. If this happens, the body needs to be lowered and the remaining load freed before the body is raised again. The vehicle should never be driven in order to free a stuck load.
- after discharge the driver should ensure that the body is completely empty.

Sheeting and unsheeting of loads

Sheeting and unsheeting of loads can be hazardous, particularly when it is carried out manually. The person doing the work can slip or lose their grip and fall while sheeting and unsheeting loads, or walking on top of loads. Falls have also resulted from torn sheets and breaking ropes.

Consider whether it is possible to use vehicles that do not require sheeting. If not, is it possible to use mechanical or proprietary sheeting systems? These can be either fully or semi-automatic, and are generally purpose-built assemblies attached to the vehicle body. They enable the load to be sheeted and unsheeted from ground level using simple mechanical aids such as a crank handle, or automatically via controls in the driver's cab.

Automatic sheeting systems can be electrically, pneumatically, or hydraulically powered and can work by unrolling sheeting from the front to the back of the vehicle body; unrolling sheets from side to side; sliding the sheet along runners or wires from front to back or side; and levering or "flipping" the sheets from centre to side or from front to back.

Where manual sheeting is unavoidable, the need for a person to go on top of the load should be avoided wherever possible.

Sheeting should be carried out away from passing traffic, pedestrians, and where possible sheltered from strong winds and bad weather. Vehicles should be parked on level ground with parking brakes on. Gloves, safety boots and where necessary eye and head protection should be provided. Where it is necessary to gain access to a load suitable ladder and hand grips should be provided.

Ropes and sheets can break or rip so the driver should avoid leaning backwards when pulling the sheet tight and should never do so at the end of the vehicle body. When pulling sheeting the driver should always have one foot behind the other to avoid overbalancing.

For further information on these issues see:

Department of Transport, Code of Practice: Safety of Loads on Vehicles, HMSO: London, 1984.

Health and Safety Executive, Workplace Transport Safety: Guidance for Employers, HMSO: London, 1995.

Health and Safety Executive, Sheeting and Unsheeting of Tipper Lorries, HMSO: London, 1996.

APPENDIX 12 VEHICLE EQUIPMENT AND OPERATIONS

A.12.1 Sampling

Testing and sampling biomass loads is likely to be necessary in biomass schemes as the fuel is received at the power station to determine dry matter content (i.e. to test whether it is within the range of moisture levels acceptable at the plant and the effective heating value of the load).

Presumably, if a suitably rapid sampling technique can be used, testing the load prior to unloading will be preferable, so that if it fails to meet the agreed fuel specification it can be rejected and taken away immediately. However this will depend upon the exact nature of the supply contract. If, for example, drying of the biomass at the power plant is standard practice, then the dry matter content could be determined after unloading and the price adjusted accordingly.

In addition, vehicles will have to be weighed on a weighbridge upon arrival at the power station to establish vehicle weight (and hence load weight and bulk density) and loads will also have to be inspected for load contamination prior to unloading.

In Sweden, on arriving at the power station, each transport vehicle is weighed at a weighbridge and then two samples are taken from the load. The sampling company are independent and have operated for a long time in the forestry industry. By using an independent organisation all parties (plant and fuel supplier) are happy that the value of the load is fairly and impartially determined.

A.12.2 On-board weighing systems

Overloading a road transport vehicle is an offence under the Road Traffic Act 1991 and carries a maximum penalty of up to £5,000 per offence. Overloading convictions can affect the decision of a Licensing Authority to suspend, revoke or renew an HGV driver's licence and action may also be taken against the O-licence holder.

Vehicle overloading can occur in a number of ways:

- the maximum permitted weight to which the vehicle has been plated (often referred to as the gross vehicle weight GVW) for the specific vehicle being used is exceeded

- the maximum permitted axle and wheel weight for the specific vehicle being used is exceeded

Drivers can make use of weighbridges to check that the gross vehicle weight of their vehicle does not exceed its plated weight limit. However in the case of loading in farms and forests there is a relatively small likelihood of a weighbridge being located nearby. In addition whilst weighbridges show gross vehicle weight, many do not readily give axle weight information.

Instead of risk being overloaded, many hauliers run their vehicles with less than full loads. Whilst this overcomes the possibility of overloading convictions it is inefficient as the vehicle is carrying less than it is capable of.

By using an on-board weighing system it is possible for the driver to ensure that the vehicle is neither over or under-loaded. The on-board weigher is attached to the vehicle and ensures that the load put onto the vehicle is the maximum load possible first time. On board weighing systems are extremely useful when transporting products that can change in bulk density due to water and moisture absorption, such as bricks, grain and wood chips.

A number of different on-board weighing systems are available, which are capable of providing the driver with varying degrees of detail about the weight of the load. The system comprises sensors (load cells) fitted between the body of the vehicle and the chassis to measure the payload of the body. Usually a weight indicator unit is located in the driver's cab, providing the driver with a digital display of the weight being carried. In the case of an articulated vehicle the indicator system can be fitted to the trailer so that the system still operates even if tractor units are changed. There are three main types of on-board weighing system:

Basic system - provides payload weight information only

Intermediate system - provides payload weight and front and rear load distribution information

Sophisticated system - provides payload weight, tare weight, gross vehicle weight and axle weight information

The weighing system can also incorporate an alarm which sounds when pre-set conditions are exceeded. On-board weighers can either be fitted to new vehicles or trailers or can be retro fitted to existing equipment.

For further information see:

Banner.S, "Weighing up the Benefits" in Commercial Motor, 8-14 September 1994, pp.40-41.

Jarvis.B, "Get on board" in Commercial Motor, 19-25 October 1995, pp.40-41.

Lowe.D, The Transport Manager's Handbook, Kogan Page: London, 1995.

Spencer.K (ed), The Essential Tipper Handbook, Roadway Publications, Surrey, 1994.

A.12.3 Automatic Sheeting Systems

Biomass loads such as straw, forestry residues and coppice will have to be sheeted if transported on open-top road transport vehicles. Loads carried by tippers and other semi-trailers and rigid vehicles can be covered using a number of sheeting systems which are available. These systems can be either fully or semi-automatic, and are generally purpose-built assemblies attached to the vehicle body. They enable the load to be sheeted and unsheeted from ground level using simple mechanical aids such as a crank handle, or automatically via controls in the driver's cab.

Currently available automatic sheeting systems can be electrically, pneumatically, or hydraulically powered and can work by unrolling sheeting from the front to the back of the vehicle body; unrolling sheets from side to side; sliding the sheet along runners or wires from front to back or side; and levering or "flipping" the sheets from centre to side or from front to back.

Automatic or semi-automatic sheeting systems reduce sheeting times and remove the need for drivers to go onto the tops of vehicles and thereby risk slipping or falling. The Health and Safety Executive encourages and promotes the use of such systems to help reduce the number of driver accidents associated with manual sheeting.

For further details see:

Health and Safety Executive, Workplace Transport Safety: Guidance for Employers, HMSO: London, 1995.

Jarvis.B, "Cover Up" in Commercial Motor, 27 April - 3 May 1995, pp.64-65.

A.12.4 Walking floor and "Ejectaload" systems

Two non-tipping load discharge systems can also be used in conjunction with tipper- or curtainsided-type vehicles, the walking floor system and the "Ejectaload". Both can be built in either rigid or articulated form. The advantage of these systems over the standard tipping body is that their volume capacity can be even greater than a standard tipper and they combine both easy loading from the top with easy unloading. These systems do not require the same degree of level, stable ground conditions that are essential when tipping a vehicle. There is however a payload penalty associated with using this type of equipment; a non-static floor typically weighs between 1 and 1.5 tonnes more than a standard floor. The other disadvantages of these systems are the extra capital expenditure and also the extra maintenance costs involved in keeping the mechanism in good working order.

The walking floor system makes use of hydraulically-driven reciprocating floor planks (usually twelve or twenty four planks made of aluminium or steel). This system is capable of discharging a load in approximately 7 minutes and can also be used to vibrate the load whilst it is being loaded helping to compact it and achieve a better payload.

The "Ejectaload" system discharges its load by means of a fabricated blade which moves the full length of the body and is powered by a horizontally-mounted hard-chromed double-acting ram. The rear tailgate is raised hydraulically by operating controls either at the front of the trailer or from the vehicle cab.

For further information on these systems see:

Banner.S, "Walking back to happiness" in Commercial Motor, 18-24 August 1994, pp.38-39.

Cunnane.P, "Ocean Harvest" in Commercial Motor, 18-24 August 1994, pp.40-41.

Hyva, Hyva Floor Systems, Hyva: Manchester, 1994.

Spencer.K (ed), The Essential Tipper Handbook, Roadway Publications: Surrey, 1994.

APPENDIX 13 BIOMASS FUEL COSTING AND PAYMENT BASIS

A number of payment and contract agreements will have to be drawn up in biomass supply systems. The fuel supplier and the power station operator will need to reach such an agreement, and the fuel supplier will also have to arrange payment levels and contracts with transport, agricultural and forestry contractors working for them, and farmers and forest owners providing the biomass fuel or their land.

Ideally all these payments and contracts for biomass fuel supply should be based on the calorific value of the biomass. By agreeing payments on a £/GJ basis, this would reflect the wet weight and dry matter content of the fuel. Additional specifications such as wood chip and bale size, tree species, and acceptable dry matter content could be agreed and incorporated into the contract.

In Sweden contracts between fuel suppliers and power station operators tend to be based on annual calorific values (Allen and Owen, 1995). Therefore if there is a poor harvest or high dry matter losses during storage the fuel supplier has to make up the total calorific value required by other means (i.e. imports, forestry industry by-products etc).

However whilst payment based on energy value may prove acceptable between fuel supplier and power station operator, contractors are not likely to be so keen on such an arrangement as they do not traditionally agree payments based on energy value (or even a dry tonnage basis). They are more familiar with either wet weight or volume as the key factor in the price paid for work conducted and either of these bases truly reflect the work that they have had to perform to harvest, process or transport biomass (i.e. they have had to fell, handle, process or transport wet not dry fuel).

Much of the specialist equipment used by contractors will have to be purchased specifically for biomass operations (although they may have some suitable existing equipment, they are unlikely to have a sufficient amount of machinery to cope with the daily demands of biomass work). In the case of road transport the vehicles will, in most biomass schemes, have to be specially designed and constructed for the operation. Therefore, given the necessary vehicle fleet requirements to service a power station (see section 10.3), the transport contractor will have to make substantial capital investments. In return he (and agricultural and forestry contractors) is likely to want a relatively long term contract with the fuel supplier/plant operator.

Another important issue to consider in drawing up contracts and agreeing payments is when the different parties will be paid (Forest Industry Group, 1996). If farmers, forest owners and agricultural/forestry contractors do not get paid until the biomass is supplied to the power station, they will not be paid for a long time after work has been conducted given the relatively long storage periods that will be necessary.

APPENDIX 14 CALCULATION OF TRAFFIC-RELATED IMPACTS OF A PROPOSED POWER STATION

This appendix contains further details of the assessment and calculation of the traffic-related impacts, undertaken on behalf of the applicant, of the proposed biomass power station discussed in section 11.5.2.

Potential traffic-related impacts

A number of potential traffic-related impacts associated with both operation, and construction, of the proposed biomass power station were identified. These were:

- Road traffic noise impact;
- Traffic-related air pollution;
- Effects on other road-users.

Brief summary of assessment procedure

- The assessment was based on a desk study using recent traffic count information and data generated by the company putting forward the development proposal;
- Baseline environmental conditions for the relevant road network were established for 1993, 1995 and 1998;
- Predicted traffic-related impacts of the proposed development were to be based on the difference between the baseline traffic data (i.e. if the development had not taken place) and generated operational traffic flows of the power station;
- Potential traffic-related impacts were identified for the proposed scheme;
- Operational traffic levels for the proposed scheme were generated and potential impacts assessed;
- The assessment methodology and criteria used in this instance were produced by the Department of Transport (DoT).

Establishing baseline information

The extent of the road network associated with the development was established and also potential receptors of environmental impacts.

Baseline traffic flows - were established through traffic counts for access roads to the proposed development. The traffic flows were projected to provide the 18-hour baseline (two-way) flows for the first year of operation.

Baseline traffic-related noise - was assessed using the standard DoT approach. Receptor distances and vehicle speeds were assumed for the roads under consideration. In this assessment baseline traffic-related noise did not exceed 68 dB(A) $L_{A10,\ 18hour}$ (the upper limit normally acceptable).

Baseline traffic-related air pollution - Predicted levels of traffic-related air pollution concentrations in 1998 were calculated.