Harvesting and Processing Forest Biomass for Energy Production in Ireland

The ForestEnergy 2006 Programme

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First published in 2007 by COFORD, National Council for Forest Research and Development, Dublin, Ireland.

ISBN 1 902696 56 5

Title: Harvesting and processing forest biomass for energy production in Ireland. The ForestEnergy 2006 programme.
Authors: Pieter D. Kofman and Tom Kent.

Citation: Kofman, P.D. and Kent, T. *Harvesting and processing forest biomass for energy production in Ireland. The ForestEnergy 2006 programme.* COFORD, Dublin.

FOREWORD

Ireland's unsustainable dependence on fossil fuels has been documented in numerous reports and policy statements, going back as far as 1973 and the first oil crisis. Despite the reports and subsequent supply shocks, the use of oil and gas has surged ahead in the intervening period, particularly during the past decade of unprecdented economic growth. This is illustrated by the fact that Ireland imported nine million tonnes of oil in 2004, double the level that occurred in 1990 (Forfás report - *A Baseline Assessment of Ireland's Oil Dependence*). Today, over 95% of Ireland's total energy requirement energy is still supplied in the form of fossil fuel.

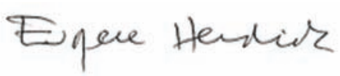
Recent events and policy developments have, however, at last begun to turn energy use and policy towards sustainable sources and the development of secure national supplies. Chief among these are energy prices, commitments under the Kyoto Protocol to reduce greenhouse gas emissions from fossil fuels, and security of supply needs.

On the price front, the cost of oil more than doubled between 2002 and 2006, with indications that prices will stay at the current $60-70/barrel level over the medium to long term. Likewise, additional costs will be incurred in meeting Kyoto compliance, given current emission levels which are 12-13% above the permitted threshold. Depending on the price of carbon dioxide, this will cost the exchequer between €200-300 million between now and the end of 2012. These factors, and the pressing need to secure a larger proportion of supply from indigenous sources, more than make the economic and strategic case for a radical change in energy policy and use.

Government and EU policy have, over the past year particularly, responded to the need to put in place fundamental changes in energy policy. Ambitious targets have been set for the use of renewables, including wood biomass. For example, the recent Bioenergy Action Plan of the Department of Communications, Marine and Natural Resources foresees that the peat-fuelled power stations (all of which are now owned by the state) will be co-fired by 30% renewable material by 2015, and that 12% of all residential and commercial heating will be powered by renewable sources (wood chip, solar, etc.) by 2020. While short rotation coppice and miscanthus will contribute to these targets, the reality is that forest-derived biomass is by far the largest potential source for these uses, and needs to be rapidly and cost-effectively mobilised if the targets are to be taken seriously.

Ireland is in the fortunate position that the record afforestation programmes of the past twenty years are beginning to become a significant source of wood-for-energy. Developing this sector requires concerted R&D and demonstration, allied to policy measures at both the supply and conversion stages, and of course investment by business. COFORD is playing its role in developing wood energy supply chains through the ForestEnergy programme that is described in this report. Over the past year, in collaboration with Teagasc, the programme has demonstrated and costed a range of options for the production of wood chip fuel, while at the same time carrying out important work on fuel quality issues, such as moisture content variation and chip specification.

This report outlines the first comprehensive investigation of wood supply chain costings and wood fuel quality carried out in Ireland. It is an important step in what COFORD anticipates will be a significant part of forest R&D over the coming years, and adds to earlier policy-related reports and publications on wood energy. It will be a useful benchmark for those considering investing in the wood energy area and provides a good basis for future work and investigations.



Dr Eugene Hendrick

Director

BROLLACH

Chomh fada siar le 1973 agus an chéad ghéarchéim ola, táthar tar éis doiciméadú a dhéanamh ar spleáchas neamh-inbhuanaithe na hÉireann ar bhreoslaí iontaise i réimse tuarascálacha agus ráitis pholasaí. D'ainneoin na tuarascálacha agus croití soláthair iartheachtach, tá borradh tagtha in úsáid gáis agus ola sa tréimhse eadránach, go háirithe le linn an deich mbliana atá imithe d'fhás eacnamaíoch gan fasach. Tá sé seo léirithe ag an bhfíric gur iompórtáil Éire naoi milliún tonna ola i 2004, dúbailt ar an leibhéal a bhí ann i 1990 (tuarascáil Forfás – *Measúnú Bonnlíne ar Bhrath na hÉireann ar Ola*). Inniu, tá os cionn 95% de riachtanas fuinnimh iomlán na hÉireann fós á sholáthar i bhfoirm breosla iontaise.

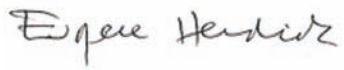
Mar sin féin, ar deireadh thiar thall tá eachtraí agus forbairtí polasaí úrnua tar éis tosú ag casadh úsáid fuinnimh agus polasaí i dtreo foinsí inbhuanaithe agus an fhorbairt de sholáthairtí náisiúnta daingne. Chun tosaigh ina measc seo tá praghsanna fuinnimh, gealltanais faoi Phrótacal Kyoto chun astuithe gáis ceaptha teasa ó bhreoslaí iontaise a laghdú, agus slándáil na riachtanas soláthair.

Ar éadan an phraghais, idir 2002 agus 2006 mhéadaigh an costas ola breis agus dúbailt, le comharthaí go bhfanfaidh na praghsanna ag an leibhéal reatha de $60-70/bairille thar an meántréimhse go fadtréimhse. Mar an gcéanna, tabhófar costais bhreise i mbaint amach comhlíonadh Kyoto, tugtha go bhfuil leibhéil reatha na n-astuithe 12-13% thar an tairseach ceadaithe. Ag brath ar phraghas na dé-ocsaíde charbóin, cosnóidh sé seo idir €200-300 milliún ar an státchiste idir é seo agus deireadh 2012. Cruthaíonn na fachtóirí seo, agus an gá práinneach chun líon soláthair níos mó ó foinse dúchasaigh a dhaingniú, an cás eacnamaíoch agus straitéiseach le haghaidh athrú radacach i bpolasaí agus úsáid fuinnimh.

Le bliain anuas ach go háirithe, tá polasaí AE agus Rialtais tar éis freagairt don ghá chun athruithe mbunúsacha a fheidhmiú i bpolasaí fuinnimh. Táthar tar éis spriocanna ardaidhmeannach a leagadh amach le haghaidh úsáid na n-ábhar inathnuaite, lena n-áirítear bithmhais adhmaid. Mar shampla, tuarann Plean Gníomhaíochta Bithfhuinnimh úrnua de chuid na Roinne Cumarsáide, Mara agus Acmhainní Nádúrtha go mbeidh stáisiúin chumhachta móinbhreosla (iad ar fad atá faoi úinéireacht an stát anois) chomhbhreoslaithe ag 30% amhábhar inathnuaite faoi 2015, agus go mbeidh 12% de theas tráchtála agus cónaithe uile á chumhachtú ag foinsí inathnuaite (slis adhmaid, gréine, s.rl.) faoi 2020. Cé go gcuirfidh roschoill gearruainíochta agus miscanthus leis na spriocanna seo, i bhfírinne is é bithmhais foraois-dhíorthaithe an fhoinse phoitéinseal is mó le haghaidh na húsáidí seo, agus tá sé riachtanach go ndéanfaí é a shlógadh go gasta agus costas-éifeachtach má táthar chun a bheith dáiríre i dtaobh na spriocanna.

Tá Éire ámharach go bhfuil cláir fhoraoisithe curiarrachta le fiche bliain anuas tar éis tosú a bheith mar fhoinse éifeachtach de adhmad um fhuinneamh. De dhíth ar fhorbairt na hearnála seo tá T&F comhaontaithe agus taispeántas, comhghuaillithe le bearta polasaí ag céimeanna soláthair agus comhshó araon, agus gan amhras infheistíocht ghnó. Tá a ról á ghlacadh ag COFORD i slabhraí an tsoláthair um fhuinneamh adhmaid a fhorbairt trí an clár ForestEnergy arna chuir síos sa tuarascáil seo. I rith na bliana atá imithe, i gcomhoibriú le Teagasc, tá an clár tar éis réimse roghanna a léiriú agus a chostáil le haghaidh táirgeadh breosla slis adhmaid, agus ag an am céanna ag baint amach obair thábhachtach ar shaincheisteanna um cháilíocht bhreosla, ár nós éagsúlacht taistoillte agus sonraíocht slise.

Imlíníonn an tuarascáil seo an chéad fhiosrú cuimsitheach ar chostálacha slabhra an tsoláthair adhmaid agus cáilíocht bhreosla adhmaid bainte amach in Éirinn. Is céim thábhachtach í sa mhéid a réamh-mheasann COFORD a bheidh mar chuid suntasach de T&F foraoise sna blianta atá le teacht, agus cuirtear le tuarascálacha agus foilseacháin polasaí-coibhneasta níos luaithe ar fhuinneamh adhmaid. Beidh sé mar tagarmharc úsáideach dóibh siúd atá ag breathnú ar infheistíocht sa réimse fuinnimh adhmaid agus soláthraítear bunús maith le haghaidh obair agus fiosruithe na todhchaí.



An Dr Eugene Hendrick

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CEN/TS 14961 *Solid biofuels – Fuel specifications and classes*.

CEN/TS 15103 *Solid biofuels – Methods for the determination of bulk density.*

IS CEN/TS 15149-1 *Solid biofuels – Methods for the determination of particle size distribution – Part 1: Oscillating screen method using sieve apertures of 3.15 mm and above*.

IS CEN/TS 15149-2 *Solid biofuels – Methods for the determination of particle size distribution – Part 2: Vibrating screen method using sieve apertures of 3.15 mm and below.*

IS CEN/TS 15149-3 *Solid biofuels – Methods for the determination of particle size distribution – Part 3: Rotary screen method.*

These can be obtained from the National Standards Authority of Ireland (NSAI): www.standards.ie

ACKNOWLEDGEMENTS

The ForestEnergy2006 programme relied heavily on many people, institutions and organisations to become a success. Therefore the authors would like to thank the following organisations and people:

- Teagasc for organising the demonstrations and for their painstaking preparations of the sites for the demonstrations;
- The forest owners for allowing us to operate in their stands;
- The management companies Greenbelt, SWS, Forestry Services for their assistance with the forest owners and for obtaining the felling licences at short notice as well as for getting the forest roads built;
- Medite for the use of lorries and weighbridge;
- The Forest Service for expediting the felling licences and roading grants;
- The contractors, both Irish and Danish for their tenacity, patience and hard work;
- The students of WIT on job placement, who did all the measurement work often under difficult conditions;
- Bord na Móna for transporting all the chip produced to the Edenderry power plant;
- The staff of COFORD for all their involvement in ForestEnergy2006;
- The management committee for their help in putting the research programme together and for their guidance.

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EXECUTIVE SUMMARY

Wood for energy is a relatively new concept in Ireland. To facilitate the development of this high-potential sector, COFORD launched the ForestEnergy 2006 technology transfer programme.

The objectives of this programme were to demonstrate the use of harvesting methods and machines used in other European countries under Irish conditions; document the productivity and costs of these methods; present working methods during felling and chipping at public demonstrations; assess the quality of the fuel produced by measuring the moisture content at time of felling and at time of chipping; and evaluate the particle size distribution of the chips.

The chips to be produced during this programme were intended for industrial scale installations, not for small domestic-sized boilers. All the chips were taken to Edenderry Power where they were co-fired with the normal peat fuel.

The technology transfer programme was successful: approximately 70 ha of thinnings and clearfells were harvested and chipped, with a total production of some 2,000 tonnes of fuel. The stands were located across the country from Roscommon to Laois, to Waterford and Cork. Commercially grown tree species in Ireland were represented in the trials: Sitka spruce (three stands), ash and sycamore (one mixed stand), birch (three stands) and lodgepole pine (one stand). Six demonstrations were held during the felling phase in spring, attracting 850 visitors, while 1,150 participants attended the five chipping demonstrations in autumn. All demonstrations were organised by Teagasc. The programme concluded with a conference, attended by over 150 delegates.

Machines used in the demonstrations were:

- a Silvatec feller-buncher;
- a Silvatec terrain chipper with an additional chip forwarder;
- a TP280 tractor chipper with tractor and trailer;
- a Jenz HEM700 truck chipper.

Several new harvesting methods were introduced:

- the whole tree method, where the trees are felled and left to dry on the spot until they are chipped in the stand. Felling is done either by chainsaw or feller-buncher;
- the whole stem method, where the trees are felled by harvester and crudely delimbed to create a brash mat;
- the integrated method, where the valuable small sawlog and stake are harvested and anything else is cut as crudely delimbed tree sections of 3-6 m;
- a chemical thinning, where the trees are killed while standing and left to dry. The chipper then fells and chips the trees in one operation.

Before harvesting, stocking and dbh distribution were measured in all stands. Areas were sub-divided into plots for each of the harvesting methods and machines. The plots were measured again after harvesting to establish thinning intensity and volume removal. Many measurements were carried out during harvesting and chipping so that the time required for each method and the productivity of the machines could be documented.

The whole tree method was the cheapest option to produce wood chip for energy, costing up to one third of traditional roundwood harvesting and chipping at roadside. In fact, the traditional roundwood method was the most expensive. The whole stem method, where a brash mat is created and trees are chipped in the stand, was also very expensive compared to the whole tree method. The chemical thinning method, with felling and chipping in the stand, was studied on very few loads, but appeared to be cheaper than the roundwood method, but more expensive than chipping of whole trees. It is important to point out that the whole tree method can only be used on soils with reasonable bearing capacity as there is no brash mat produced that will support the machines.

There was little difference in the cost per produced unit of chips between the TP280 tractor-mounted chipper and the Silvatec terrain chipper.

While the productivity of the Silvatec was three to four times higher than the tractor-mounted chipper, this was balanced by a similar ratio between the hourly costs of the two machines.

An overview of all methods and stands and an average cost per cubic metre solid biomass is given in Table 1. The machines used were not fully adapted to typical Irish terrain conditions. They need either wider tyres or with band tracks (to reduce the need for a brash mat).

By harvesting whole trees or crudely delimbed assortments, additional biomass can be extracted from the stand. However, amounts varied widely, because in some stands some or parts of the trees had to be placed under the wheels of the machines to protect the soil. However, on average, in the Sitka spruce stands, 50% additional biomass was removed using the whole tree method. It is important to note that only wood was removed, which has a low nutrient content. Most of the nutrients in a tree are in the leaves and needles, which had dropped off and were left on the site following summer drying.

The weather during the seasoning period was about average for rainfall and slightly higher than average for temperature. Despite this, wood drying varied considerably between assortments and sites. The conifer wholetree assortments had the highest moisture losses, probably due to the transpiration effect of the attached needles. Uncovered roundwood and other energywood did not lose moisture. The clearfelled assortments dried far better than the thinned assortments, probably due to greater wind exposure.

The particle size classification showed that all assortments produced wood chip where at least 80% of the material passed a screen with 45 mm round holes. Also, all assortments produced chip with less than 5% fines, with the exception of lodgepole pine which still had many needles attached. The oversize percentage was rarely over 2% for any assortment. Despite this, the European Technical Specification 14961 rejected many assortments and classed most assortments as either P100 or P63. This was due to the presence of a higher proportion of oversize particles than allowed by the specification.

Bulk density tests indicated that, as expected, broadleaf chips have a higher bulk density than conifer chips.

The energy density calculations allowed the estimation of production costs based on energy of wood chip produced. This indicated that whole tree spruce wood chip was produced for €2.03 per Giga joule (GJ). This was the most economic energy production system, though terrain chipped broadleaves also performed very well, considering the mean volume per tree.

The conclusion of the trials in 2006 is that wood for energy is a viable product from Irish forests, but more research should be carried out to obtain more reliable data on productivity, costs, increase in biomass removal, and ways to reduce moisture content through covered storage.

Table 1: Overview of all harvesting and chipping methods, crops included and costs at roadside.

Assortment	Felling method	Stand	Chipper	Average cost at roadside €/m^3 solid biomass
Whole tree	Chainsaw	Sitka spruce thin	Tractor TP280	€19.34
Whole tree	Chainsaw	Sitka spruce thin	Silvatec	€14.31
Whole tree	Feller-buncher	Sitka spruce thin	Silvatec	€18.86
Whole stem	Harvester	Sitka spruce thin	Silvatec	€40.30
Whole tree chemical	Silvatec	Sitka spruce thin	Silvatec	€24.62
Tree section	Harvester/forwarder	Sitka spruce thin	Jenz	€52.43
Pulpwood	Harvester/forwarder	Sitka spruce thin	Jenz	€46.05
Whole tree	Chainsaw	Ash/sycamore	Tractor TP280	€26.88
Whole tree	Chainsaw	Ash/sycamore	Silvatec	€27.84
Whole tree	Feller-buncher	Ash/sycamore	Silvatec	€30.94
Whole tree	Feller-buncher/forwarder	Ash	Jenz	€44.36
Whole tree	Feller-buncher	Planted birch	Tractor TP280	€37.08
Whole tree	Feller-buncher	Naturally regenerated birch	Tractor TP280	€39.37
Whole tree	Feller-buncher	Sitka spruce/birch	Silvatec	€37.73
Whole tree	Feller-buncher	Lodgepole pine	Silvatec	€18.23
Whole tree	Chainsaw	Lodgepole pine	Silvatec	€17.58

1. INTRODUCTION

The wood for energy sector is not well developed in Ireland, and as such is in a 'chicken and egg' situation. On one hand people would like to save money by using wood as a fuel, but they have difficulty finding fuel suppliers. On the other hand, potential producers of wood fuel are reluctant to invest money in wood fuel harvesting machinery because they have no customers and because they are not used to the harvesting systems. There is also some uncertainty about whether machines and methods developed in other countries are suitable for Irish conditions.

To overcome these barriers, COFORD launched ForestEnergy2006, a technology transfer programme to investigate large scale wood fuel harvesting from private forests for supply to large installations.

The aims of ForestEnergy 2006 were:

- to demonstrate suitable equipment for harvesting wood for energy from other European countries under Irish conditions;
- to document the productivity and costs of these systems;
- to study the natural drying of wood for energy under Irish conditions;
- to investigate the quality of the fuel in terms of particle size distribution and bulk density .

In 2005, during the demonstration of a Danish Silvatec chipper processing green trees in Ireland, it became clear that there was a need to demonstrate the whole harvesting chain and also to wait for the trees to dry before chipping. ForestEnergy2006 therefore included both felling and chipping.

A variety of stands and locations were selected: three Sitka spruce first thinnings, one ash/sycamore stand, and clearfells of naturally regenerated birch and poor quality lodgepole pine on cutaway Midland bogs.

Harvesting operations were publicly demonstrated, with participants led on a guided tour of methods and machines in operation. Demonstrationss were held in early spring during felling, and late summer during chipping. The final results were presented at a conference in December.

This report presents the results of all the studies carried out on the machines, the drying behaviour of the harvested wood, and the quality of the wood chip produced.

2. TRIAL DESCRIPTIONS

STAND DESCRIPTIONS

The requirement of ForestEnergy 2006 to demonstrate a range of harvesting and chipping systems placed a constraint on the site selection for the programme. Sites had to be geographically located to satisfy the conflicting needs for a representative spread for public demonstrations, and minimising between-site transportation as the machines were available for a limited time. A minimum area of 15 ha was set for conifer sites and 10 ha for the broadleaf site to effectively demonstrate and record performance of the range of systems.

Sites needed to be homogeneous, without large gaps caused by frost or other factors, to ensure comparable conditions between systems. Good bearing capacity, no waterlogging, and no steep slopes were requirements at all sites to allow all methods to be demonstrated.

The sites had to be accessible to machinery and transport vehicles. Sites with existing roads were preferred. The forest landing area needed to be able to accommodate wood in three different piles, and have sufficient access for curtain-sider lorries, either by backing in or by having a turntable. The landing area needed to be wide enough to accommodate piles of wood, the chipper and curtain-sider next to each other.

General geographic areas were targeted for different sites, and sites were identified in all target regions. A suitable conifer/broadleaf site in intimate mixture could not be found, so a second broadleaf site was selected. Bord na Móna trial sites were added to the programme. Figure 2.1 indicates the target regions and actual site locations.

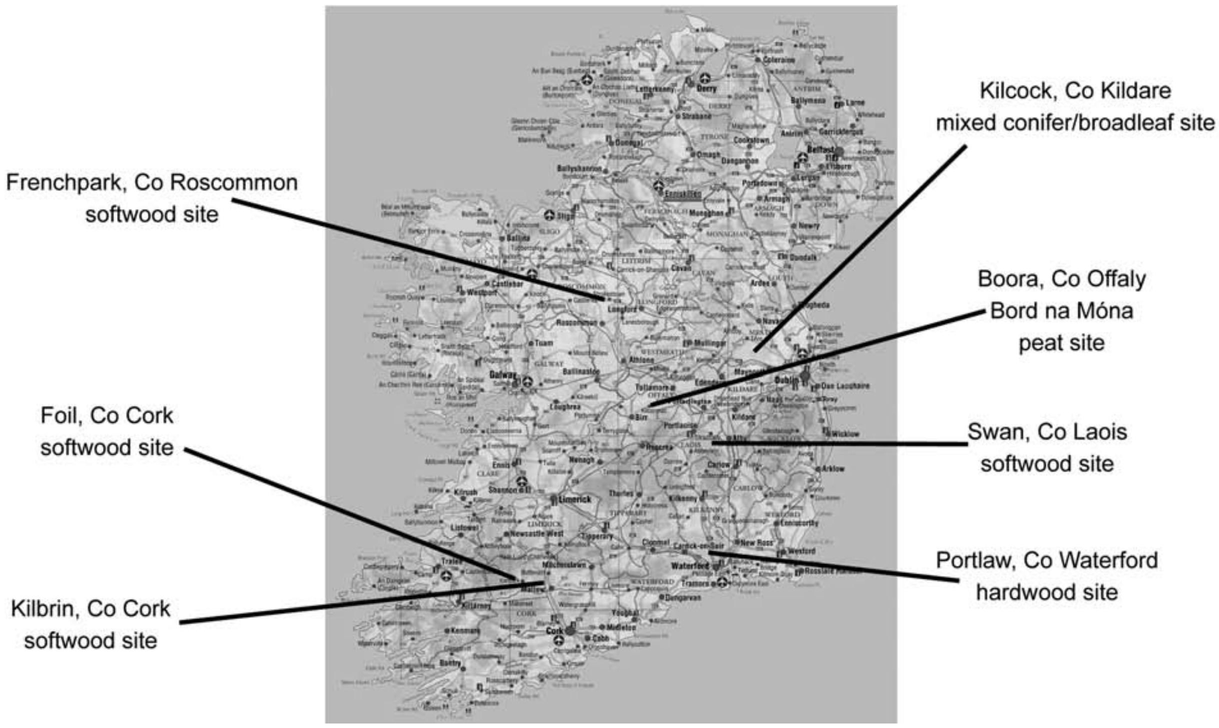

Figure 2.1: ForestEnergy 2006 trial sites.

Conifer stand descriptions

Three conifer sites were planned, but in fact four sites were selected. Two sites were used for the trials in Cork as there was insufficient productive area at each one to trial all systems.

All sites consisted of 100% Sitka spruce, at a good stocking rate and diameter range of 12 – 16 cm mean dbh. Only Swan and Kilbrin had good access with roads constructed. Access had to be created in both Frenchpark and Foil, but this was accomplished in time for harvesting operations to begin. Table 2.1 provides the basic site details.

Broadleaf stand description

The original plan was to carry out work on both a pure broadleaf stand and an intimately mixed broadleaf/conifer stand, but a mixed stand could not be identified. A second broadleaf stand was identified at Kilcock, Co Kildare. A public demonstration of mechanical harvesting and firewood production was held at this site in March 2006 only.

The broadleaf site at Portlaw, Co Waterford, consisted of two stands, one each of ash and sycamore. The total area harvested amounted to 7.2 ha, made up of 4 ha of sycamore and 3.2 ha of ash. This site was very fertile, being an alluvial soil adjacent to the River Suir. The trees were nine years old, but already at a top height of 9 m and mean dbh of 8 cm. The stocking was 2640 trees per hectare. The site was adjacent to the public road and a bell mouth entrance, 100 m of forest road and a turntable were constructed prior to harvesting.

Cutway peatland (Bord na Móna) trial description

Bord na Móna identified four stands at Boora that could be clearfelled and chipped. The lodgepole pine stand consisted of stems with very poor form and heavy branching. The planted birch stand was a shelter belt, seven rows wide. The naturally regenerated birch stand had developed on a small area over a period of 15 to 20 years. The Sitka spruce/birch site was originally a pure plantation of Sitka spruce that had failed and hadbecome colonised almost completely by birch. Site details for each stand are summarised in Table 2.2.

STUDY METHODS

Stand data were collected during inventories before and after harvesting. Time studies measured productivity during harvesting and chipping operations. Samples were taken for moisture content to investigate the effects of seasoning. The quality of the chips was determined.

Inventory before and after harvesting

Stem number and dbh measurements were recorded at all stands before harvesting began. The stands were sub-divided into marked plots. The area of each plot was established using a GPS.

Table 2.1: Site details for conifer thinning sites.

Conifer Sites	Frenchpark	Swan	Kilbrin	Foil
Age (years)	15	15	14	16
Treated area (ha)	18.6	16.1	9.3	6.7
Species	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce
Estimated yield class	22	20	20	22
Mean dbh (cm)	15.0	13.8	12.5	15.5
Mean height (m)	10.2	9.5	8.7	11.2
Stocking (trees/ha)	2552	2326	2612	2477

Table 2.2: Site details for cutway peatland (Bord na Móna) trial sites.

Plots	Lodgepole pine	Planted birch	Naturally regenerated birch	Sitka spruce/birch
Age	13	10	15+	15
Treated area (ha)	5.4	0.71	0.11	0.44
Mean dbh (cm)	9	9	11	10
Mean height (m)	5.2	7	9.2	6.2
Stocking (trees/ha)	2102	2649	2617	3101

During and after felling, trees were measured to establish stand height and the diameter and size of the harvested trees. These measurements were carried out in all stands.

A second investory was carried out after the harvesting and chipping operations to determine stem number after thinning, and thus the thinning intensity.

Time study

Time studies were carried out for all machines during harvesting and chipping. For each operation the productive time was recorded, as well as delay times and unproductive time.

Productive time is the time used to produce something useful such as felling a tree, moving between trees, loading wood on a forwarder, unloading etc. Delay times can be caused by machine failure, or personnel requirements such as rest or lunch breaks. Unproductive time would be when the machine has to be stopped, e.g. to answer a telephone call. Each of these instances was recorded.

In the simple version of the time study, the stopwatch was started at a given time and the number of produced units counted until the stopwatch was stopped again. If any unproductive or delay times occurred, these were recorded. The time per unit was calculated by dividing the total productive time by the number of produced units. For example, the chainsaw operator felled a number of trees in a given time span.

Another simple study recorded how much time a single cycle would take: the stopwatch was started when the forwarder left the road and was stopped after the machine had unloaded again at the roadside.

More advanced time studies were carried out using a Husky field computer and time study software SIWORK3. This software makes it possible to record very small time elements. It is possible, for example, to sub-divide the felling of a tree by chainsaw in 5 to 6 smaller time elements. The main advantage of this system is that the data file can be transferred directly to another computer and the data imported in a spreadsheet for detailed analysis and calculations.

During felling operations there were up to four different simultaneous operations, and three during chipping.

Moisture content

During felling in February/March the initial moisture content of the felled trees was established.

Samples were taken at each stand from the following assortments:

- whole trees;
- whole stems;
- 3 m roundwood;
- energy wood (3-6 m crudely delimbed roundwood).

Five trees/logs were taken from each assortment and chipped individually with a small chipper (TP200 turntable). The machine was towed from site to site and had its own 52 kW diesel engine.

From each separate tree or log, five samples were taken and put into paper bags. The bags were identified and weighed within minutes of sampling. They were transported to Waterford Institute of Technology where they were placed in a drying cabinet for 48 hours, at a temperature of 105°C. This is a procedure adapted from the CEN/TS 14774-2 Technical Specification *Solid biofuels – Methods for the determination of moisture content – over dry method – Part 2: Total moisture – simplified method*. The adaptation was that the samples were dried in the original paper bags. The advantage of using paper bags is that the samples are not handled again and can start drying the minute they are inserted. Storing the samples in a dry, well ventilated room allows moisture to evaporate before the samples enter the drying cabinet. If the samples had been collected in plastic bags, condensation would have occurred on the inside of the bags and small particles would have stuck to the inside of the bags. The samples would have to be handled again just before they went into the drying cabinet. Since there was a large number of samples, a long time delay in drying was expected. If the samples had been stored in plastic bags, fermentation would probably have occurred.

During chipping in August/September many samples were taken from the seasoned wood. Three to five samples were taken from each chipper load as well as from each truck load that was filled by the truck chipper. These samples were also dried at 105°C.

Size classification

For size classification of the chips, large 60 litre samples were placed in plastic bags. These bags were transported to Denmark, since there was no size classification equipment available in Ireland at the time.

Each sample was pre-dried in a ventilated drier to a moisture content of below 20%. The samples were then sub-divided into four smaller samples in a sample divider. If the sub-samples were not small enough, two of the first sub-samples were mixed and sub-divided again until samples of 2 to 3 kg were obtained.

Three of the four smaller samples were used for size classification, while the fourth was stored as a back-up until all classifications were finished and the data analysed.

The size classification was carried out according to CEN/TS 15149 *Solid biofuels – Methods for the determination of particle size distribution – Part 1: oscillating screen method using sieve apertures of 3.15 mm and above*.

The samples were put onto the top screen of the stack of sieves and the machine was operated for 15 minutes (Figure 2.2). The contents of each screen (63, 45, 16, 8, 3.15 mm round holes and bottom pan) were then weighed. After weighing, overlong particles (longer than 100 mm) were sorted out and divided into two classes: between 100 and 200 mm long and over 200 mm long. These classes were weighed again.

Figure 2.2: The oscillating screen for size distribution measurement of the chips.

The final particle size distribution measurement is the average of the results of the three sub-samples.

The results were also tested against the quality requirements as listed in CEN/TS 14961 *Solid biofuels – Fuel specifications and classes*.

Bulk density of the chips

CEN/TS 15103 *Solid biofuels – Methods for the determination of bulk density* was used to obtain the bulk density of the chips.

Round stainless steel pots of 50 litres were made according to the specification (Figure 2.3). These were filled to overflowing with chips and shaken to allow the contents to settle. The excess was removed with a scantling. The weight of the pot with chips was then measured. The measurement was repeated at least once.

In this way the wet bulk density (bulk density as received) was measured. Together with the moisture content of that particular load, the dry bulk density was calculated.

MACHINERY USED

Felling machines

In the late winter of 2005-2006, felling was carried out with a Gremo 958HPV (Figure 2.4) for all methods where assortments were produced. The machine was equipped with a Loglift parallel crane with 10 m reach and a SP551 harvesting head. The harvesting head can handle trees up to 43 cm in diameter. For some of the trials, especially where crude delimbing was required, the hydraulic pressure on the delimbing knives was reduced, so that they

Figure 2.3: Stainless steel pot for the bulk density measurement.

were almost in a floating position. In this way the maximum amount of green material was removed from the stems and a reasonable amount of the branches was left as stubs so as to increase the amount of biomass to be removed.

All the assortments produced by the Gremo harvester were forwarded to the roadside with a light Valmet 820 forwarder (Figure 2.5). This machine has a carrying capacity of 8,500 kg. The forwarder was equipped with band tracks on the rear wheels to increase the grip and the flotation of the machine.

Both the Gremo harvester and the Valmet forwarder were operated by William Houlihan and Co Ltd.

The Silvatec 656TH feller-buncher is a machine new to Ireland (Figure 2.6). In principle, the base machine could be any harvester, as the special features are around the harvesting head. The harvesting head is not equipped with feed rollers or delimbing knives. Instead, the head has two sets of arms, which can grab and hold one or more trees after they have been cut from the stump. The head has an extra stabilising cylinder, which makes it possible to handle trees in a standing position. Since this machine is mainly used for selection thinning, the trees are taken in a standing position from the stand and left in small bunches along the rack for chipping after summer drying. The head was mounted on a Silvatec crane with a reach of 7.5 m. The trees were felled by hydraulic chainsaw up to a maximum diameter of 30 cm.

The feller-buncher and its operator were hired from the Danish State Forest Service.

Figure 2.4: The Gremo harvester producing energy wood tree section.

Figure 2.5: The Valmet forwarder.

Figure 2.6: The Silvatec feller-buncher.

Chipping machines

Since the type of chipping machines to be used in the demonstrations were not yet available in Ireland, all machines were rented from Danish contractors.

Three different chippers were used:

- The Silvatec 878 CH terrain chipper with Silvatec chip forwarder;
- The TP280 tractor-mounted terrain chipper on a Valtra tractor with a high tipping trailer;
- The Jenz HEM700 truck chipper.

The Silvatec 878CH chipper has been designed especially for chipping whole trees in thinnings (Figure 2.7). The machine is rather narrow, to work in Danish stands. For the demonstrations in Ireland, wider tyres of 600 mm (compared to the usual 500 mm) were mounted. It would have been preferable to have the machine on band tracks as well, but the narrow build of the machine did not permit tracks to be mounted without major modifications.

The Silvatec has a disc chipper with a diameter of 120 cm and two knives. The chipper can handle trees up to a diameter of 35 cm. The trees are lifted into the chipper with a Cranab 290HL parallel crane. The grapple can double as a felling head to fell occasional trees that are in the way. The machine carries a container which can accumulate up to 16 m^3 loose volume of chip. The chips are delivered by lifting the entire container 3.5 m and then tipping over the rear hinge of the container so that the chips fall from a height into the loading bay of the chip forwarder. The chip container can be levelled hydraulically to compensate for side slopes up to 10 degrees.

Figure 2.7: The Silvatec terrain chipper.

The Silvatec chip forwarder (Figure 2.8) has a container that has a capacity equal to that of the chipper. The top boards and the front board can be opened hydraulically. When reversing towards the chipper, the driver can see through the chip forwarder because the head and rear board are open. Just before receiving the load, these boards are closed. After receiving the loads, the side boards are closed to compress the load slightly and to avoid spillage. After driving to the road, the chips can be unloaded from a height of 3.2 m. The entire container is lifted on a scissor-like mechanism and then tipped sideways. The lower side board is opened and the chips fall out. The lower side board can also be used to flip the chips further into the container.

Figure 2.8: The Silvatec chip forwarder.

The Silvatec chipper was operated by its Danish owner and the chip forwarder by his usual assistant.

The other terrain chipper was a Valtra tractor (Figure 2.9). The TP280 disc chipper was mounted on the three point linkage of the permanently reversed tractor. A special frame was mounted between the chipper and the tractor to carry the crane. All controls for both the chipper and the crane were mounted in the cabin of the tractor. The chipper has a capacity of maximum 28 cm stem diameter and has two knives. The spout of the chipper is elongated over the roof of the tractor to the chip trailer. On the former nose of the tractor a hitch has been made to which the high tipping trailer is attached. The trailer has a capacity of 12 m^3 loose volume of chip. The trailer tips at a height of 3.2 m. The drawbar of the trailer can be hydraulically steered to reduce the turning radius of this long set of equipment.

Figure 2.9: The Valtra TP280 terrain chipper with chip trailer.

The Valtra terrain chip combination was operated by its Danish owner.

The Jenz HEM700 chipper was mounted on a trailer and towed by a normal timber truck (Figure 2.10). In this case the pulling truck was a Scania 144/530, equipped with an Epsilon timber crane with

Figure 2.10: The Jenz HEM700 towed by a timber truck.

a reach of 9 m. The chipper is fed by the crane of the truck. The crane operator has a remote control in the cabin on the crane for the chipper. The Jenz HEM700 is a drum chipper with 20 small knives mounted in two spirals over the width of the drum. The advantage of the small knives is that if one gets damaged, it can be replaced easily without changing the others. The machine can handle stems up to 70 cm in diameter or stacks of smaller wood, which can fill the infeed opening of 70*100 cm. The machine is equipped with a spout that can rotate 360 degrees and the flap at the end of the spout can be adjusted. Both functions are controlled remotely. It is therefore possible to fill trucks standing either next to the machine or behind the machine. The chips can be blown over fairly long distances, as was shown when trucks were filled from the rear, where the loading bay was over 12 m long. The chipper is mounted on a turntable, so that the infeed table could be pointed at the stack of timber to allow the shortest possible travel length for the crane.

The machine was operated by its usual Danish operator.

WORKING METHODS

The working methods differed between the Sitka spruce, broadleaved and clearfell stands, but in all cases the harvesting was done well in advance of the chipping operation. The whole trees or whole stems remained in the forest for summer drying so that they drop their needles/leaves. The assortments were forwarded to the roadside. The industrial assortments were taken to the industry shortly afterwards, while the energy wood remained stacked at the roadside for chipping after summer drying. The piles of roundwood were usually covered by plastic to prevent rain from entering the pile and improve drying. The piles were only covered on the top, not the sides.

Sitka spruce stands

In the Sitka spruce stands six harvesting methods were used:

- row thinning, where the trees were felled by chainsaw and left in the stand as whole trees.
- selection thinning after row thinning by feller-buncher as whole trees.
- row and selection thinning, standard method by harvester with small sawlogs, stakewood and 3 m pulpwood. All assortments forwarded to the roadside.
- row and selection thinning, integrated method by harvester with small sawlogs, stakes and crudely delimbed 3-6 m tree sections. All assortments forwarded to the roadside.
- row and selection thinning, whole stem method by harvester.
- row thinning by chemical thinning.

Row thinning in Sitka spruce by chainsaw

This method is suitable for stands with a reasonable to good bearing capacity, since the method does not require any brash on the ground to improve the bearing capacity.

The first part of the first thinning is usually a row thinning (Figure 2.11), where every 6th or 7th row is felled. The trees are felled by chainsaw and left in a roof tile arrangement in the stand for seasoning. Small trees in the rows adjacent to the rack should be felled and placed on top of the trees of the rack.

Usually the rows are felled in such a way that the terrain chipper can later travel up one row and down the next. This also means that the rows must be interconnected at each end. This is done 5-10 m before the end of the lines if the lines do not end at a forest road. Making the cross rack this distance away from the end means the stand is less exposed to the wind. There must be enough space for the chipper to cross from one row to the next. Any drains that have to be crossed should be filled with logs to aid the pasage of the machine.

Whole trees should remain in the stand for seasoning or drying for at least one summer.

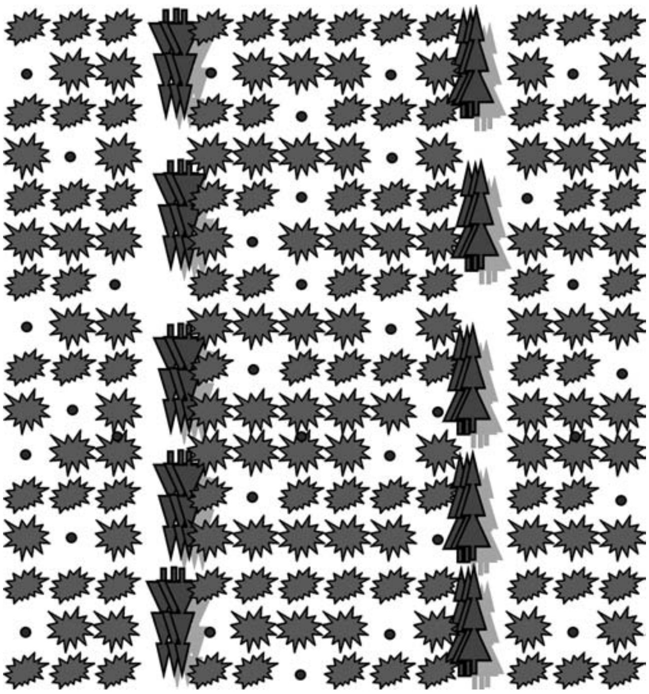

Figure 2.11: Schematic drawing of a row thinning.

Care must be taken during felling that trees are completely severed from the stump. Even a small connection between the stump and the tree will allow the tree to live on and will minimize natural drying.

When dry, the trees are chipped with a terrain chipper, either a self propelled machine like the Silvatec terrain chipper, or a crane-fed chipper mounted on a tractor pulling a high tip trailer.

Selection thinning in Sitka spruce by feller-buncher

This method is suitable for stands with a reasonable to good bearing capacity, since the method does not require any brash on the ground to improve the bearing capacity.

The second part of the first thinning, the selection thinning, is carried out in the rows remaining between those removed and chipped.

During this operation, the future crop trees are favoured and diseased, and deformed trees are removed. Birch or willow, where they occur,can be felled for chipping as well.

The feller-buncher reverses through the stand. The machine operator selects and fells the trees and deposits them in bunches in the rack. The machine can handle the trees in an upright position, which is why trees can be deposited in the rack.

Again, the machine moves through the stand and leaves the trees in a roof tile arrangement, one row with the tops pointing in one direction, in the next row in the other direction (Figure 2.12).

The whole trees remain in the stand for chipping after summer drying.

The trees are chipped with a terrain chipper, either a self-propelled machine such as the Silvatec terrain chipper or a crane-fed chipper mounted on a tractor pulling a high tip trailer.

Row and selection thinning, standard method by harvester

This method is suitable on terrain with a lower bearing capacity, since all brash and tops are left on the ground in front of the harvester to form a brash mat.

This is the normal harvesting method. The harvester performs a combined row and selection thinning. Where possible, small sawlog or stakewood are harvested, while anything not suitable is cut into 3 m pulpwood. The top diameter of the pulpwood is usually 7 cm. The harvesting pattern is shown in Figure 2.13.

After harvesting, the wood is forwarded to the roadside and stacked in assortment piles. All industrial roundwood is taken to the end user as soon as possible. The pulpwood is left for summer drying and chipping in the autumn.

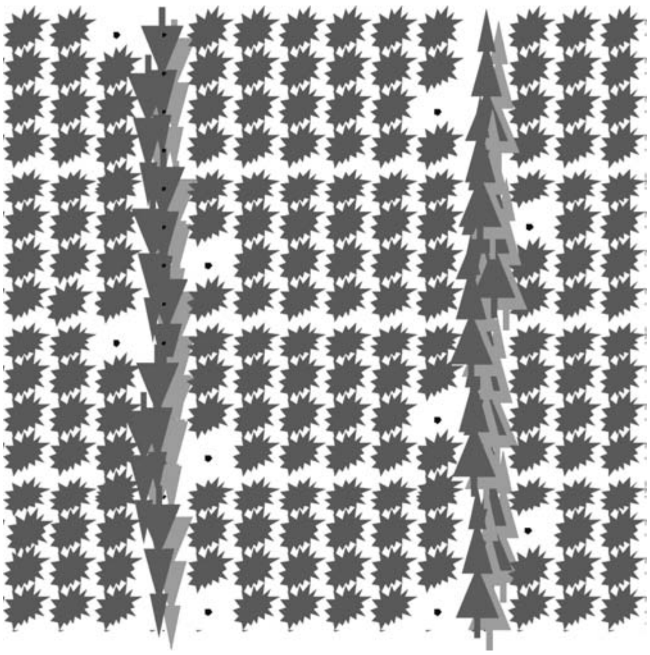

Figure 2.12: Schematic felling pattern for the selection part of the first thinning.

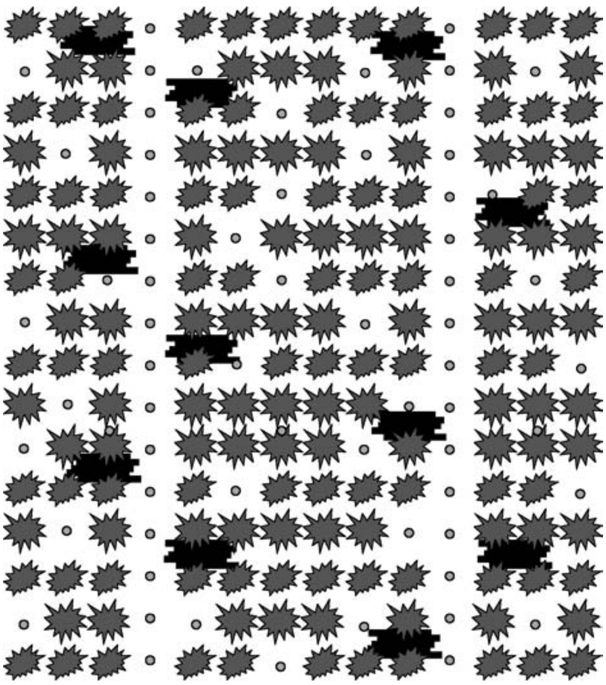

Figure 2.13: Schematic harvesting pattern for the standard thinning by harvester.

Row and selection thinning, integrated method by harvester

This method is suitable for stands with a lower bearing capacity, since all the brash is left on the ground. If the ground is really soft, the tops are also left in the stand or taken to the roadside.

The method is also suitable for stands where the thinning has been delayed, so that some sawlog and stakewood can be harvested, and in areas where pulpwood commands a low price.

As in the previous method, the harvester carries out a combined row and selection thinning. If possible, small sawlog and stakes are produced. Any tree or part of a tree which is not suited for these two assortments is crudely delimbed into tree sections of 3 to 6 m. The method is illustrated in Figure 2.14.

The harvester should be slightly adjusted for this method. The pressure on the delimbing knives should be reduced, while the pressure on the feed rollers should be increased for the delimbing of the tree sections. The original settings should be maintained for delimbing industrial roundwood to prevent damage to the wood.

Decreasing the pressure on the delimbing knives results in a poorer delimbing than the standard method. The purpose of crudely delimbing is to remove the green part of the branches, while leaving as much biomass on the stem as possible. The increase in feed roller pressure should cause the spikes on the feed rollers to penetrate the bark, which will improve drying. The bark insulates the stem and prevents drying, so puncturing the bark improves drying.

The assortments are forwarded to the roadside. The pile of tree sections is carefully placed in a sunny, windy position, not in shade or shelter. A sheet of plastic covers the top of the pile, and this is kept in place by bundles of energy wood. The stack should slope to the rear to lead the rain away from the pile.

The energy wood is chipped at the roadside by a large chipper, such as a truck-mounted chipper, and the chips are blown straight into a curtainsider or walking floor truck for transport to the consumer.

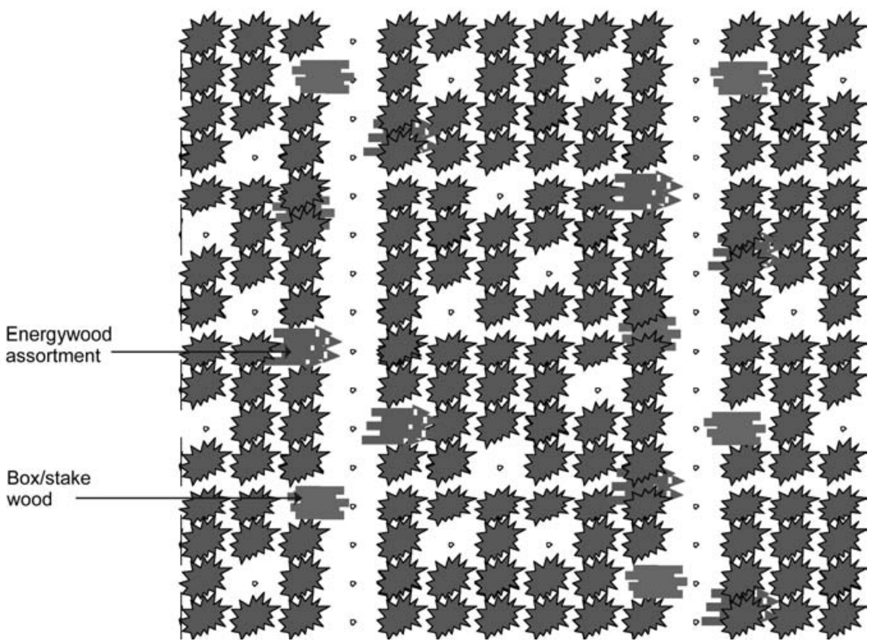

Figure 2.14: Schematic drawing of the stand lay out after integrated harvesting.

Row and selection thinning, whole stem method by harvester

This method is a variation on the whole tree method. Instead of producing crudely delimbed tree sections, crudely delimbed whole stems are produced. It is suitable for areas with a low bearing capacity, since most of the brash is left in the stands for the machines to operate on.

Instead of using a felling machine, the trees are felled and processed by a harvester. A combined row and selection thinning is carried out. The trees are taken from the stand and processed parallel to the machine in full length, until the machine can no longer handle them. Then one can choose to cut off the top and place it in front of the machine, or release the tree with the top remaining.

The method is illustrated in Figure 2.15.

The harvester should be slightly adjusted when using this method, by reducing the pressure on the delimbing knives while increasing the pressure on the feed rollers. This achieves the same effects as outlined in the previous method.

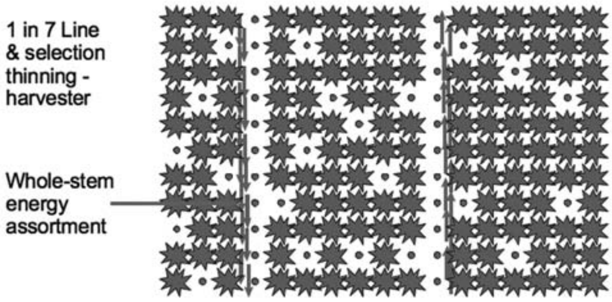

Figure 2.15: Schematic harvesting pattern for the whole stem method.

Chemical thinning

In this method trees in the rows to be removed are crudely brashed to improve access to the stem. The stems are then cut so that the cambium is exposed at least two places per 10 cm diameter of the stem (a tree under 10 cm should have two cuts, trees over 10 cm should have three to four cuts) (Figure 2.16). Undiluted Roundup™ is applied to the wounds with a brush or a spray gun, like the ones used for stump treatment with urea. The spray gun does not drip as much as the brush. It is easier to brash and wound the line of trees before treating them with the herbicide.

This method was investigated to find out if the trees would die, and if it was possible to harvest them with the felling head on the Silvatec terrain chipper.

Since the soil is not disturbed during the initial treatment, the original bearing capacity is maintained. This method is thus suitable for stands with a low bearing capacity and especially stands vulnerable to windthrow. Since the trees remain standing, they die off slowly, allowing the remaining trees to gradually take over.

Figure 2.16: A wounded and treated tree in the rack.

When the trees are dead and the needles and the small twigs have fallen off, they are felled and chipped in one operation by the terrain chipper.

Very small trees, under 5-6 cm diameter, are neither brashed nor chemically treated, but just cut free of the stump. Those trees are left standing. Because of their small size and weight, they are not hazardous even while standing. The advantage is that the chipper does not have to spend time felling such small trees but can chip them easily.

Broadleaved stand

Three methods were used in the broadleaved stand:

- row and selection thinning, where the trees were felled by chainsaw and left in the stand.
- row and selection thinning, where the trees were felled by feller-buncher and left in the stand.
- row and selection thinning, where the trees were felled by feller-buncher and forwarded to the roadside as whole trees.

Row and selection thinning, felled by chainsaw

The method is suitable on areas with a reasonable bearing capacity.

In this method one row out of 6 or 7 is felled and the remainder of the stand is selection thinned. Felled trees in the row thinning are placed in a roof tile arrangement. The trees from the selection thinning have to be placed with their butt end in the rack at a maximum angle of 30 degrees. This is difficult work for the chainsaw operator. If the trees are left at an angle wider than 30 degrees, they will be dragged across the remaining trees during chipping and may cause stem damage. Chipping will be much slower because the machine will have to wait for the trees from the selection thinning to be chipped before moving on to the next tree. The method is illustrated in Figure 2.17.

Whole trees are chipped with a terrain chipper after a summer drying. It can be difficult to find the felled trees after summer if there has been intense growth of brambles or other vegetation.

In ash stands felled in late winter and before the sap rises it should be possible to chip the trees shortly after felling because the natural moisture content is much lower than at other times of the year.

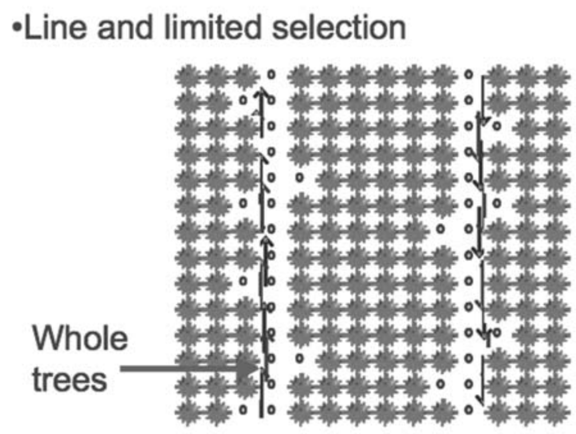

Figure 2.17: Felling pattern in broadleaved stand.

Row and selection thinning by feller-buncher

This method is suitable for terrain with a reasonable bearing capacity.

Chainsaw felling associated with the selection part of combined thinning is very hard work, so this was an attempt to do the whole operation with a feller-buncher. This is not possible in conifer stands because the branches impede the driver's view. This is not the case in broadleaved stands.

First a row thinning is carried out. Trees are felled from the row and placed in small bunches in a more or less standing position along the side of the rack. At the end of the row the operator reverses through the rack, while doing selection thinning in the remaining rows. When a bunch of trees from the rack is encountered it is picked up and placed in the rack in a roof tile arrangement (Figure 2.18).

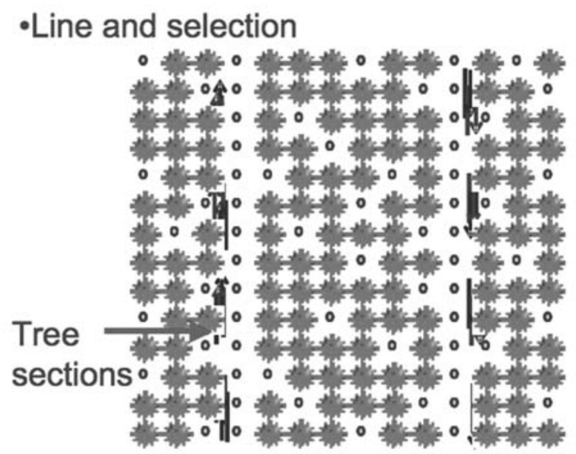

Figure 2.18: Thinning pattern of the feller-buncher in a combined row and selection thinning in broadleaved stand.

For the terrain chipper, this method is much preferred over trees that are felled by chainsaw. All the trees are in front of the chipper and it can move steadily forward, using the crane to lift then into the chipper. Less damage is caused to the remaining stand than where trees are felled by chainsaw.

Row and selection thinning by feller-buncher, forwarded to roadside

This method is suitable on terrain with a reasonable to good bearing capacity, since forwarding takes place shortly after the harvesting. If forwarding was delayed until after summer drying, the wood would become too brittle and much would be lost during forwarding.

The feller-buncher was used for combined row and selection thinning, but the trees were placed in bundles in open spaces in the stand for forwarding to the roadside later. The open spaces were either natural or created by selection thinning (Figure 2.19).

The machine did a lot of short distance reversing to unload whole trees from the felling head onto a pile.

Forwarding of trees up to 8 m long was possible. The tops protruded behind the forwarder, but they were sufficiently pliable that they could be moved around corners without causing serious damage to the remaining trees.

The pile of whole trees was covered with plastic to keep out the rain. The pile sloped to the rear, so that the water ran off. The trees were chipped by a truck chipper and the chips were blown straight into a walking-floor truck.

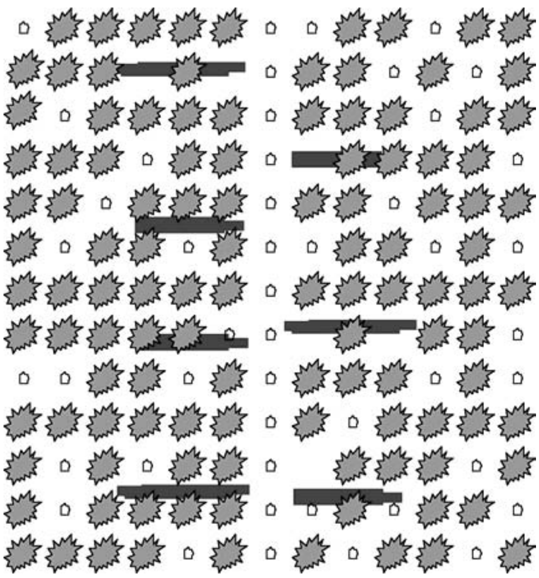

Figure 2.19: Harvesting pattern for a combined row and selection thinning in a broadleaved stand where the trees are forwarded to the roadside.

Clearfell areas

Two methods were applied in the clearfell:

- clearfell by feller-buncher, with trees left on the area.
- clearfell by chainsaw, with trees left on the area.

Clearfell by feller-buncher

This method was applied in a planted birch stand, a natural regeneration birch stand, in a failed stand of planted Sitka spruce that was then colonised by birch and other trees, and on a large area of lodgepole pine, which was cleared for a partridge reintroduction project.

The machine grabbed one or more trees at a time and severed them from the stump. The trees were piled in a long windrow to the left of the machine in a roof tile arrangement (Figure 2.20).

The pine trees had poor form with heavy branching down to the ground. A chainsaw operator had to precede the machine to brash the trees, so that the machine operator could see the stems and manoeuvre the felling head into place.

The harvesting head was not suitable in stands with many small trees because the saw chain would hop off the guidebar repeatedly.

Clearfell by chainsaw

A strip of the lodgepole pine was clearfelled by chainsaw to compare the results of the feller-buncher with chainsaw felling.

Clearfelling badly shaped pine was difficult. Often there were several stems on a stump. The instruction was to fell all the trees in one direction within a 5-6 m wide strip. In the next strip the trees were felled in the other direction, so that the chipper could drive back and forth on the area while chipping all the time (Figure 2.21).

The natural lean of the trees made it difficult for the chainsaw crew to fell them in the opposite direction.

The wood was chipped with a terrain chipper. Pine loses its needles very slowly and so two summer drying periods may be required for complete needle drop.

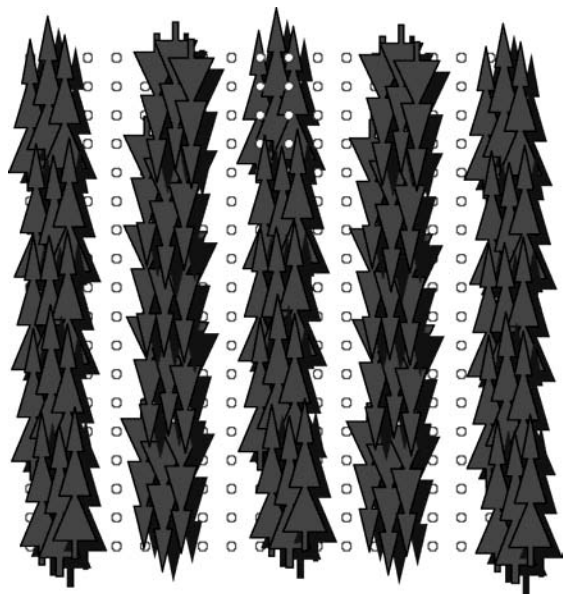

Figure 2.20: Felling pattern on a clearfell of small trees.

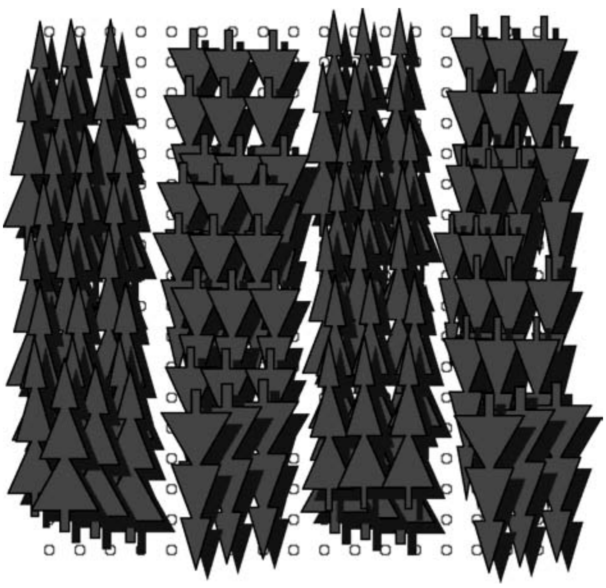

Figure 2.21: Felling pattern after motor-manually clearfelling small pine.

UNITS AND CONVERSION FACTORS

To be able to add costs of different operations such as felling, forwarding and chipping together, the volume used in all tables is cubic metre solid biomass (m^3 s). This means that, for example, during chipping where the output is normally given in cubic metre loose volume of chip (m^3 lv), this has to be converted to cubic metre solid biomass (m^3 s).

Usually the conversion factor for m^3 lv to m^3 s is between 0.3 and 0.4, depending on the type of chipper, the base materials etc. In this report a conversion factor of 0.33 has been used. This means that 1 m^3 lv of chip contains 0.33 m^3 s of wood.

The output of the harvesting machines has been calculated based on the solid volume of the whole stem of the average tree. This does not take into account the extra biomass in the branches, which nevertheless are chipped. In the results tables of the chipping operation, the amount of additional biomass harvested was calculated by dividing the load by the number of trees in that load and then using the conversion factor for solid wood. The volume per tree of this solid biomass was then divided by the measured amount of stem volume, also expressed in cubic metre solid.

This percentage of additional biomass was then used to reduce the felling costs, which were based on the stemwood only. The final felling costs reflect the additional biomass.

All the time studies in the report were taken as productive time only. This means that all delay times have been excluded, e.g. repairs, rest, maintenance, telephone calls, coffee breaks. These delay times vary from day to day and can only be recorded over a long period (weeks or even months) to get to a reliable average. The duration of the studies was too short to allow this, so a standard allowance of 30% for all machine work and 70% for all chainsaw felling has been added to the net productive time. The resulting time is called a productive machine hour, or pmh. There are 8 pmh in a normal working day.

The allowance percentage is based on experience over many years of time studies, but if the allowance percentage is found to be excessive or too low, than the allowance can be replaced with one's own percentage and the results recalculated.

Machine costs were not calculated, but the actual hourly rates that were paid during the trials were used. These are clearly stated in the tables.

The moisture content of the chips is reported as the percentage of total weight, so the moisture that has evaporated from the sample is divided by the wet weight of that sample. This is the usual way of reporting moisture content in fuel chip. Since fuel chips can be rather wet if harvested fresh, indicating the moisture content by dry weight could result in moisture contents of above 100%.

The bulk density of the chips is also reported. The wet bulk density is the weight of a given volume of chips at the moisture content it was at reception. This figure is difficult to compare to others, because of differences in moisture content. With the moisture content of the load of chips from which the wet bulk density was taken, the wet bulk density has been recalculated to the dry bulk density, i.e. the bulk density of bone dry wood in chip form.

WEATHER CONDITIONS DURING 2006

Weather clearly has an effect on wood drying behaviour. Separating harvesting and chipping with a seasoning period takes advantage of ambient energy to dry trees which are felled and left in situ, or stacked at roadside. Higher air temperature provides more energy for evaporation, wind carries moisture-laden air away from the wood, promoting more rapid evaporation, and, crucially, low relative humidity allows the air to take up more of the evaporated moisture. Rainfall, on the other hand, increases relative humidity, and wets the wood, unless it is adequately covered.

It was outside the scope of the ForestEnergy 2006 programme to measure weather directly on site. Temperature accumulation, measured in degree-days above 0^{o}C, and rainfall over the seasoning period of March to August 2006, inclusive, were obtained from the monthly mean data collected by Met Éireann at nearby climatological stations (listed in Table 2.3).

Monthly cumulative rainfall for the period March to August 2006 is compared to the thirty-year average for each of the climatological stations in Table 2.4. Total accumulated rainfall over the seasoning period is also presented.

Mean daily temperature for each month from March to August 2006 is presented in Table 2.5. This is compared with the 30-year average mean daily temperature values. Accumulated degree-days over 0^{o}C are also calculated.

The rainfall and degree-day data sets for Claremorris are shown in Figure 2.22. The trends are typical of those found on the other sites. Total accumulated rainfall over the seasoning period was typical of the 30-year average. However, the monthly rainfall differed greatly, with May receiving over twice the average rainfall and June, July and August all drier than normal. Temperature accumulation was slightly higher in 2006 when compared to the 30-year average. Overall, seasoning conditions, based on rainfall and temperature over the period, were slightly better than average.

Table 2.3: Location of ForestEnergy 2006 sites and Met Éireann climatological stations used as sources of meteorological data.

Crop	ForestEnergy 2006 site	Climatological station
Conifer	Frenchpark, Co Roscommon	Claremorris
	Swan, Co Laois	Kilkenny
	Kilbrin, Co Cork	Cork Airport
	Foil, Co Cork	Cork Airport
Broadleaf	Portlaw, Co Waterford	Kilkenny
Broadleaf and conifer	Bord na Móna, Boora, Co Offaly	Birr

Table 2.4: Mean monthly and cumulative rainfall March to August 2006 compared with 30-year averages for the same variables.

Site	Frenchpark		Kilkenny		Cork Airport		Birr	
Trial Site	Frenchpark		Portlaw, Swan		Kilbrin, Foil		Boora (Bord Na Móna)	
	mm							
Month	2006	30-year av.	2006	30-year av.	2006	30-year av.	2006	30-year av.
March	106.7	95.8	80.7	62.2	111.4	97.1	83.6	60.7
April	53.5	62.3	23.0	51.4	31.0	67.7	37.7	52.5
May	168.8	77.9	98.2	61.9	134.5	83.4	123.6	61.7
June	39.1	71.1	27.2	50.5	14.6	68.8	19.3	55.2
July	47.9	63.8	39.6	52.5	58.3	66.4	49.4	59.1
August	53.3	96.6	45.8	69.4	67.2	88.7	53.1	77.6
Cumulative rainfall	469.3	467.5	314.5	347.9	417.0	472.1	366.7	366.8

Table 2.5: Mean daily temperature per month and accumulated degree days for 2006.

Station	Frenchpark		Kilkenny		Cork Airport		Birr	
Trial Site	Frenchpark		Portlaw, Swan		Kilbrin, Foil		Boora (Bord na Móna)	
	0^oC							
Month	2006	30 year Av.	2006	30 year Av.	2006	30 year Av.	2006	30 year Av.
March	5.7	5.9	6.2	6.1	5.8	6.3	5.7	7.9
April	7.9	7.6	8.8	7.9	8.5	7.7	8.4	7.9
May	10.7	10.0	11.2	10.3	10.5	10.2	10.8	10.4
June	14.2	12.6	15.4	13.3	14.5	12.9	15.1	13.2
July	16.5	14.3	17.5	15.2	16.4	14.8	17.5	14.9
August	15.4	14.0	15.8	14.7	15.4	14.5	15.1	14.6
Degree-days Accumulation (^oC over 0^oC)	2160	1976	2298	2071	2181	2038	2227	2115

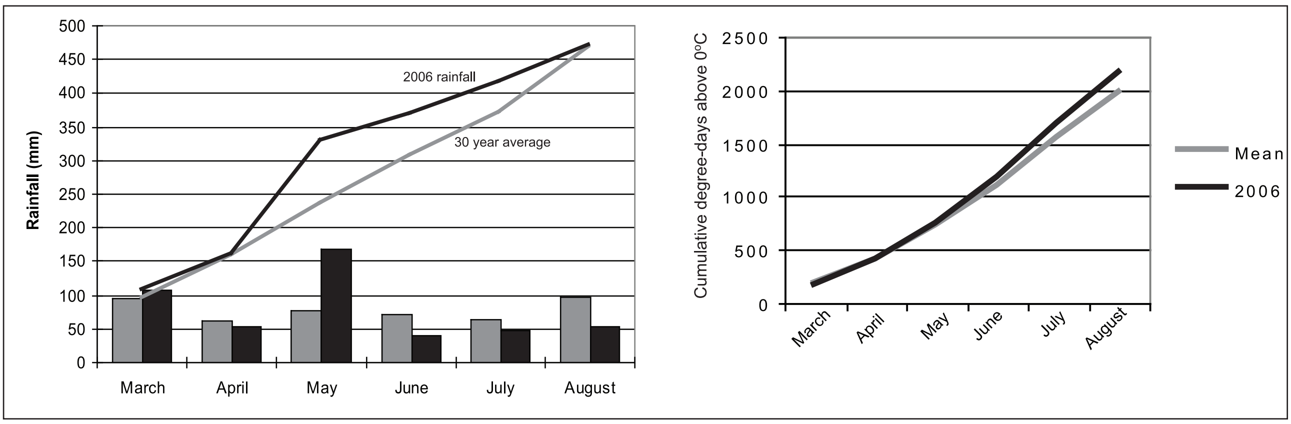

Figure 2.22: Variation in rainfall and temperature between 2006 and 30 year average at Claremorris.

3. RESULTS

In order to carry out the detailed calculations presented in subsequent chapters, either the average dbh from other stands has been used, or an estimate has been made based on previous experience. In these cases the figures are in red. In all the studies, only the net productive work time was recorded. To convert net time into an 8-hour working day, allowances for rest, maintenance, set up etc. must be added. For all machine operations a 30% allowance has been added, for chainsaw felling 70% and for chemical thinning 50% allowances. These allowances can be replaced by estimates based on other conditions and the figures recalculated.

All time factors are given in centiminutes (cmin) instead of in seconds. A centiminute is a decimal unit which is found by dividing the number of seconds by 60 and multiplying by 100. The advantage of centiminutes is that they can be added and subtracted without having to calculate in base 60 (60 seconds to a minute, while there are 100 cmin to a minute).

For all costs, the real costs per hour paid in the programme were used. The hourly costs are specified in the tables and can be replaced by local or company-specific estimates and recalculated.

All costs have been calculated to cubic metre solid biomass, including, where appropriate, branch biomass.

Costs refer to the end point of each operation: for the chainsaw felling, feller-buncher and the whole stem harvesting this means in the stand; for the assortment methods, this means in the stand for the harvester, but at the roadside for the forwarder. For all terrain chipping operations, the costs are given for chips delivered at the roadside in a pile, while for the truck chipping operation the costs are given for the chips loaded onto road transportation.

HARVESTING

Many different methods were investigated, so the results are summarized according to the general harvesting method: chainsaw, feller-buncher, harvester and forwarding of the assortments.

Chainsaw felling, whole trees

This method was applied in all Sitka spruce thinnings as a row thinning only. It was also used for the clearfelling of lodgepole pine at the cutway peatland (Bord na Móna) site, and in the ash/sycamore stand as a combined row and selection thinning. The results of the studies are found in Table 3.1.

The costs of the chainsaw felling varied from €2 to €6 per m^3 solid biomass. This variation was caused by factors such as the use of five different chainsaw operators and the additional biomass percentage. In Swan, the chipper operators were instructed to put the tops of the trees to be chipped

Table 3.1: Productivity and cost estimates for chainsaw felling of whole trees.

Site	Frenchpark	Swan	Kilbrin	Portlaw	Boora (Bord na Móna)
dbh (cm)	13.3	14.4	12.6	9.1	9.0
Tree species	Sitka spruce	Sitka spruce	Sitka spruce	Ash	Lodgepole pine
Harvesting method	Row	Row	Row	Row + selection	Clearfell
cmin/tree	29.1	38	57	35.4	83
Allowance 70% (cmin/tree)	20	27	40	25	58.1
Total cmin/tree	49	65	97	60	141.1
Trees/pmh	121.3	92.9	61.9	99.7	42.5
Stem volume per tree (m^3 solid)	0.063	0.082	0.056	0.026	0.011
m^3 solid/hr	7.64	7.62	3.47	2.59	0.47
Cost €/m^3 at €25/hr	3.27	3.28	7.21	9.64	53.45
Extra biomass % avg Silvatec+tp	63	8	38	64	703
Cost €/m^3 solid including extra biomass	2.01	3.04	5.22	5.88	6.66

under the machine wheels to avoid damage to the soil, and this reduced the amount of additional biomass. At the cutway peatland (Bord na Móna) site the large amount of additional biomass reduced the felling costs per solid cubic metre of biomass. While it was useful for comparison purposes this was a one-off, untypical operation: the crop needed to felled but was unsuitable for mechanical operations as the trees were bushy (with heavy branches down to the ground), had multiple stems and pronounced lean, which made it difficult to fell them.

Felling by feller-buncher, whole trees

This method was applied in all Sitka spruce stands as a selection thinning only. In the lodgepole pine stand, the machine was used to clearfell a small area. In the broadleaved stand, the machine performed a combined row and selection thinning. The machine clearfelled a planted birch stand, and two natural regenerated birch stands of different ages, one of which contained some planted Sitka spruce.

To demonstrate the feller-buncher in a selection thinning in Sitka spruce, the row trees were removed shortly before the selection thinning by a harvester/forwarder combination. This meant that there were three passages of machines in the stand within two weeks during February/March, which would not happen in practice. It led to some problems with traction and occasional bogging. When the chipper arrived in August, the soil had not recovered and the operator was instructed to put the tops of the trees under the wheels to avoid further damage to the soil. Again this is not a normal operating procedure, but necessary due to the time constraints of the project.

The results of the studies are shown in Table 3.2. The costs of the feller-buncher for selection thinning in conifers varied from €5.7 to €8.26 per m^3 solid biomass. No time studies were conducted at the Kilbrin site, so the average time for the Frenchpark and Swan sites was used with the tree measurements from Kilbrin. At the Swan site tops had to be placed under the wheels of the the chippers to protect the soil, hence the decrease in biomass.

Felling by harvester, crudely delimbed whole stems

This method was employed in all Sitka spruce stands. The machine performed a combined row and selection thinning in the stands and left the harvesting residues in front of the wheels, while the stems were put on one side of the rack. The results are in Table 3.3.

Table 3.2: Productivity and cost estimates for felling by feller-buncher.

Site	Frenchpark	Swan	Kilbrin	Portlaw	Portlaw	Bord na Móna	Bord na Móna	Bord na Móna	Bord na Móna
dbh cm	12.3	16	11.8	9.8	8.2	9.0	9.1	10.9	9.9
Species	Sitka spruce	Sitka spruce	Sitka spruce	Ash/ sycamore	Ash	Lodgepole pine	Birch, planted	Birch old	Birch/Sitka spruce
Method	selection	selection	selection	row + selection	row + selection	clearfell	clearfell	clearfell	clearfell
Felling time cmin/tree	36.5	32.1	34.3	32	28.1	29.8	35.3	30.9	36.6
Allowance 30%, cmin/tree	10.9	9.6	10.3	9.6	8.4	8.9	10.6	9.3	11.0
Total cmin/tree	47.4	41.7	44.6	41.6	36.5	38.7	45.9	40.2	47.6
Trees/pmh	126	144	135	144	164	155	131	149	126
Stem volume per tree, m^3 solid	0.054	0.102	0.05	0.03	0.018	0.011	0.02	0.032	0.017
m^3 solid/hr	6.804	14.688	6.73	4.33	2.96	1.70	2.61	4.78	2.14
Cost €/m^3 at €100/hr	14.70	6.81	14.86	23.11	33.82	58.70	38.24	20.92	46.65
Increase biomass %	157	-3	80	111	113	703	101	-5	115
Cost €/m^3 solid incl. extra biomass	5.72	7.02	8.26	10.95	15.88	7.31	19.03	22.02	21.70

Table 3.3: Productivity and cost estimates for felling of whole stems by harvester.

Site	Frenchpark	Swan	Kilbrin
dbh	13.3	14.4	12.6
Species	Sitka spruce	Sitka spruce	Sitka spruce
Harvest method	row + selection	row + selection	row + selection
Method	whole stem	whole stem	whole stem
cmin/tree	93	93	93
Allowance 30%, cmin/tree	28	28	28
Total cmin/tree	121	121	121
Trees/pmh	49.6	49.6	49.6
Stem volume per tree, m^3 solid	0.063	0.082	0.056
m^3 solid/hr	3.13	4.07	2.78
Cost €/m^3 at €110/hr	35.18	27.03	39.58
Extra biomass%	54	-1	16
Cost €/m^3 s incl.extra biomass	22.85	27.30	34.12

This method was new to the operator and he needed a lot more experience before an accurate cost could be derived for this method. It is difficult to change from clean delimbing of assortments to crudely delimbed whole stems. The costs varied from nearly €23 to €34 per m^3. The size of the trees and the amount of additional biomass have a large influence on the cost.

Felling by harvester, integrated harvesting

This method was employed in all Sitka spruce stands. The machine performed a combined row and selection thinning. Where possible, small sawlogs or stake wood was produced as well as 3-6 m crudely delimbed tree sections. The logging residues were put in the rack in front of the machine as a protective mat. The assortments were all forwarded to the roadside. The results are presented in Table 3.4.

It was not posssible to measure the increase in biomass using this method as the amount of crudely delimbed tree sections was insufficient to fill more than one truck with chips.

The high costs at Frenchpark were caused by two factors: the trees were relatively small and the operator had to get used to the method. It is difficult to adjust from having to produce neatly delimbed standard length assortments to producing a combination of neatly delimbed box and stakewood as well as crudely delimbed tree sections of varying length.

Felling by harvester, standard method

This method was employed in all Sitka spruce stands. The machine performed a combined row and selection thinning. Where possible small sawlogs or stake wood was produced as well as neatly delimbed

Table 3.4: Productivity and cost estimates for integrated harvesting with the harvester.

Site	Frenchpark	Swan	Foil
dbh	11.7	15.0	13.3
Tree species	Sitka spruce	Sitka spruce	Sitka spruce
Harvest method	row + selection	row + selection	row + selection
Method	integrated	integrated	integrated
cmin/tree	115	80	83
Allowance 30%, cmin/tree	35	24	25
Total cmin/tree	150	104	108
Trees/pmh	40.1	57.7	55.6
Stem volume per tree, m^3 solid	0.049	0.089	0.074
m^3 solid/hr	1.97	5.13	4.11
Cost €/m^3 at €110/hr	55.94	21.42	26.73
extra biomass%			
Cost €/m^3 s incl.extra biomass	55.94	21.42	26.73

3 m pulpwood. The results are presented in Table 3.5.

In this method no extra biomass can be expected, since normal box, stake and pulpwood assortments were produced. The costs at Foil were low because of the large size of the trees as costs are clearly influenced by the size of the trees.

Forwarding of the assortments

All the assortments (small sawlog, stake, 3 m pulpwood and energy tree sections) were forwarded to the roadside and stacked. At Swan, Portlaw and Foil the stacks were covered with plastic to protect them from rain. The results are shown in Table 3.6.

No extra biomass was measured. The greater volume carried on the forwarder in the integrated method is a result of the greater length of the wood, on average some 4.5 m compared to 3 m of standard pulpwood. In two cases no time studies were carried out on the forwarding and in these cases the average of the other two stands has been taken (shown in italics). In the ash stand in Portlaw the number of whole trees carried in each load was counted. By multiplying this number by the average stem volume of the harvested trees the actual stem volume of the load was calculated. The number of trees chipped with the truck chipper was also counted, which gave an indication of the amount of additional biomass.

Chemical thinning by chainsaw

Chemical thinning was carried out by chainsaw. Three different ways of applying herbicide were investigated. In all cases, the trees were crudely brashed and the stem was cut in several places. Undiluted glyphosate (Roundup™) was applied either by a spraygun, brush or shot applicator. The results of the study are presented in Table 3.7.

The cost of brashing and application of the

Table 3.5: Productivity and cost estimates for standard harvest by harvester.

Site	Frenchpark	Swan	Foil
dbh	13.9	13.1	15.3
Tree species	Sitka spruce	Sitka spruce	Sitka spruce
Harvest method	row + selection	row + selection	row + selection
Method	standard	standard	standard
cmin/tree	87	101	96
Allowance 30%, cmin/tree	26	30	29
Total cmin/tree	113	131	125
Trees/pmh	53.1	45.7	48.1
Stem volume per tree, m^3 solid	0.069	0.067	0.103
m^3 solid/hr	3.66	3.06	4.95
Cost €/m^3 at €110/hr	30.05	35.93	22.21
Extra biomass%			
Cost €/m^3 s incl.extra biomass	30.05	35.93	22.21

Table 3.6: Forwarding productivity and costs.

Site	Frenchpark	Swan	Foil	Frenchpark	Swan	Foil	Portlaw
dbh	13.9	13.1	15.3	11.7	15.0	13.3	8.2
Tree species	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Ash
Harvest method	row + selection	row + selection	row + selection	row + selection	row + selection	row + selection	row + selection
Method	Standard	Standard	Standard	Integrated	Integrated	Integrated	Whole tree
min/load	27	27.9	26.2	30.8	38	45.1	28.8
Allowance 30%, min/load	8	8	8	9	11	14	9
Total min/load	35	36	34	40	49	59	37
Loads/pmh	1.7	1.7	1.8	1.5	1.2	1.0	1.6
Volume per load, m^3 solid	6	6	6	7.5	7.5	7.5	1.31
m^3 solid/hr	10.26	9.93	10.57	11.24	9.12	7.68	2.11
Cost €/m^3 at €90/hr	8.78	9.07	8.52	8.01	9.87	11.73	42.74
Additional biomass%							158
Cost €/m^3 incl. extra biomass	8.78	9.07	8.52	8.01	9.87	11.73	16.57

Table 3.7: Productivity and cost of chemical thinning by chainsaw.

Site	Frenchpark	Swan	Kilbrin
dbh	11.1	15	12.1
Tree species	Sitka spruce	Sitka spruce	Sitka spruce
Harvest method	Row	Row	Row
Application method	Knapsack applicator	Brush	Spraygun
Min/tree	0.62	0.81	0.61
Allowance 50%, min/tree	0.31	0.41	0.31
Total min/tree	0.93	1.22	0.92
Trees/pmh	64.5	49.4	65.6
Volume per tree, m^3 solid	0.044	0.089	0.051
m^3 solid/pmh	2.84	4.40	3.34
Cost €/m^3 at €30/hr incl chemicals	10.57	6.83	8.97
Additional biomass%	58	23	94
Cost €/m^3 inclusive additional biomass	6.69	5.55	4.62

chemicals was much higher than the felling cost. Two sets of equipment are required and intensive brashing is necessary to create sufficient wounding on the stem for the chemicals to be effective.

The trees at Frenchpark were not harvested due time constraints of the Silvatec chipper, so the average for the increase in biomass has been used.

RESULTS OF THE CHIPPING TRIALS

Results of the studies on the three different chippers are presented by machine and method. In the original plan, plots were reserved for a specific machine, but sometimes machines helped out in other plots, providing further information.

Chipping with the tractor-mounted terrain chipper

This machine was used in row thinning in Sitka spruce, in a combined row and selection thinning in ash/sycamore and in a clearfellof planted and natural regeneration birch.

At Frenchpark, the machine unloaded into a tractor-trailer combination at the main landing, because the stand was too far away from the loading area of the trucks. At the other locations, the machine mostly delivered the chips to the stacking area, but sometimes the Silvatec chip forwarder would take a load. Results of the time studies are presented in Table 3.8.

The costs for the tractor chipper varied in the three conifer stands from €12.60 to €24.20 per m^3 solid biomass. The highest costs were encountered in Swan, where the width of the row varied a lot, making it difficult for the machine to move about. The rows were very long and once the machine had a load, it had to reverse out of the stand to deliver the load to the pile at the roadside.

In general, the costs for chipping small sized broadleaves was in the order of €20 per m^3 solid biomass. Even though the productivity of the tractor chipper is much lower than that of the Silvatec, the costs are comparable because the hourly costs are also much lower than those of the Silvatec.

Chipping with the self-propelled Silvatec terrain chipper

The Silvatec was used in three plots in each of the Sitka spruce stands:

- Whole trees from selection thinning with the feller-buncher.
- Whole stems from combined row and selection thinning with the harvester.
- Whole trees from the chemical thinning.

In all stands the Silvatec also chipped part of the plot of row thinning, which was intended for the tractor chipper.

In the ash/sycamore stands the machine worked in the combined row and selection thinning by the feller-buncher, but also in the chainsaw felled row and selection thinning.

At the Bord na Móna site, the Silvatec chipped the trees from the combined Sitka spruce/birch stand and from the premature clearfell of lodgepole pine.

At Frenchpark the chemical plot was not chipped. In Swan only a small section of the chemically thinned plot was taken, because the trees

Table 3.8: Productivity and chip production costs for tractor-mounted terrain chipper.

Site	Frenchpark	Swan	Kilbrin	Portlaw	Boora (Bord na Móna)	Boora (Bord na Móna)	Boora (Bord na Móna)
Species	Sitka spruce	Sitka spruce	Sitka spruce	Ash	Birch (planted)	Birch (naturally regenerated)	Birch (naturally regenerated)
Felling	Whole tree chainsaw	Whole tree chainsaw	Whole tree chainsaw	Whole tree chainsaw	Whole tree feller-buncher	Whole tree feller-buncher	Whole tree feller-buncher
Chipper	Tp	Tp	Tp	Tp	Tp	Tp	Tp
Travel empty (cmin)	0.8	2.74	4.25	3.43	4.24	4.24	5.4
Fell (cmin)				0.61			1.58
Chip (cmin)	20.3	32.51	15.29	23	23.6	22.9	22.64
Travel loaded (cmin)	0.61	4.51	5.28	4.7	5.28	5.28	6.74
Unload (cmin)	2.09	1.93	2.77	1.5	1.96	1.96	1.92
Wait (cmin)							
Manoeuvre (cmin)			2.97		1.91	1.91	
Sub total (cmin)	23.8	41.69	30.55	33.24	36.99	36.29	38.28
Allowance 30% (cmin)	7.14	12.51	9.17	9.97	11.10	10.89	11.48
Total (cmin)	30.94	54.20	39.72	43.21	48.09	47.18	49.76
Loads/pmh	1.94	1.11	1.51	1.39	1.25	1.27	1.21
Volume m^3 lv load	12.4	11.3	12	9.27	12	12	11.8
Volume m^3 lv/phm	24.0	12.5	18.1	12.9	15.0	15.3	14.2
Volume m^3 s/pmh (base 0.33)	7.9	4.1	6.0	4.2	4.9	5.0	4.7
Cost at €100/pmh per m^3 solid	12.60	24.22	16.72	23.54	20.24	19.86	21.30
Avg volume stemwood, measured	0.063	0.082	0.056	0.026	0.020	0.032	0.020
Avg volume per tree after chipping 33%	0.099	0.070	0.072	0.037	0.040	0.030	0.025
Additional biomass%	57	-14	29	44	101	-5	25

were still too green. Only at Kilbrin was a reasonable number of trees harvested. At all three locations, the chemical had killed the small trees (<10 cm dbh), but trees over 10 cm dbh had survived, although not in good health. The suggestion is that bigger trees required more herbicide than was applied.

Table 3.9 shows the results of the chipping of trees felled with the feller-buncher, including the three Sitka spruce stands and the broadleaved stand. The method was studied on two consecutive days at Frenchpark.

The costs of chipping the bunched Sitka spruce trees from the selection thinning are similar for the three stands, varying from €11.30 to €14.40 per m^3 solid biomass. Chipping ash at Portlaw was expensive because the chipper had to wait a long time for the chip shuttle to return. If the waiting time is disregarded, then the costs are similar to those in the conifer stands. The sycamore chipping at Portlaw was much cheaper than the chipping of the ash trees, even though the trees were small in both parts of the stand.

At Swan the increase in biomass was negative, because the tops of many trees were placed under the machine wheels to prevent further soil damage.

Table 3.10 presents the results of the studies on the whole stems, felled by harvester. These studies were only carried out in the Sitka spruce stands.

The cost of chipping the whole stems were almost the same as chipping whole trees after the feller-buncher and were in the order of €13-15 per m^3 solid biomass. The ‘additional’ biomass at Swan was negative because material had to be placed under the wheels of the machine for flotation.

Table 3.11 presents the results of the studies on the chainsaw felled trees, including the three Sitka spruce stands, the broadleaved stand and the lodgepole pine stand.

Table 3.9: Productivity and costs for trees felled with the feller-buncher.

Site	Frenchpark	Frenchpark	Swan	Kilbrin	Portlaw	Portlaw
Tree species	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Ash	Sycamore
Felling	Whole tree feller-buncher	Whole tree feller-buncher	Whole tree feller-buncher	Whole tree feller-buncher	Feller-buncher	Feller-buncher
Chipper	Silvatec	Silvatec	Silvatec	Silvatec	Silvatec	Silvatec
Travel empty (cmin)	1.5	0.66	1.81		1.0	
Fell (cmin)	0.07				0.4	
Chip (cmin)	5.77	9	8.19	7.35	10.9	10.78
Travel loaded (cmin)	0	0.1		0.09	0.6	0.36
Unload (cmin)	1.43	1.23	1.13	1.46	1.4	1.36
Wait (cmin)	0			1.73	10.4	0.7
Manoeuvre (cmin)	0			1.15	1.8	1.55
Sub total (cmin)	8.77	10.99	11.13	11.78	26.45	14.75
Allowance 30% (cmin)	2.63	3.30	3.34	3.53	7.94	4.43
Total (cmin)	11.40	14./29	14.47	15.31	34.39	19.18
Loads/hr	5.26	4.20	4.15	3.92	1.74	3.13
Volume m^3 lv load	15	15	15	15	15	15
Volume m^3 lv/hr	78.9	63.0	62/2	58.8	26.2	46.9
Volume m^3 solid/pmh at 0.33	26.1	20.8	20.5	19.4	8.6	15.5
Cost per m^3 solid at €295/pmh	11.32	14.19	14.37	15.2	34.15	19.05
Avg volume stemwood, measured	0.054	0.054	0.102	0.05	0.03	0.026
Avg volume per tree after chipping (base 0.33)	0.118	0.160	0.099	0.09	0.069	0.045
Increase in biomass% (base 0.33)	118	196	-3	80	129	72

Table 3.10: Productivity and chip production costs for the Silvatec chipping using the whole stem method.

Site	Frenchpark	Swan	Kilbrin
Tree species	Sitka spruce	Sitka spruce	Sitka spruce
Felling	Whole stem	Whole stem	Whole stem
Chipper	Silvatec	Silvatec	Silvatec
Travel empty (cmin)		1.42	0.25
Fell (cmin)			0.04
Chip (cmin)	8.55	7.51	6.73
Travel loaded (cmin)	0.43		0.44
Unload (cmin)	1.2	1.14	1.36
Wait (cmin)			1.94
Manoeuvre (cmin)			0.8
Sub total (cmin)	10.18	10.07	11.56
Allowance 30% (cmin)	3.05	3.02	3.47
Total (cmin)	13.23	13.09	15.03
Loads/hr	4.53	4.58	3.99
Volume m^3 lv load	15	15	15
Volume m^3 lv/hr	68.0	68.7	59.9
Volume m^3 solid/pmh at 0.33	22.4	22.7	19.8
Cost per m^3 solid at €295/pmh	13.14	13.00	14.93
Avg volume stemwood, measured	0.063	0.082	0.056
Avg volume per tree after chipping (base 0.33)	0.097	0.081	0.065
Increase in biomass% (base 0.33)	54	-1	16

Table 3.11: Productivity and chip production costs for the chainsaw felled trees chipped by the Silvatec.

Site	Frenchpark	Swan	Kilbrin	Portlaw	Portlaw	Boora	Boora
Tree species	Sitka spruce	Sitka spruce	Sitka spruce	Sycamore	Ash	Lodgepole pine	Lodgepole pine
Felling	Chainsaw	Chainsaw	Chainsaw	Chainsaw	Chainsaw	Chainsaw	Chainsaw
Chipper	Silvatec	Silvatec	Silvatec	Silvatec	Silvatec	Silvatec	Silvatec
Travel empty (cmin)	0.08	1.18	0.42		1.48	0.37	
Fell (cmin)			0.18	0.15	0.61	0	
Chip (cmin)	6.52	7.11	6.51	12.97	12.91	7.79	6.71
Travel loaded (cmin)	0.48		0.21		0.59	0.43	
Unload (cmin)	1.13	1.12	1.49	1.39	1.4	1.41	1.3
Wait (cmin)			0.78			0.3	
Manoeuvre (cmin)			1.14	1.53	2.08	0.65	
Sub total (cmin)	8.21	9.41	10.73	16.04	19.07	10.95	8.01
Allowance 30% (cmin)	2.46	2.82	3.22	4.81	5.72	3.29	2.40
Total (cmin)	10.67	12.23	13.95	20.85	24.79	14.24	10.41
Loads/hr	5.62	4.90	4.30	2.88	2.42	4.21	5.76
Volume m^3 lv load	15	15	15	15	15	15	15
Volume m^3 lv/hr	84.3	73.6	64.5	43.2	36.3	63.2	86.4
Volume m^3 solid/pmh at 0.33	27.8	24.3	21.3	14.2	12.0	20.9	28.5
Cost per m^3 solid at €295/pmh	10.60	12.15	13.86	20.71	24.62	14.14	10.34
Avg volume stemwood, measured	0.063	0.082	0.056	0.026	0.018	0.011	0.011
Avg volume per tree after chipping base 0.33	0.107	0.109	0.082	0.042	0.038	0.087	0.088
Increase in biomass% (base 0.33)	70	33	47	61	113	695	703

The cost of chipping whole trees from a line thinning felled by chainsaw in Sitka spruce were slightly less than those of the trees felled by the feller-buncher. This is probably because the terrain had not been disturbed by any machine before the chipper arrived. In the broadleaved stand at Portlaw, the costs were slightly higher than for the trees felled by feller-buncher. This was because the trees from the selection thinning only had their butt end in the rack and the machine had to wait until the trees had been processed by the chipper before moving forward. In some cases the operator chose to leave some of the trees to prevent damage to the crop trees. In the lodgepole pine stand at the Bord na Móna site, two studies were carried out, with similar results. The costs were relatively low because of the large increase in biomass from the double and triple stems and heavy branches.

Table 3.12 shows the results of the studies on the felling and chipping with the Silvatec chipper of the chemically thinned stands. Trees in these plots were felled by the Silvatec with the felling head in the grapple. The driver had to drop the tree before putting it into the chipper and collect it again because there was no protruding part of the tree that could be put into the chipper. In most cases, the machine had to back away a short distance to provide space for the tree to drop down before entering the chipper.

Only one complete load was produced at the Swan site because the trees were still too green, and the buyer of the chips did not want green chips. At Frenchpark there was insufficient time to process the chemically thinned stand, so the trees remained standing. At all three stands the small trees under about 10 cm dbh had been killed by the chemical, those between 10 and 15 cm still had green lower branches. While the larger trees showed some treatment effect they were green all over.

The cost of chipping chemically thinned plots is considerably higher than where trees that have been felled, but the advantage is that the terrain is not disturbed before the chipper arrives.

Chipping with Jenz 700 truck-mounted chipper

It was planned to use the Jenz chipper to chip the stacks of neatly delimbed 3 m pulpwood as well as the piles of crudely delimbed tree sections in the Sitka spruce stands as well as one pile of whole trees in the broadleaved stand.

During the preparations for the felling studies in each of the Sitka spruce stands, one plot had been row thinned by harvester with hardly any delimbing. This wood had been forwarded out to make place for the feller-buncher.

Table 3.12: Productivity and chip production costs for chemically thinned trees chipped by the Silvatec.

Site	Swan	Kilbrin
Tree species	Sitka spruce	Sitka spruce
Felling	Chemical thinned	Chemical thinned
Chipper	Silvatec	Silvatec
Travel empty (cmin)	2.00	0.94
Fell (cmin)		0.34
Chip (cmin)	11.58	12.14
Travel loaded (cmin)		
Unload (cmin)	1.10	1.5
Wait (cmin)		
Manoeuvre (cmin)		4.31
Sub-total (cmin)	14.68	19.23
Allowance 30% (cmin)	4.40	5.77
Total (cmin)	19.08	25.00
Loads/hr	3.14	2.40
Volume m^3 lv load	15	15
Volume m^3 lv/hr	47.2	36.0
Volume m^3 solid/pmh at 0.33	15.6	11.9
Cost per m^3 solid at €295/pmh	18.96	24.83
Average volume stemwood, measured	0.089	0.051
Average volume per tree after chipping (base 0.33)	0.110	0.099
Increase in biomass% (base 0.33)	23	94

It was planned that the logs from the standard method (neatly delimbed 3 m pulpwood) and the integrated method (crudely delimbed tree sections) would be kept separate during the chipping. This turned out to be impractical. The trucks taking the chips from the truck chipper had a capacity of some 80 m^3 loose volume and had to carry a complete load every time. The amount of cleanly delimbed pulpwood was insufficient to fill a truck. In all but one case the limited amount of small sawlogs and stake wood was chipped.

Table 3.13 presents the results of the chipping studies on the Jenz truck chipper. It shows that the costs of chipping with the Jenz machine are much lower than those of the other chippers and vary from €5.70 to €13.40 per m^3 solid biomass. In general, the machine has a very large capacity and relies on trucks being available at all times to be filled. The number of observations in each location was limited because there was a limited amount of wood and the trucks carried a large volume of chip.

The Jenz chipper was also used to chip bundles of logging residues that had been harvested in November 2005. At that time the bundles comprised freshly harvested green logging residues, including all needles and twigs. The bundles were held together with twine and were made by the Timberjack bundling machine. These bundles had been forwarded to the roadside and left in low piles of maximum 3 bundles high. The bundles were taken by timber truck to Weyerhäuser in Clonmel and chipped for fuel.

The chipping of these bundles was not easy as they contained many small stones, picked up during the bundling process. The bundles had not dried and consisted of very black composted material. The moisture content was very high, which made discharging the chips difficult. The twine of the bundles wrapped around moving parts of the chipper and necessitated several hours of repair time some days later.

The chipping of the bundles was not studied. The moisture content of the bundles was determined. The position of the bundles in each stack was also recorded.

The Jenz also chipped a pile of crudely delimbed tree sections that were harvested in November 2005 as a precursor to the present programme. Those tree sections were forwarded green to the roadside and left there in two big piles. The piles were situated in a narrow spot in the shade. The wood was taken by timber truck to the yard of Weyerhäuser in Clonmel and chipped there for fuel. These chips were of low quality and high moisture content. Even though the chipping was studied, the results are not presented here since the harvesting and transportation costs are unknown.

Table 3.13: Productivity and cost estimates for the Jenz truck chipper.

Site	Frenchpark	Frenchpark	Swan	Swan	Kilbrin	Kilbrin/Foil	Portlaw
Tree species	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Sitka spruce	Ash
Felling	Energy wood	Energy wood	Energy wood/tree sections	Energy wood	Energy wood	Energy wood/tree sections	Whole tree
Chipper	Jenz	Jenz	Jenz	Jenz	Jenz	Jenz	Jenz
Travel empty (cmin)	7.16	0.98		7.45	8.19		1.49
Fell (cmin)							
Chip (cmin)	29.06	10.20	25.3	26.52	30.66	30.5	53.49
Travel loaded (cmin)							
Unload (cmin)							
Wait (cmin)							
Manoeuvre (cmin)	10.33	1.54	1.2	14.77	7.24	1.2	5.73
Sub total (cmin)	46.55	12.72	26.5	48.74	46.09	31.7	60.71
Allowance 30% (cmin)	13.97	3.82	7.95	14.62	13.83	9.51	18.21
Total (cmin)	60.52	16.54	34.45	63.36	59.92	41.21	78.92
Loads/pmh	0.99	3.63	1.74	0.95	1.00	1.46	0.76
Volume m^3 lv load	80	24	82	80	80	82	80
Volume m^3 lv/pmh	79.3	87.1	142.8	75.8	80.1	119.4	60.8
Volume m^3 solid/pmh (base 0.33)	26.2	28.7	47.1	25.0	26.4	39.4	20.1
Cost per m^3 solid at €268/pmh	10.24	9.33	5.69	10.72	10.14	6.80	13.35
Avg volume per tree after chipping							0.046
Avg volume stemwood, measured							0.018
Increase in percentage							158


COFORD

4. COMPARISON AND COSTS OF HARVESTING CHAINS IN CONIFERS

Chapter 3 presented the results of the studies on the separate machines and methods. Chapter 4 combines the different machines and methods in a harvesting chain evaluation. Where possible an average cost is given next to the range of costs found during the studies.

In all cases the productivity is expressed in cubic metres solid biomass, including the additional biomass harvested. The costs are based on the actual amounts paid for the machines during the trials.

WHOLE TREE METHOD, MOTOR-MANUAL FELLING, TERRAIN CHIPPING BY TRACTOR CHIPPER

This row thinning method was studied in three Sitka spruce stands. The cost calculation is based on the results of the three stands (Table 4.1).

There was considerable variation in total costs for this method, ranging from €13.25 to €24.64 per cubic metre solid biomass with an average over the three stands of €19.34.

WHOLE TREE METHOD, MOTOR-MANUAL FELLING, TERRAIN CHIPPING BY SILVATEC

Although it was originally not intended that the Silvatec would chip trees felled by chainsaw in row thinning, the machine helped out in all three Sitka spruce stands (Table 4.2).

There was some variation in the total costs per cubic metre solid biomass, but not as large as with the tractor chipper, and the average cost was lower. The felling costs were the same in both cases, the main difference was in chipping costs and productivity.

WHOLE TREE METHOD, FELLED BY FELLER-BUNCHER, TERRAIN CHIPPING BY SILVATEC

This method was also trialed in the three Sitka spruce stands. Both the feller-buncher and the terrain chipper were hindered by the terrain conditions that had deteriorated after the passage of a harvester and

Table 4.1: Productivity and costs of the chainsaw felled whole tree row thinning chipped by tractor chipper.

Site	Frenchpark	Swan	Kilbrin	Average
Productivity m^3 solid biomass/pmh				
Chainsaw fell	12.45	8.22	4.79	8.49
Tractor chip	8.9	4.6	6.7	6.73
Cost €/m^3 solid biomass				
Chainsaw fell (€25/pmh)	2.01	3.04	5.22	3.42
Tractor chip (€100/pmh)	11.24	21.6	14.91	15.92
Total cost €/m^3 solid biomass	13.25	24.64	20.13	19.34

Table 4.2: Productivity and costs of the chainsaw felled whole tree row thinning, chipped by Silvatec.

Site	Frenchpark	Swan	Kilbrin	Average
Productivity m^3 solid biomass/pmh				
Chainsaw fell	12.45	8.22	4.79	8.49
Silvatec chipper	31.2	27.2	23.9	27.43
Cost €/m^3 solid biomass				
Chainsaw fell (€25/pmh)	2.01	3.04	5.22	3.42
Silvatec chipper (€295/pmh)	9.46	10.84	12.36	10.89
Total cost €/m^3 solid biomass	11.47	13.88	17.58	14.31

a forwarder to take out the trees of the row thinning immediately prior to the feller-buncher operation. This is not the normal procedure, but had to be done to show the system at work, and the results were negatively influenced by the preparation of the stand.

Under normal circumstances, the feller-buncher would not be used until at least a year after the row thinning trees had been chipped with a terrain chipper after felling by chainsaw. This provides time for the terrain to recover after the first chipping operation.

An overview of the results is given in Table 4.3. The feller-buncher was not studied at Kilbrin, so the average time consumption per tree of the two other stands was combined with the actual tree dimensions from the Kilbrin site.

The costs for this system are considerably higher than those of the previous Silvatec systems, but still lower than for the tractor chipper.

WHOLE STEM METHOD, FELLED BY HARVESTER, CHIPPED BY SILVATEC TERRAIN CHIPPER

This method was applied in all three Sitka spruce stands. This method was totally new to the harvester operator and some of the results may have been influenced by this. The results are presented in Table 4.4.

The costs for this method are considerably higher than for the whole tree methods, due to the high costs of the harvesting. The costs of chipping are similar to those for the whole tree method.

WHOLE TREE METHOD, CHEMICALLY THINNED, FELLED AND CHIPPED BY SILVATEC TERRAIN CHIPPER

Chemical thinning was carried out in the three Sitka spruce stands, but due to time constraints the Silvatec only attempted chipping the trees in two of them. Even then, only one load was taken at Swan, and three at Kilbrin, so the averages presented in Table 4.5 are based on a small number of observations.

The cost of this method was considerably higher than those for the other whole tree methods, due to the time required for the chipper to fell and handle the trees. The machine had much lower productivity than for the other whole tree methods.

It is necessary that all trees are fully killed off before chipping. If this is not the case the moisture content will be too high. Trees should therefore be treated in late winter or early spring and checked to see if they all are dead by August. An extra application should be administered to any living trees. Chipping can be carried out once all the trees

Table 4.3: Productivity and costs of the trees felled by feller-buncher and chipped by Silvatec terrain chipper.

Site	Frenchpark	Swan	Kilbrin	Average
Productivity m^3 solid biomass/pmh				
Feller-buncher	17.48	14.24	12.11	14.61
Silvatec chipper	29.2	23.3	23	25.17
Cost €/m^3 solid biomass				
Feller-buncher (€100/pmh)	5.72	7.02	8.26	7.00
Silvatec chipper (€295/pmh)	10.1	12.66	12.82	11.86
Total cost €/m^3 solid biomass	15.82	19.68	21.08	18.86

Table 4.4: Productivity and costs of the whole stem method.

Site	Frenchpark	Swan	Kilbrin	Average
Productivity m^3 solid biomass/pmh				
Harvester	4.82	4.05	3.22	4.03
Silvatec chipper	25.2	25.4	22.2	24.27
Cost €/m^3 solid biomass				
Harvester (€110/pmh)	22.85	27.3	34.12	28.09
Silvatec chipper (€295/pmh)	11.72	11.6	13.31	12.21
Total cost €/m^3 solid biomass	34.57	38.9	47.43	40.30

Table 4.5: Productivity and costs of felling and chipping chemically thinned trees with the Silvatec terrain chipper.

Site	Frenchpark	Swan*	Kilbrin	Average
Productivity m^3 solid biomass/pmh				
Chainsaw treat		5.41	6.47	5.94
Silvatec fell chipper		17.4	13.3	15.35
Cost €/m^3 solid biomass				
Chainsaw plus treat (€30/pmh)		5.55	4.62	5.09
Silvatec chipper (€295/pmh)		16.91	22.15	19.53
Total		22.46	26.77	24.62

* One observation only

have shed their needles. Very small trees (under 5-6 cm dbh) need not be treated but can be severed at the stump and left hanging. Those trees are so light, that were they to fall, the risk of injury is low. An advantage of this method is that motor-manual felling can be avoided and the soil is not disturbed before the chipper arrives. A disadvantage is that the method only be used for row thinning and on a few trees in the rows immediately adjacent to the outrow. Reaching into the stand for a selection thinning, would slow the chipping operation.

INTEGRATED HARVESTING OF ENERGY WOOD AND INDUSTRIAL ASSORTMENT, FORWARDING AND ROADSIDE CHIPPING

This method was attempted in the three Sitka spruce stands. The harvester operator had to get used to producing a badly delimbed energy assortment of varying length. After harvesting, the wood was forwarded to the roadside and stacked. At Swan and Kilbrin, the piles were covered with plastic to keep out the rain.

The wood was chipped by a Jenz truck chipper. The machine was fed by the crane of the truck. The results are given in Table 4.6.

Due to the low productivity of the harvester, the costs of this method are much higher than those of the other methods shown. The cost of chipping roundwood at the roadside was low compared to chipping in the stand, but the process of getting the wood to the roadside was very expensive.

Even accepting a standard cost of €22-25 per m^3 solid wood at the roadside for harvesting and forwarding, the cost of the chips would be much higher than in the other methods, in the order of €30-€35 per m^3 solid.

The small amounts of roundwood produced in the trials and the large capacity of the trucks taking the chips away, meant it was not possible to calculate an increase in biomass by harvesting the crudely delimbed tree sections. No truck was solely filled with chips from either the crudely delimbed energy tree sections or by clean 3 m pulpwood.

Table 4.6: Productivity and costs of the integrated method with harvesting, forwarding and chipping at the roadside.

Site	Frenchpark	Swan	Foil	Average
Productivity m^3 solid biomass/pmh				
Harvester	1.97	5.13	4.11	3.74
Forwarder	11.24	9.12	7.68	9.35
Jenz truck chipper	30.75	40.4	36/9	36.02
Cost €/m^3 solid biomass				
Harvester (€110/pmh)	55.94	21.42	26.73	34.70
Forwarder (€90/pmh)	8.01	9.87	11.73	9.87
Jenz chipper (€268)	8.72	7.32	7.56	7.87
Total cost €/m^3 solid biomass	72.67	38.61	46.02	52.43

TRADITIONAL ROUNDWOOD METHOD, CHIPPING PULPWOOD AT ROADSIDE

This method was tried in all Sitka spruce stands as a reference method. The plots where this method were attempted were the smallest in the trials, so limited pulpwood was produced. For roadside chipping, the same productivity figures as for the energy tree sections were used. The results are presented in Table 4.7. The forwarder data from Frenchpark are an average taken from the other forwarding studies.

The costs were much higher than those of the whole tree harvesting methods due to the high cost of the harvesting and terrain transportation of the assortments.

COMPARISON OF ALL METHODS IN CONIFERS

All methods for harvesting wood for energy in conifer stands that were studied in the ForestEnergy2006 programme are compared to each other, based on the results presented earlier (Table 4.8). The costs are given per m^3 solid of biomass delivered in chip form at the roadside in a pile, so blown into the truck by the Jenz chipper. For the assortment methods the price also includes delivery in road transportation trucks.

Table 4.8 shows clearly that the whole tree methods are the least expensive for harvesting wood for energy because of the high productivity of the systems and the large increase in biomass from the branches. The cheapest method is where the Silvatec chipper processes the trees that have been felled in row thinning by chainsaw.

Chemical thinning is considerably less expensive than methods where assortments were produced with a harvester and forwarded to the roadside. The whole stem method is much more expensive than the whole tree methods. It should be noted that the machines used in these trials were not optimally adapted to the Irish terrain circumstances. The machines should have been equipped either with much wider tires or band tracks. Usually the damage caused in the rows by the harvesting machines was minimal. Damage, if it occurs, tends to be on the cross racks, where most transportation and turning takes place. It may be better to thin the cross racks to waste and put all available wood and branches from these headlands on the ground to support the machines, particularly on wet sites. The brash mat created should last until at least the next thinning.

Table 4.7: Productivity and costs of the standard harvesting method with chipping of the pulpwood at roadside.

Site	Frenchpark	Swan	Foil	Average
Productivity m^3 solid biomass/pmh				
Harvester	3.66	3.06	4.95	3.89
Forwarder	10.26	9.93	10.57	10.25
Jenz truck chipper	30.75	40.4	36.9	36.02
Cost €/m^3 solid biomass				
Harvester (€110/pmh)	30.05	35.93	22.21	29.40
Forwarder (€90/pmh)	8.78	9.07	8.52	8.79
Jenz chipper (€268)	8.72	7.32	7.56	7.87
Total cost €/m^3 solid biomass	47.55	52.32	38.29	46.05

Table 4.8: Comparison of total cost per cubic metre solid biomass for all methods in conifers.

Assortment	Felling method	Chipper	Average cost at roadside €/m^3 solid biomass
Whole tree	Chainsaw	Tractor TP280	€19.34
Whole tree	Chainsaw	Silvatec	€14.31
Whole tree	Feller-buncher	Silvatec	€18.86
Whole stem	Harvester	Silvatec	€40.30
Whole tree chemical	Silvatec	Silvatec	€24.62
Tree section	Harvester/forwarder	Jenz	€52.43
Pulpwood	Harvester/forwarder	Jenz	€46.05

5. COMPARISON AND COSTS OF HARVESTING CHAINS IN BROADLEAVES

In the 2006 trials one broadleaf stand at Portlaw was harvested, comprised of a block of ash and a block of sycamore. The results for the separate operations in the harvesting chains are presented. The individual results are taken from Chapter 3. In all cases productivity is expressed in m^3 solid biomass, including additional biomass harvested. The costs are based on those actually paid for the machines during the trials.

In another ash stand at Kilcock, an attempt was made to harvest stemwood with a harvester in a combined row and selection thinning. The stems were not straight and often had heavy branches at awkward angles, making this a daunting task for the operator. However, even though the operation was carried out successsfully, it was of insufficient duration for a time study.

WHOLE TREE METHOD, MOTOR-MANUAL FELLING, TERRAIN CHIPPING BY TRACTOR

This system was carried out in a combined row and selection thinning where the trees had been felled by chainsaw. The trees from the selection thinning had been felled at a steep angle to the rack and their butt ends dragged into the rack.

The productivity and costs are shown in Table 5.1. As the trees were small, productivity was low. The long transport distance to where the chips could be dumped also increased the costs.

WHOLE TREE METHOD, MOTOR-MANUAL FELLING, CHIPPING BY SILVATEC TERRAIN CHIPPER

The Silvatec chipper also chipped part of the motor-manually felled block (Table 5.2).

The low productivity was caused by the Silvatec having to wait for the chip forwarder to travel a long distance with the chips. The costs were similar to that of the tractor chipper. The trees that had been felled in the selection thinning were sometimes left because they would have damaged the remaining trees when being pulled into the chipper.

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, TERRAIN CHIPPING BY SILVATEC

Another part of the stand was thinned with a combined row and selection thinning by the feller-buncher. The trees were bunched in the rack in a roof tile arrangement. The results are given in Table 5.3.

The trees were rather small and the working method was complicated for the feller-buncher, so the productivity of the feller-buncher was low and the costs high. The improved presentation of the trees did not result in a substantial increase in productivity of the Silvatec chipper. The total costs were slightly higher than those for the motor-manual felling methods.

Table 5.1: Harvesting productivity and costs of harvesting whole broadleaved trees, felled by chainsaw and chipped by tractor chipper.

Site	Portlaw
Productivity m^3 s biomass/pmh	
Chainsaw fell	4.24
Tractor chip	4.8
Cost €/m^3 s biomass	
Chainsaw fell (€25/pmh)	5.88
Tractor chip (€100/pmh)	21
Total €/m^3 s biomass	26.88

Table 5.2: Harvesting productivity and costs of harvesting whole broadleaf trees, felled by chainsaw and chipped by Silvatec terrain chipper.

Site	Portlaw
Productivity m^3 s biomass/pmh	
Chainsaw fell	4.24
Silvatec chipper	13.4
Cost €/m^3 s biomass	
Chainsaw fell (€25/pmh)	5.88
Silvatec chipper (€295/pmh)	21.96
Total €/m^3 s biomass	27.84

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, FORWARDING TO ROADSIDE, CHIPPING BY TRUCK CHIPPER

Part of the ash block was thinned in this way. A heavy thinning was carried out to release the trees with potential to produce hurley butts. The trees were felled and piled at right angles to the rack. From there they were picked up by the forwarder and transported to a pile at the roadside which was covered by plastic.

The pile was chipped by the truck chipper and the chips were blown straight into a walking-floor truck. The results are presented in Table 5.4.

The productivity of the feller-buncher was low and forwarding was slow and cumbersome with low volumes of wood carried due to all the branches. The chipping was reasonably fast. The total costs for this method are much higher than for the other whole tree methods with chipping in the stand.

COMPARISON OF METHODS

All methods for harvesting wood for energy from broadleaves that were studied in ForestEnergy 2006 are compared to each other, based on the results given in previous chapters (Table 5.5). The costs are given per m^3 solid of biomass delivered in chip form at the roadside in a pile. For the assortment methods, the price also includes the delivery in road transportation trucks.

In this case, the results are not based on an average as only one stand was harvested (Table 5.5).

Whole tree methods with in-stand chipping were considerably cheaper than chipping whole trees at the roadside. The total cost per m^3 solid biomass is much higher than in conifers because of the relatively small size of the broadleaved trees.

Table 5.3: Harvesting productivity and costs of harvesting whole broadleaf trees, felling by feller-buncher and chipping by Silvatec terrain chipper.

Site	Portlaw
Productivity m^3 s biomass/pmh	
Feller-buncher	9.13
Silvatec chipper	17.4
Cost €/m^3 s biomass	
Feller-buncher (€100/pmh)	10.95
Silvatec chipper (€295/pmh)	19.99
Total €/m^3 s biomass	30.94

Table 5.4: Harvesting productivity and costs of harvesting whole trees felled by feller-buncher, forwarded to roadside, chipped by truck chipper.

Site	Portlaw
Productivity m^3 s biomass/pmh	
Feller-buncher	6.3
Forwarder	5.44
Jenz truck chipper	22.5
Cost €/m^3 s biomass	
Feller-buncher (€100/pmh)	15.88
Forwarder (€90/pmh)	16.57
Jenz chipper (€268)	11.91
Total €/m^3 s biomass	44.36

Table 5.5: Comparison of the total cost per m^3 solid biomass for all methods in broadleaved stands.

Assortment	Felling method	Chipper	Cost at roadside (€/m^3 s biomass)
Whole tree	Chainsaw	Tractor TP280	€26.88
Whole tree	Chainsaw	Silvatec	€27.84
Whole tree	Feller-buncher	Silvatec	€30.94
Whole tree	Feller-buncher/forwarder	Jenz	€44.36

6. COMPARISON AND COSTS OF HARVESTING CHAINS AT THE CUTWAY PEATLAND (BOORA) SITE

The individual operations described in Chapter 3 are combined here in harvesting chains.

Several different stands on cutaway peatland were tackled: a planted birch stand, a natural regeneration birch stand, a Sitka spruce stand which had mostly failed and had been colonised by birch, as well as a large block of poor quality lodgepole pine that had to be clearfelled. In all stands, the trees were felled by feller-buncher as a clearfell. Part of the lodgepole pine stand was felled by chainsaw.

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, CHIPPING BY TRACTOR CHIPPER OF PLANTED BIRCH

The trees were ten years old and planted in rows and in long, narrow strip adjacent to a species trial. Felling was by feller-buncher with stems piled to one side of the machine. Chipping was carried out by the tractor chipper and the chips placed in a pile at the roadside. The results are presented in Table 6.1.

Since the trees were very small, the productivity of the machines was low and the costs relatively high. The strip was also very long and narrow, so there was a lot of travel time.

Table 6.1: Productivity and costs for harvesting whole trees, felling by feller-buncher, chipping by tractor chipper, planted birch.

Site	Boora Planted birch
Productivity m^3 solid biomass/pmh	
Feller-buncher	5.24
Tractor chipper	5.5
Cost €/m^3 solid biomass	
Feller-buncher (€100/pmh)	19.03
Tractor chipper (€100/pmh)	18.05
Total €/m^3 solid biomass	37.08

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, CHIPPING BY TRACTOR CHIPPER, NATURALLY REGENERATED BIRCH

This was a small area of older, naturally regenerated birch. The trees grew in clumps with some butt sweep that caused difficulties for the feller-buncher. The results are presented in Table 6.2.

The tractor chipper had to travel more than a kilometre to dump the chips in a pile, which greatly reduced chipping productivity.

Table 6.2: Productivity and costs for harvesting whole trees in naturally regenerated birch, felled by feller-buncher and chipped by tractor chipper.

Site	Boora Naturally regenerated birch
Productivity m^3 solid biomass/pmh	
Feller-buncher	4.54
Tractor chipper	5.6
Cost €/m^3 solid biomass	
Feller-buncher (€100/pmh)	22.02
Tractor chipper (€100/pmh)	17.71
Total €/m^3 solid biomass	39.73

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, CHIPPING BY SILVATEC, POOR QUALITY SITKA SPRUCE AREA COLONISED BY BIRCH

The feller-buncher encountered a lot of problems in this stand. The trees were unevenly spaced and often grew in clumps. The size of trees varied greatly. Felled stems were piled in one large strip alongside the feller-buncher and chipped with the Silvatec chipper. The results are shown in Table 6.3.

The productivity of the feller-buncher in this stand was low due to the problems described and was the main cause of the high costs.

Table 6.3: Productivity and costs for harvesting whole trees, felled by feller-buncher, chipped by Silvatec, in a failed Sitka spruce area colonised by birch.

Site	Boora Sitka spruce/naturally regenerated birch
Productivity m^3 solid biomass/pmh	
Feller-buncher	4.6
Silvatec chipper	18.4
Cost €/m^3 solid biomass	
Feller-buncher (€100/pmh)	21.7
Silvatec chipper (€295/pmh)	16.03
Total €/m^3 solid biomass	37.73

WHOLE TREE METHOD, FELLING BY FELLER-BUNCHER, CHIPPING BY SILVATEC OF PREMATURE CLEARFELL OF LODGEPOLE PINE

The lodgepole pine stand was removed to create additional habitat for reintroduced partridge. The stand had been very heavily damaged by pine-shoot moth, with the result that most of the trees had badly shaped and/or multiple stems, allied to very heavy branching. This also explains the large increase in biomass harvest using whole tree methods. Trees felled with the feller-buncher were forwarded to the roadside outside the trials after chainsaw felling. The results are shown in Table 6.4. The massive increase in biomass enabled a reasonable cost for this operation to be achieved.

Table 6.4: Productivity and costs for harvesting whole trees, felling by feller-buncher, chipping by Silvatec of premature clearfell of lodgepole pine.

Site	Boora Lodgepole pine
Productivity m^3 solid biomass/pmh	
feller-buncher	13.56
Silvatec chip	27.7
Cost €/m^3 solid biomass	
Feller-buncher (€100/pmh)	7.31
Silvatec chip (€295/pmh)	10.92
Total €/m^3 solid biomass	18.23

WHOLE TREE METHOD, FELLING BY CHAINSAW, CHIPPING BY SILVATEC OF PREMATURE CLEARFELL OF LODGEPOLE PINE

Part of the stand was clearfelled by chainsaw and chipped using the Silvatec for comparison with the feller-buncher method. The results are presented in Table 6.5. Felling by chainsaw was not much slower than by feller-buncher, so the total costs were comparable to that of the feller-buncher method.

Table 6.5: Productivity and costs for harvesting whole trees, felling by chainsaw, chipping by Silvatec of premature clearfell of lodgepole pine.

Site	Boora Lodgepole pine
Productivity m^3 solid biomass/pmh	
Chainsaw fell	3.76
Silvatec chip	27.7
Cost €/m^3 solid biomass	
Chainsaw fell (€25/pmh)	6.66
Silvatec chip (€295/pmh)	10.92
Total €/m^3 solid biomass	17.58

COMPARISON OF METHODS

All methods for harvesting wood for energy from clearfell on cutaway peatland that were studied in ForestEnergy 2006 were compared with each other, based on the results given in Chapter 3. The costs are given per cubic metre solid of biomass delivered in chip form at the roadside in a pile. For the assortment methods the price includes the delivery in road transportation trucks.

The results (Table 6.6) are not based on an average since only one stand of each species was harvested. The costs of harvesting the birch were high because of the high costs of felling. The chipping costs were as before.

The costs of harvesting the lodgepole pine were only acceptable because of the massive increase in biomass harvest due to the bushy nature of the trees and multiple stems. Also the needles had not fully fallen off and this also contributed to the increase in biomass.

Table 6.6: Comparison of the total cost per m^3 solid biomass for all methods at the Boora site.

Assortment	Felling method	Stand	Chipper	Cost at roadside (€/m^3 solid biomass)
Whole tree	Feller-buncher	Planted birch	Tractor TP280	€37.08
Whole tree	Feller-buncher	Naturally regenerated birch	Tractor TP280	€39.37
Whole tree	Feller-buncher	Sitka spruce/birch	Silvatec	€37.73
Whole tree	Feller-buncher	Lodgepole pine	Silvatec	€18.23
Whole tree	Chainsaw	Lodgepole pine	Silvatec	€17.58

7. HARVESTING CHAIN COST AND CHIP QUALITY COMPARISON

This section examines the relationship between the chip quality produced and the cost of production. The data gathered in previous sections are integrated to estimate the production cost of wood energy from each system employed in ForestEnergy 2006.

Many wood chip assortments, derived from several species, using a variety of harvesting and chipping systems, were produced in the programme. Previous sections have described these systems in detail and the accumulated supply chain production cost for each system was calculated. Various quality parameters were assessed for each assortment, including the moisture content, particle size distribution and bulk density.

The key quality parameter for wood chip is the net calorific value as received by the end-user. Ultimately, wood used for energy generation must be quantified and traded on its ability to meet a particular energy demand load. Moisture content is the key parameter that affects the net calorific value of wood. The lower the moisture content, the higher the net energy output at combustion. Unlike other roundwood timber supply chains, the wood chip supply chain from forest thinnings separates the harvesting operation and the chipping operation to facilitate ambient seasoning of the material to be chipped. The optimum supply chains are those that not only have the lowest production costs, but also promote maximum seasoning for higher net energy output from the wood fuel.

The main benefit of this work is to present costs in a manner compatible with other energy options. The ability to trade wood fuel on energy content, the knowledge of quantification and conversions from standing trees to energy output, and the confidence in systems developed to measure wood fuel for sales purposes are key criteria for the successful development of a commercial wood fuel sector in Ireland. The figures presented below give the wood fuel buyer some insight into production costs in terms comparable to other fuels and for the seller, the figures represent a baseline from which a competitive fuel price can be set.

METHODS USED IN ESTIMATING PRODUCTION COST OF WOOD ENERGY

Net calorific value is related to gross calorific value, which is the energy released on complete combustion of the fuel to combustion gases and solid ash. The gross calorific value of wood is approximately 19 Giga joules per tonne (GJ/t) of dry matter for broadleaves and 19.2 GJ/t for conifers. This is about 40% that of oil, by dry weight. The actual energy output from wood fuel combustion is lower due to the energy used in evaporating water from the fuel. Therefore, the net calorific value varies with the moisture content of wood at the time of combustion.

The measurement of fuel calorific value in a bomb calorimeter employs complex equations to describe the reaction. Many analyses have demonstrated, however, that net calorific value and moisture content are closely related. This relationship can be described using a simple equation, suitable for general use. The equation describes the net calorific value per green tonne of wood, based on moisture content value, as received. It should be noted that such equations only describe the effect of moisture content and have only been derived for conifer and broadleaf species grown in northern Europe. In the absence of equations developed for Irish species, the following equations were used:

- *Conifer net calorific value (Giga joules per green tonne)*
  *= [19.2 – (0.2164 * Moisture Content %)]*

- *Broadleaf net calorific value(Giga joules per green tonne)*
  *= [19.0 – (0.2144 * Moisture Content %)]*

The effect of moisture content on net calorific value is illustrated in Figure 7.1. These equations allow the energy content per green tonne of each assortment to be estimated, from measured moisture content. Each green tonne of wood chip produced

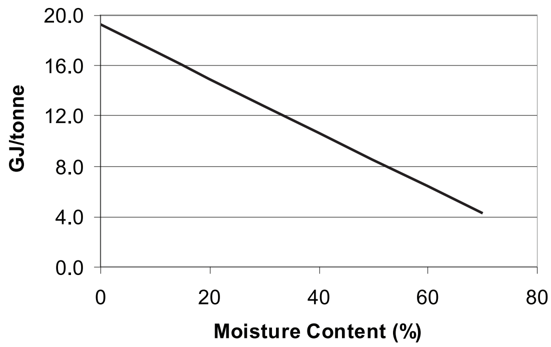

Figure 7.1: Relationship between net calorific value and moisture content of wood.

can be converted to bulk volume using the measured bulk density (as received) for that assortment. Therefore the energy content per cubic metre loose volume can be calculated. Energy content per cubic metre solid volume is required in order to present the energy content of each assortment in a manner compatible with the production cost of that assortment. Energy content (GJ/m^3 solid volume) can be calculated using the standard conversion factor of 0.33, from loose volume to solid volume. Finally, the production cost can be expressed per Giga joule of energy content. An example is provided in Table 7.1 to demonstrate the method of calculation.

WOOD ENERGY PRODUCTION COST COMPARISON FOR CONIFER SYSTEMS

The supply chain costs of the harvesting and chipping systems employed in conifer thinnings, expressed on the basis of energy content, are presented in Table 7.2. The production costs are divided by the calculated energy density, to derive the cost per Giga joule. These figures only document costs up to the forest road, and do not include road transportation costs.

The energy density of Sitka spruce varied little between assortments. Energy density is increased by lower moisture content or higher bulk density (dry weight). The energy density figure for the tree section assortment of 7.7 GJ/m^3 is an example of this, as the bulk density recorded for this assortment was high, though it only consisted of one sample, made up of three sub-samples. As such, this energy density may not be representative. Overall, the costs per Giga joule reflect the cost of production per cubic metre.

Table 7.1: Methodology used in calculating production cost for wood energy.

Site	Kilbrin	Swan	Frenchpark
Species	Sitka spruce	Sitka spruce	Sitka spruce
Assortment	Whole stem	Whole stem	Whole stem
Chipper	SL	SL	SL
Mean moisture content %	49.1	57.2	52.0
Step 1: Calculation of net calorific value			
Equation: NCV (GJ/green tonne) = 19.2 - (0.2164*MC%)			
Net calorific value (Giga joules per green tonne)	8.6	6.8	7.9
Step 2: Calculation of energy content per cubic metre loose volume			
Equation: Energy content (GJ/m^3 loose volume) = NCV * [bulk density (as received)/1000]			
Bulk density (as received) (kg/m^3)	277	320	329
Energy content GJ/m^3 loose volume	2.4	2.2	2.6
Step 3: Calculation of energy content per cubic metre solid volume			
Equation: Energy content (GJ/m^3 solid volume) = Energy content (GJ/m^3 l. v.) x loose volume/solid volume conversion factor			
Loose volume/solid volume conversion factor (assumed)	0.33	0.33	0.33
Energy content per cubic metre solid volume	7.2	6.6	7.9
Step 4: Calculation of mean energy content per assortment			
Mean energy content for whole stem assortment in conifers (GJ/m^3 s)	7.2		
Step 5: Calculation of production cost per energy output			
Equation: Cost per Giga joule = Production cost per m^3 solid volume/energy content (GJ/m^3)			
Mean production cost for whole stem assortment in conifers	€40.30		
Cost for whole stem assortment in conifers (€/GJ)	**€5.56**		

Table 7.2: Supply chain costs (€/GJ) in conifers.

Assortment	Felling method	Chipper	Average cost at roadside €/m³ solid biomass	Energy Density Giga joules/m³	Cost per Giga joule €/GJ
Whole tree	Chainsaw	Silvatec	€14.31	7.0	€2.03
Whole tree	Feller-buncher	Silvatec	€18.86	7.0	€2.68
Whole tree	Chainsaw	TP280	€19.34	7.0	€2.77
Whole tree chemical	Silvatec	Silvatec	€24.62	6.9	€3.58
Whole stem	Harvester	Silvatec	€40.30	7.2	€5.62
Pulpwood	Harvester/forwarder	Jenz	€46.05	7.1	€6.53
Tree section	Harvester/forwarder	Jenz	€52.43	7.7	€6.78

WOOD ENERGY PRODUCTION COST COMPARISON FOR BROADLEAF SYSTEMS

The costs for energy wood from broadleaves are detailed in Table 7.3. The whole tree assortments felled by chainsaw and chipped by both the Silvatec and tractor-mounted TP280 chipper consisted of both sycamore and ash. The feller-buncher/Silvatec assortment was sycamore only, and the assortment chipped on the landing by the Jenz chipper was all ash.

The most interesting aspect of the cost per Giga joule for broadleaves is that the assortments felled by chainsaw are almost on a par with the whole tree systems in conifers. This is despite the much greater costs per cubic metre, due to the relatively very small mean volume per tree in broadleaves. The gap is closed due to the higher energy density of broadleaves, because of their lower moisture content and higher bulk density. Similar to the conifers, the system that involved extracting to roadside for chipping was more expensive than the terrain chipping systems, despite the higher energy density.

WOOD ENERGY PRODUCTION COST COMPARISON FOR SYSTEMS USED AT CUTWAY PEATLAND (BORD NA MÓNA) SITES

The energy density and costs of energy produced are described in Table 7.4 for the stands felled at the cutway peatland (Bord na Móna) sites. As already stated the lodgepole pine is described as Lodgepole 1 (harvested in March) and Lodgepole 2 (harvested in June).

In contrast to the other trials, all Bord na Móna plots were clearfells, and as stated previously this may have have led to the greater moisture content reductions found over the drying period. The energy density achieved by all assortments was comparable with ash, with the exception of the lodgepole pine, which was harvested in June and had less drying time. This explains why the chainsaw-felled lodgepole had a higher cost per GJ, despite having a lower production cost per m³.

Table 7.3: Supply chain costs (€/GJ) in broadleaves.

Assortment	Felling method	Chipper	Cost at roadside €/m³	Energy Density GJ/m³	Cost per Giga joule €/GJ
Whole tree	Chainsaw	TP280	€26.88	9.5	€2.82
Whole tree	Chainsaw	Silvatec	€27.84	9.8	€2.85
Whole tree	Feller-buncher	Silvatec	€30.94	9.2	€3.37
Whole tree	Feller-buncher/forwarder	Jenz	€44.36	10.9	€4.07

Table 7.4: Supply chain costs (€/GJ) for systems used at the cutway peatland (Bord na Móna) sites.

Stand	Assortment	Felling method	Chipper	Cost at roadside €/m³	Energy density GJ/m³	Cost per Giga joule €/GJ
Lodgepole 1	Whole tree	Feller-buncher	Silvatec	€18.23	8.9	€2.04
Lodgepole 2	Whole tree	Chainsaw	Silvatec	€17.58	7.7	€2.28
Planted birch	Whole tree	Feller-buncher	TP280	€37.08	9.9	€3.74
Sitka spruce/birch	Whole tree	Feller-buncher	Silvatec	€37.73	9.8	€3.86
Naturally regenerated birch	Whole tree	Feller-buncher	TP280	€39.37	9.9	€3.97

DISCUSSION AND CONCLUSIONS ON WOOD ENERGY PRODUCTION COSTS

Trading wood fuel by energy content will be a prerequisite for large-scale deployment. Only a part of the supply chain was priced in this way for ForestEnergy 2006. Some cost elements were not included such as the standing price of timber expected by the landowner, the road transportation cost and the profit expected by the wood fuel supplier. The main reason they were excluded was the level of variability and to a certain degree, subjectivity in these cost elements. However, developing total, delivered-in price estimates for wood fuel will be important for development of this sector. Methods of estimating these cost elements in a clear, robust manner should be researched.

The importance of reducing the moisture content of wood fuel to increase the net calorific value cannot be over-emphasised. Higher energy density comes at no additional direct production cost; therefore trading wood fuel at the lowest moisture content achievable increases the profit margin. Seasoning wood in the forest does require time, during which timber and harvesting costs have to be borne without return. Additional expenditure on forced drying could be investigated, as the reduced seasoning period and increased energy price may be price competitive in certain circumstances.

The estimation of net calorific value from moisture content may require some validation for Irish conditions and species. The equations for conifers and broadleaves are crucial for ensuring that wood fuel is traded on a fair basis. These equations express a complex energy interaction during wood fuel combustion as a simple relationship. The accuracy and efficacy of the equations need to be well understood and trusted by all parties involved in wood fuel trading, whose price is determined partially by their use.

A conversion factor from solid wood volume to loose volume of wood chip of 0.33 has been used throughout this report. This conversion factor, while generally accurate, should be further investigated to reveal the level of variation, depending on the assortment chipped and the chipper used.

The other key parameter affecting energy density, apart from moisture content, is bulk density. As this is largely determined by basic density, further research should be carried out in identifying optimum species, age classes and assortment types that contain wood of high density for wood fuel production.

8. CHIP QUALITY

The primary objective of the ForestEnergy 2006 programme was to demonstrate forest harvesting and chipping supply chains to produce high quality wood chip for energy. Determination of quality requires an understanding of the parameters that define this in wood chip. In structural timber the key quality criteria relate to strength. In wood chip for energy the criteria relate to the delivered energy from the chip when combusted as a fuel. In essence, wood chip is competing with established, well-proven fuels, the qualities of which are largely taken for granted through frequent use. This same familiarity needs to be developed for wood chip to be traded: predictable energy contents based on weight and volume; consistent chip size for even flow; moisture content that will allow storage without decomposition.

The European Technical Specifications for solid biofuels are tools developed to ensure a quality standard develops in the wood energy sector. CEN/TS 14961 *Solid biofuels – Fuel specifications and classes* describes the essential quality parameters that need to be sampled and stated on traded wood chip. These parameters include moisture content, particle size class, bulk density and energy content. The following sections describe the studies carried out on these parameters to determine wood chip quality from the ForestEnergy 2006 trials.

MOISTURE CONTENT CHANGE

The objective of the investigation was to determine the moisture content of all assortments at time of harvesting in March 2006 and in August when the chipping took place. In addition to determining the efficacy of seasoning over the summer period, the moisture content analysis facilitated wood chip description according to the specifications formulated for wood chip properties in CEN/TS 14961 *Solid biofuels - Fuel specifications and classes*. The recognised moisture content classes are described in Table 8.1.

The moisture content measurements taken in August were used in estimating the net calorific value of the different wood chip assortments. This in turn enabled the calculation of a production cost for energy output. The calculations involved other datasets measured, including the bulk density and production cost of each harvesting and chipping system.

Moisture content is the key factor in determining the net energy content of wood fuel, and the length of time wood chip can be stored without decomposing. Lowering the moisture content increases the net calorific value. If moisture content is reduced to below 30% wood chip can be stored for a period of months. Further moisture content reduction will increase the storage period.

Trees use large quantities of water in photosynthesis and to transport nutrients in solution. Freshly felled trees retain this moisture and then release it slowly as the wood seasons.

Seasoning requires:

1. heat energy for moisture to evaporate from the wood;
2. good air flow to carry moisture as water vapour from the wood surface; and
3. low relative humidity in the air so that additional water vapour can be absorbed.

These conditions are used for air drying sawn wood and in kiln drying. Energy life cycle considerations and costs indicate that artificial drying of wood chip is not the preferred method, and air drying is the better approach. Seasoning was therefore carried out in the forest before chipping of all assortments harvested in the ForestEnergy 2006 programme.

Table 8.1: Moisture content classes (expressed as % of total weight, as received).

Moisture Content Class	Maximum Moisture Content	Comment
M20	≤20%	Dried
M30	≤30%	Suitable for storage
M40	≤40%	Limited suitability for storage
M55	≤55%	-
M65	≤65%	-

Method of determining moisture content

The European Technical Specification IS CEN/TS 14774:2 *Methods for the determination of moisture content - oven dry method - Part 2: Total moisture – simplified method* was used in this study. Moisture content determination starts with selecting the appropriate sample size and intensity of sampling. Each sample should be a minimum of 300 g in total weight. The wet weight of the sample is determined before it is placed in an oven at 105°C until constant weight is achieved (usually within 24 hours). The oven temperature is above boiling which promotes full moisture evaporation. When the sample is removed from the oven the dry weight is determined. Wet and dry weight are then used to express moisture content in either of two ways:

Dry basis:

*Moisture content (%) = [(wet weight – dry weight)/dry weight] * 100*

This method is typically used in the panelboard sector as the Oven Dry Bark Free Tonne Method of quantifying wood intake.

Wet basis:

*Moisture content (%) = [(wet weight – dry weight)/wet weight] * 100*

Wet basis is used in European Technical Specifications as the standard method for expressing moisture content of solid biofuels, including wood chip.

Moisture content sampling in March 2006

Moisture content was measured in March 2006 during harvesting operations at each site and again in August 2006 during chipping operations. In March a small self-powered chipper was available and samples were prepared as follows: five whole trees were sampled from each assortment and completely chipped; five moisture content sub-samples were selected from each sample tree, weighed immediately and labelled. Samples were transported to Waterford Institute of Technology (WIT) for drying. In addition to the assortment samples, other species were sampled, if available, in order to gain knowledge of moisture content of growing trees in Ireland.

Moisture content sampling in August 2006

During chipping operations in August, samples were selected from all assortments as the chipper was processing the material. The sampling took place as chips were loaded for road transport in the case of the Jenz truck chipper, or as chips were unloaded at the forest landing by the Silvatec chip forwarder or tractor-trailer. A minimum of three sub-samples per load were taken for each assortment. A maximum of fifty sub-samples were taken for any one assortment. The wet weights of these sub-samples were immediately measured and labelled for oven drying at the laboratory facilities at WIT.

The procedure for moisture content determination varied from that described in the technical specification. All sub-samples were a minimum of 1000 g in weight and were contained within paper bags, rather than the plastic bags specified. As the sub-sample was weighed for wet weight immediately, it was possible for water to evaporate from the wood chip through the paper bag without the formation of condensation. It also allowed samples to be placed in the oven without being reloaded into trays. The wet and dry weights of the paper bags were measured and excluded from the moisture content calculations.

Moisture content results for conifers

Table 8.2 describes the mean sampled moisture content in March and again in September for all the assortments produced in conifer first thinnings. The moisture content classes are applied based on the specification described in Table 8.1. A simple indicator of the efficacy of seasoning is given by comparing the moisture content classes in March and again in August. A good result is indicated by a shift to a lower moisture content class in August.

On average, across the four sites, the whole tree assortment had the lowest initial moisture content and seasoned most. This comparatively better seasoning may be explained by the transpiration effect of the needles continuing to draw moisture out of the tree after it is felled. This appears to be borne out by the whole tree assortment result in Frenchpark, where the smaller change in moisture content was more than likely due to the fact that the majority of trees were not completely cut through during felling, so moisture could still be drawn up into the stem.

The energy wood assortment, where green material with needles was stacked gave the poorest results. This may have been due to poor air circulation in the storage stack, resulting in moisture being retained. The reduction in roundwood

Table 8.2: Moisture content trends in Sitka spruce energy assortments between March and August 2006.

Site	Assortment	Chipper	March Samples		August Samples		MC Change
			MC %	MC Class	MC %	MC Class	%
Swan	Whole tree	Silvatec	60.45	M65	47.70	M55	-12.75
Swan	Roundwood	Jenz	65.15	none	54.90	M55	-10.25
Swan	Whole tree	TP280	60.45	M65	50.67	M55	-9.78
Swan	Energywood	Jenz	66.11	none	58.92	M65	-7.19
Swan	Whole tree (chemical)	Silvatec	60.45	M65	54.42	M55	-6.03
Swan	Whole stem	Silvatec	62.65	M65	57.20	M65	-5.45
Kilbrin	Whole tree	Silvatec	56.80	M65	40.75	M55	-16.05
Kilbrin	Whole stem	Silvatec	63.05	M65	49.13	M55	-13.92
Kilbrin	Whole tree	TP280	56.80	M65	45.82	M55	-10.98
Kilbrin	Whole tree (chemical)	Silvatec	56.80	M65	49.46	M55	-7.34
Frenchpark	Whole stem	TP280	60.06	M65	50.45	M55	-9.61
Frenchpark	Whole stem	Silvatec	60.06	M65	52.01	M55	-8.05
Frenchpark	Whole tree	Silvatec	56.84	M65	53.00	M55	-3.84
Frenchpark	Energy wood	Jenz	61.82	M65	61.45	M65	-0.38
Frenchpark	Whole tree	TP280	56.84	M65	56.78	M65	-0.06
Frenchpark	Roundwood	Jenz	61.57	M65	62.62	M65	1.05
Frenchpark	Whole tree (chemical)	Silvatec	56.84	M65	not harvested		
Foil	Roundwood	Jenz	62.27	M65	54.05	M55	-8.22
Foil	Energy wood	Jenz	59.71	M65	55.64	M65	-4.07

moisture was also relatively poor in comparison to the whole tree assortment. This is significant as this assortment is standard thinning practice. Covering the stacks with plastic did have some effect, however, as covered roundwood at Foil and Swan achieved M55, whereas the uncovered roundwood in Frenchpark actually gained moisture.

Chemical thinning achieved M55 in treated trees at Kilbrin and Swan (where the Silvatec was able to harvest). The Frenchpark chemical thinning plot was not entirely dead and will be chipped at a later date.

In most cases assortments benefited from seasoning by shifting to a lower moisture content class, with the exception of four assortments: two energy wood assortments, a whole stem and whole tree assortment.

Moisture content results in broadleaves

The broadleaf first thinning site at Portlaw, Co Waterford, with stands of ash and sycamore, provided the basis for the moisture content assessment. Two initial species assortments in March became five by August, as terrain chipping by Silvatec and tractor-mounted chipper was carried out in both species, and, in addition, ash was chipped at the forest landing by the Jenz. The trend in moisture content over the study period is presented in Table 8.3.

The most interesting result was that ash felled in March had a moisture content of 35.9%, without any seasoning. In fact, seasoning ash in the stand was largely ineffective, with the resulting moisture content of terrain chipped ash in August being

Table 8.3: Development of moisture content in harvested broadleaf energy assortments between March and August 2006.

Species	Chipper	March Samples		August Samples		MC Change
		MC %	MC Class	MC %	MC Class	%
Sycamore	Silvatec	46.2	M55	35.3	M40	-10.8
Sycamore	TP280	46.2	M55	35.4	M40	-10.8
Ash	Jenz	35.9	M40	29.4	M30	-6.5
Ash	Silvatec	35.9	M40	35.7	M40	-0.2
Ash	TP280	35.9	M40	38.2	M40	2.3

between 35.7% and 38.2%. These results may be attributed to the light open canopy found in ash, which encouraged lush ground vegetation to develop. This, in turn, created a humid microclimate that may have prevented seasoning. The ash forwarded to the forest landing did fall in moisture, but only by 6.5%. Sycamore assortments were higher in moisture content in March but lost moisture while seasoning in the stand prior to terrain chipping. This may be because the dense canopy in sycamore prevented ground vegetation from developing. Assortments other than the terrain chipped ash benefited from seasoning by moving to lower moisture content categories in August, in comparison to March.

Moisture content trends in species harvested at cutway peatland (Bord na Móna) sites

The four trial sites at Bord na Móna were sampled for moisture content in March, and subsequently in August when the lodgepole pine site was split into two sections. This was because the stand was only partially felled in March, while the remainder was felled in June. In all cases the samples taken in March and again in August were whole tree assortments. The initial mean moisture content and moisture content on chipping are presented in Table 8.4. The difference in moisture content is calculated and the wood chip assortments are allocated to moisture content classes according to the technical specification, before and after seasoning.

The moisture content reduction in the Bord na Móna trial assortments was much higher than those achieved in the conifer and broadleaf thinning sites. The moisture content of lodgepole pine felled in March halved over the five-month seasoning period, while trees felled in June reduced to 18.6%. The results for the birch and mixed spruce and birch stands were also better than at the thinning sites. The Bord na Móna trials were clearfells, as opposed to thinnings, with open, exposed areas that may have facilitated drying. Birch achieved M40, but the stands were smaller and more sheltered than the lodgepole pine. Also, the development of ground vegetation was a factor limiting moisture loss. In summary, the moisture content class of all assortments at the Bord na Móna trials improved as a result of seasoning.

Moisture content trends - discussion and conclusions

The trend in moisture content over the period March to August 2006 was not consistent in all assortments. In general the broadleaf and Bord na Móna assortments displayed a good response to seasoning, with the exception of ash seasoned in the row as a whole tree. However, the moisture content of ash in March was already comparable to the best results achieved by other species assortments after five months of seasoning.

The conifer assortments reacted differently to seasoning. The mean moisture content for freshly felled Sitka spruce in March was 60%, and this fell on average by 9%, to 51%, over the seasoning period. The actual change in moisture content depended on the assortment. Figure 8.1 illustrates the variation in post-seasoning moisture content between assortments.

The relatively good performance of the whole tree assortment in achieving a greater moisture content reduction should be further investigated. The harvesting system employed for this assortment is very different to the standard practice. If this method is confirmed to produce good quality chip, at an economic price, training will be required to implement it effectively.

Target moisture content for small wood chip end-users should be around 30%, in order to store a supply of chip for reasonably long periods. Storage is a less critical issue for larger end-users, as the throughput would be faster and as a rule-of-thumb the larger the boiler the less sensitive it is to moisture content, and in some cases 45-55% moisture content

Table 8.4: Moisture content trends March and August 2006, in species harvested at cutway peatland (Bord na Móna) sites.

Species	March Samples		August Samples		MC Change
	MC %	MC Class	MC %	MC Class	%
Lodgepole pine 1	54.6	M55	27.4	M30	-27.2
Lodgepole pine 2	54.6	M55	36.0	M40	-18.6
Birch	50.8	M55	32.6	M40	-18.3
Sitka spruce/birch	52.3	M55	34.9	M40	-17.4
Naturally regenerated birch	48.3	M55	36.7	M40	-11.6

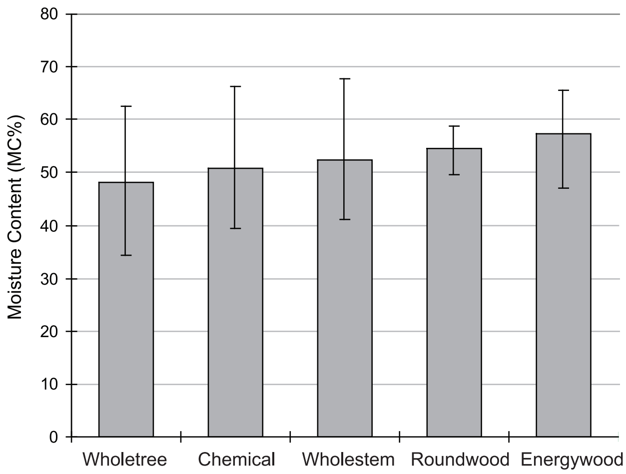

Figure 8.1: Variation in moisture content in August between conifer assortments.

will be fully acceptable. However, as a general rule, all energy assortments should be seasoned to maximise the energy output and overall economic benefit.

The seasoning period of five months was not sufficient to reduce the moisture content of all assortments to less than 40%. Seasoning wood over longer periods and in different configurations needs therefore to be investigated.

Also, it is not practical to harvest wood-for-energy only in spring, and allow it to season over the summer for winter use. Machines need to kept working to repay capital investment and energy generation is of course year-round. Futhermore, moisture content changes over the year in the growing tree. This needs to be investigated to identify harvesting windows for different species and allow adequate seasoning time for wood to reach the target moisture content.

Seasoning wood in the forest involves using ambient energy to evaporate the moisture from wood. The key climatic factors are temperature, relative humidity, rainfall and wind. The influence of these factors on wood drying should be investigated, with the aim of developing simple climatic indicators for predicting the seasoning period necessary for wood.

CHIP QUALITY: PARTICLE SIZE DISTRIBUTION

The aim of this study was to gather data on particle size distribution of wood chip produced and to describe wood chip assortments to CEN/TS 14961 *Solid biofuels – Fuel specifications and classes.* The two main size issues are the nominal size of chip being produced and the range of particle sizes, or size distribution, produced. Nominal particle size refers to the size range to which the majority of chips should conform. Size distribution refers to the spread of particle sizes and proportions in each particle size class. The nominal size classes, and allowable size distribution range described by CEN/TS 14961 are described in Table 8.5.

Four wood chip size classes are specified: P16, P45, P63 and P100. All size classes require that a minimum of 80% by weight of all particles can pass through a sieve with apertures of the indicated size. In addition, the proportion of fine particles less than 1 mm in size can never exceed 5% for any size class. Finally, a maximum of 1% oversize particles is allowable, with the allowable maximum particle size length ranges from 85 mm for P16, to 200 mm length for P100.

Both nominal particle size and particle size distribution are a function of the type of chipper used, the cutting angle of the knives and the wear on the knives. The tree species, wood assortment and presence of contaminants will also influence size distribution. Higher density woods cause knives to wear more quickly. Whole trees and energy wood assortments with branches will result in more overlong particles as some branches will pass through the chipper insufficiently reduced. Contaminants, such as stones or soil, will also quickly destroy knives.

Homogenous particle size facilitates the flow of chips into the combustion chamber and even, predictable combustion of wood fuel in the chamber. Oversize particles impede and interrupt chip flow by catching in the feed augers and causing bridging. Fine particles combust too rapidly in the combustion

Table 8.5: Specification of particle size distribution for wood chip.

Size Class	Main Fraction (>80% of weight)	Fine Fraction (<5% of weight)	Coarse Fraction Maximum Particle Length
P16	3.15 mm < P < 16 mm	< 1 mm	Max. 1% > 45 mm, All <85 mm
P45	3.15 mm < P < 45 mm	< 1 mm	Max 1% > 63 mm
P63	3.15 mm < P < 63 mm	< 1 mm	Max 1% > 100 mm
P100	3.15 mm < P < 100 mm	< 1 mm	Max 1% > 200 mm

chamber, leading to variable heat generation, and become air-borne as fly ash in the flue. In addition, a high proportion of fine particles increases respiratory risk and explosion risk in storage.

The importance of wood chip class classification is that it allows a wood chip boiler manufacturer to specify the correct wood fuel for the boiler system. This means that the wood fuel buyer can include the specification as a condition of contract with wood chip suppliers. Correct size specification is crucial for all wood chip end-users as boilers will operate most efficiently with the correct size material. Correct specification is particularly important for end-users with smaller boilers designed to operate on a narrow specification of small, regular wood chip. Ultimately, the wood chip price should reflect the quality of wood chip size, both in terms of nominal size and homogeneity.

Method of testing for chip size classification

Each assortment was sampled for particle size classification testing during the chipping phase. Two CEN Technical Specifications are available, describing procedures for determining particle size classification:

I. IS EN 15149-1 *Solid biofuels – Methods for the determination of particle size distribution – Part 1: Oscillating screen method using sieve apertures of 3.15 mm and above*.

II. IS CEN/TS 15149-3 *Solid biofuels – Methods for the determination of particle size distribution – Part 3: Rotary screen method.*

A sample (minimum of 50 litres) was gathered, bagged and labelled for each wood chip assortment. These samples were transported to the Danish Forest and Landscape Institute wood fuel testing centre at Velje, Denmark. Sample preparation involved pre-drying each sample to below 20% moisture content (Figure 8.2). Sub-samples were produced using a sample divider. One sub-sample was labelled and stored as a reference sample. The other sub-samples were analysed using one of the two available methods. In most cases sub-samples of the same assortment were tested using both methods.

Rotary screen method

The rotary screen consists of a series of cylindrical sieve rings, each with an inner diameter of 500 mm and length of 400 mm, fitted sequentially to form a large perforated drum. Trays are located under the sieves to collect the separated fraction. The sizes of the sieve apertures are 3.15, 8, 16, 45 and 63 mm; anything greater than 63 mm passes into a final tray. Each empty tray is initially weighed. Each sub-sample is pushed at a constant rate into the rotating drum to ensure that all particles pass through the drum. When the sub-sample has passed through completely the full trays are removed, weighed, recorded and emptied. Figure 8.3 shows a sample sub-divided into particle size categories in the trays. The weight of each particle size class fraction is calculated.

Figure 8.2: Air-drying particle size sample prior to analysis.

Oscillating screen method

The oscillating screen consists of a number of sieves, each with a minimum surface area of 1200 cm^2, stacked vertically on top of a mechanical device that oscillates horizontally in either one or two dimensions for 15 minutes per sub-sample. Typically sieves with apertures of 3.15, 16, 45 and 63 mm are used. The clean, empty trays are weighed. Individual sub-samples are spread evenly in the top tray. After the allocated time, each tray is removed from the machine ensuring no particles are lost and each full tray is then reweighed. The weight of each particle size class fraction is calculated.

In both methods, overlong particles (particles greater than 100 mm or greater than 200 mm in length) are removed and weighed separately. Where fine particle content less than 3.15 mm exceeds 5%

Figure 8.3: Separation of wood chip particles into size categories in the rotary sieve.

averaged to give the particle size distribution of the assortment sample. Particle size distribution is compared to the specification table to establish the particle size class category. An example is presented in Table 8.6. Interpreting the size category for the sample presented requires consulting the particle size class specifications shown in Table 8.5. The fine fraction (<1 mm) is less than 5% of total weight; the oversize (>100 mm) is less than 1% and the size category containing at least 80% of the main fraction is at 45 mm, which contains 94.7%. Therefore the sample can be classed as a P45 chip.

Results of conifer chip size classification

Results assessed for each size and assortment using the rotary sieve method are presented in Table 8.7. Size classes are expressed as the percent of the total weight represented by each class.

Clear trends emerge from Table 8.7. None of the assortments was expected to be in the P16 size class

of total weight, then this fraction should be re-sieved in accordance with IS CEN/TS 15149-2 *Solid biofuels – Methods for the determination of particle size distribution – Part 2: Vibrating screen method using sieve apertures of 3.15 mm and below.* Additional separation of the fine particles below 1 mm was not carried out on any assortment samples, as it was deemed unlikely that any sub-samples would contain over 5% content of particles under 1 mm. Figure 8.4 shows the division of an assortment sub-sample into the different particle size categories; in this case the whole tree wood chip produced by the Silvatec chipper at Frenchpark.

The weight of each particle size class fraction is expressed as a percentage of the total sub-sample weight. The results of the three sub-samples are

Figure 8.4: Wood chip assortment sub-sample divided into particle size categories.

Table 8.6: Example of sub-sample particle size class fraction presentation.

	Particle Size Class	Size Class Weight (g)	Size Class (% total weight)	Cumulative Main Fraction (% of total weight)
Fine Fraction	<1 mm	3.3	0.10 %	
	1 mm < 3.15 mm	123.5	3.8 %	
Main Fraction	3.15 mm < 16 mm	1183.0	36.4 %	36.4%
	16 mm < 45 mm	1894.8	58.3 %	94.7%
	45 mm < 63 mm	22.8	0.7 %	95.4%
	63 mm < 100 mm	3.3	0.1 %	95.5%
Oversize	100 mm < 200 mm	16.3	0.5 %	
	> 200 mm	3.3	0.1 %	
		3250.0	100.0 %	

as the chippers used were not capable of producing chip to meet this class. However, neither did any of the assortments reach the medium P45 size class. This is surprising considering that in nearly all cases over 80% of chips were less than 45 mm in size, and the chippers were set to produce a chip of this nominal size.

In a number of cases, the chip assortment was deemed not to fall into any specified size class, despite the use of well maintained, professional chipping equipment.

In the tree sections and roundwood assortments from the Cork sites, chipped using the Jenz truck chipper, there was a large proportion of fine

Table 8.7: Conifer chip assortment particle size classes.

Chipper	Assortments	Site	Fines <3.15 mm	Small <8 mm	Medium <16 mm	Large <45 mm	Extra Large <63 mm	Over Large 63 >100 mm	Over Size >100 mm	Over Size >200 mm	Size Class
						% total weight					
Silvatec	Whole tree	Kilbrin, Cork	2.0	3.1	10.4	71.2	11.4	0.0	1.8	0.1	P100
Silvatec	Whole tree (Chemical)	Kilbrin, Cork	2.1	4.8	12.4	71.8	6.6	0.9	1.2	0.4	P100
Silvatec	Whole stem	Kilbrin, Cork	1.3	3.8	10.3	66.8	10.2	4.1	1.8	1.6	none
Silvatec	Whole stem	Swan	1.1	2.9	7.2	63.9	18.8	5.3	0.5	0.3	P100
Silvatec	Whole tree	Swan	2.1	2.3	7.3	55.4	18.0	9.4	3.4	2.1	none
Silvatec	Whole tree (Chemical)	Swan	5.1	8.1	13.6	63.8	5.7	1.9	1.6	0.2	P100
Silvatec	Whole tree	Frenchpark	3.6	6.4	11.3	60.7	11.2	3.9	2.3	0.6	P100
Silvatec	Whole stem	Frenchpark	2.7	4.1	8.1	61.0	15.3	5.0	3.7	0.0	P100
TP280	Whole tree	Kilbrin, Cork	2.5	5.9	24.8	63.9	1.6	0.6	0.7	0.0	P63
TP280	Whole tree	Swan	3.0	5.0	23.2	54.5	7.8	2.1	4.0	0.6	P100
TP280	Whole tree	Frenchpark	4.4	9.2	29.0	51.5	2.6	1.3	1.4	0.6	P100
Jenz	Tree Sections	Kilbrin, Cork	11.6	12.1	25.7	46.7	1.9	0.0	1.8	0.1	none
Jenz	Roundwood	Foil, Cork	8.6	20.7	58.6	9.7	1.4	0.4	0.5	0.1	none
Jenz	Energy Wood	Foil, Cork	3.2	8.1	30.0	56.4	1.4	0.1	0.6	0.2	P63
Jenz	Tree Sections	Swan	2.9	6.4	20.1	62.0	5.7	1.2	1.7	0.0	P100
Jenz	Roundwood	Swan	1.3	4.6	21.2	65.3	4.4	2.8	0.4	0.0	P63
Jenz	Roundwood	Swan	5.1	8.1	13.6	63.8	5.7	1.9	1.6	0.2	P100
Jenz	Energy Wood	Swan	4.3	8.9	25.9	57.2	2.6	0.0	1.1	0.0	P100
Jenz	Roundwood	Frenchpark	5.8	7.9	27.6	55.4	1.9	0.0	1.5	0.0	P100

particles. As it could not be determined if more than 5% was less than 1 mm, these assortments did not meet any specified size class. In all other assortments, the presence of oversize particles was the key factor preventing achievement of a smaller particle size class.

The whole stem assortment from Cork and whole tree assortment from Swan, both chipped by the Silvatec, achieved no specified size class. This was because, in both cases, the proportion of particles greater than 200 mm exceeded the allowable maximum of 1%. Twelve assortments were allocated to the P100 size class because the total oversize fraction exceeded 1%, while the fraction greater than 200 mm was less than 1%.

The remaining wood chip assortments could be specified as P63 because the oversize proportion did not exceed 1%.

An accumulation of over 1% oversize particles (> 100 mm length) prevents any assortment from achieving P16 or P45 according to CEN/TS 14961. In general, the proportion of oversize particles did not exceed 2% of total weight. The maximum proportion of oversize particles (> 100 mm) was 5.5% for the whole tree assortment, chipped by the Silvatec at Swan. In general, higher proportions of oversize material were found in assortments containing branch material.

Results of broadleaf chip size classification

Wood chip production in broadleaf first thinnings was carried out at Portlaw, Co Waterford, only. Both ash and sycamore was harvested on the site and presented for chipping as whole tree assortments. The two terrain chippers processed both ash and sycamore, while the Jenz truck-mounted chipper processed ash only. The particle size classification for samples analysed using the rotary sieve are presented below in Table 8.8.

As with the conifer results, the size class interpreted for the broadleaf chips were not as expected. All wood chip assortments contained over 80% particles of less than or equal to 45 mm in size. Similarly fine particles were under the 5% maximum limit in all cases. The presence of oversize particles was the factor that prevented classification of the broadleaf into lower size classes. In most cases, the absolute quantities of oversize particles varied very little from the maximum allowable, but strict interpretation of the specification limits resulted in allocating chip to larger size classes than expected.

The ash chipped by the Jenz chipper could not be classified as P45 even though only 4.2% of particles were over 45 mm. This was because 1% is the limit on particles over 63 mm size for the P45 size class, and the sample contained 1.3%. The sycamore assortment processed by the TP280 tractor-mounted chipper had 2.1% of particles over 45 mm, but was categorised as P100 because 1.5% of particles were greater than 63 mm, again above the maximum allowable of 1%. Likewise, TP280-processed ash had 1.5% of particles above 63 mm.

The Silvatec was expected to produce a mean chip size larger than the other two chippers. Though the sieving clearly demonstrated this, the allocation to the specified size classes did not follow the expected pattern. The Silvatec produced 18.3% and 20.3% particles over 45 mm in sycamore and ash respectively. Even so, only 5.3% and 2.4% of particles were over 63 mm in each case, yet the chips did not achieve P63. The presence of 1.4% and 1.1% particles over 100 mm, 0.4% and 0.1% over the limit of 1%, shifted these chip assortments into the P100 category.

Results of size classification of wood chip from stands on cutaway peatland (Bord na Móna) sites

Five assortments were harvested and chipped at the four Bord na Móna sites at Boora, Co Offaly. The lodgepole pine stand was divided in two, based on the date of felling, and each section was chipped

Table 8.8: Broadleaf chip assortment particle size classes.

Chipper	Species	Fines 3 mm	Small 8 mm	Medium 16 mm	Large 45 mm	Extra Large 63 mm	Over Large 63>	Over Long 100 mm >	Over Long 200 mm >	Size Class
						% total weight				
Jenz	Ash	1.8	7.5	23.7	62.8	2.9	0.5	0.8	0.0	P63
TP280	Sycamore	3.2	7.2	24.7	62.8	0.6	0.1	1.4	0.0	P100
Silvatec	Sycamore	0.9	2.0	7.5	71.4	13.0	2.8	1.9	0.6	P100
TP280	Ash	1.2	4.9	23.3	67.5	1.6	0.0	1.2	0.3	P100
Silvatec	Ash	0.8	2.8	8.5	67.6	17.9	1.3	1.0	0.1	P100

separately by the Jenz truck chipper and Silvatec systems. The Silvatec also processed the poor quality Sitka spruce stand that had been invaded by birch. The tractor-mounted TP280 chipper operated in both the naturally regenerated birch stand and planted birch stand. The samples from all wood chip assortments were analysed with the rotary sieve method (Table 8.9).

All assortments produced wood chip where over 80% of particles were between 8 mm to 45 mm in size. Both lodgepole pine assortments failed to make any size class. This was due to 7.5% fines in the case of the Jenz-chipped material. The material consisted of small trees with a very high proportion of branches and in particular the many brown needles still attached contributed to the high fine content. The lodgepole pine chipped by the Silvatec produced 1.2% particles over 200 mm, which was 0.2% above the limit for P100 size class chip.

The naturally regenerated birch plot, chipped by the TP280 tractor–mounted chipper produced the only P45 chip of all assortments on all sites. The vital factor was that the percentage particles over 63 mm accumulated to less than 1% of total by weight. The planted birch and Sitka spruce/birch assortments achieved P100, because the oversize particle content was over the limit of 1%.

Discussion and conclusions on wood chip size classification

The study used European Technical Specifications in analysing particle size distribution and allocating wood chip samples to size classes. In all cases, apart from the lodgepole pine which still had needles attached, the assortments were considered suitable for wood chip production; the chippers used were well maintained and they were operated by skilful, experienced personnel. Sample collection and preparation were carried out to the European Technical Specifications.

The expectation was to produce good quality wood chip, suitable for use by larger scale, commercial energy end-users, with the chippers selected and adjusted to produce a P45 size class wood chip. The results did not conform to expectations, in that only one assortment of twenty-nine tested produced P45 wood chip. Six assortments did not meet any size class specified by CEN/TS 14961, while four assortments made the P63 class. Worryingly, 18 assortments, made up of different species, with and without branch material, and chipped by all three chippers were placed in the P100 class. This did not accurately describe the nominal size and particle size distribution variation observed in the wood chip from the different assortments. Figure 8.5 shows the mean particle size distribution of all chips produced by each chipper. It is clear that the TP280 and Jenz produced wood chip of a similar particle size distribution, whereas the Silvatec wood chip contains a much higher proportion of larger particles. This difference was not identified by the specification nor reflected in the size classes achieved by wood chip assortments.

The study identified two distinct problems with the European Technical Specifications in their current format. The first related to the two procedures for carrying out particle size distribution analysis. The results from sample assortments classified using the rotary sieve were unpromising, so sub-samples of the same assortment were

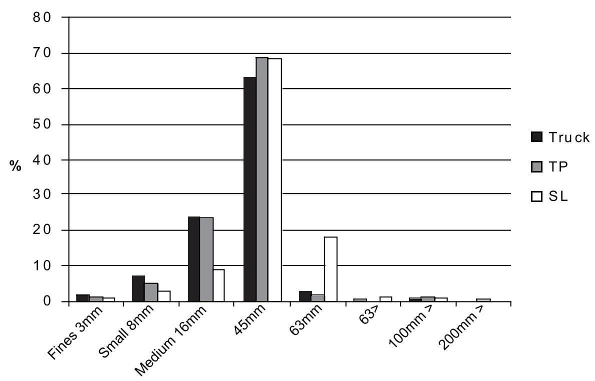

Figure 8.5: Mean particle size distribution by chipper type.

Table 8.9: Wood chip particle size classes of chipped assortments from stands on cutaway peatland (Bord na Móna) sites.

Chipper	Species	Fines 3 mm	Small 8 mm	Medium 16 mm	Large 45 mm	Extra large 63 mm	Over large 63>	Over long 100 mm >	Over long 200 mm >	Size Class
						% total weight				
Jenz	Lodgepole pine 1	7.5	16.2	25.8	44.1	1.3	1.2	3.1	0.7	none
Silvatec	Lodgepole pine 2	3.7	8.9	12.9	57.7	9.1	3	3.4	1.2	none
Silvatec	Sitka spruce/birch	3.4	5	13.6	68.4	5.1	2	2	0.5	P100
TP280	Naturally regenerated birch	3.8	7.4	29.5	57.9	0.7	0.1	0.5	0.1	P45
TP280	Planted birch	2.6	8.8	28.1	54.8	2.9	0.1	1.8	0.8	P100

sampled using the oscillating sieve, in order to determine if there were inconsistencies in the procedures. The results from the oscillating sieve procedure were compared with those from the rotary sieve (Table 8.10).

The results show almost no consistency between the two methods, with the oscillating sieve results indicating that the wood chip did not meet any specified size class in most cases. The oscillating sieve produced much higher percentages of fines (<3.15 mm) in comparison to the rotary screen. This may be partially explained by the vigorous motion of the sieve in operation causing abrasion of particles. Oversize particle proportions were similar to those measured using the rotary screen.

This leads to the second problem identified with the CEN/TS 14961. The specification limits oversize particles to less than 1% total volume. The main reason wood chip assortments did not meet the expected size class of P45 was the presence of oversize particles in excess of the 1% maximum limit. In effect, a typical sub-sample consisted of 2000-3000 g of air-dried wood chip. This means the maximum weight of oversize particles allowed was 20-30 g. In some cases, this may have consisted of one or two particles only. In other cases, more oversize particles were measured but did not accumulate to the maximum 1% of weight. This reveals a weakness in the standards. If the presence of oversized particles is acceptable, the maximum limit should be reduced to a more robust proportion, compatible with commercial wood chip production, and consistent with good fuel flow. If oversized particles are unacceptable, there should be an absolute exclusion, meaning all traded wood chip should be screened. This is unlikely to be achievable.

The primary purpose of the technical specifications should be to support best practice in wood fuel production and give confidence to wood fuel consumers that wood chip quality can be assured. The problems identified by this study reduces confidence in the specifications being workable. The wood energy supply chain requires an effective balance between the requirements of end-users for good quality wood chip for energy generation, and the ability of wood fuel traders to produce a competitively priced wood fuel using existing, commercially available chippers. The technical specifications should provide the framework and guidelines to achieve this balance. The specifications are in the process of revision, and it is recommended that the results found in this study be taken into account in this work.

Table 8.10: Comparison of size classes allocated using the rotary and oscillating sieve methods.

Site	Species	Assortment	Chipper	Rotary Sieve	Oscillating Sieve
Frenchpark	Sitka spruce	Whole tree	TP280	P 100	None
Frenchpark	Sitka spruce	Whole tree	Silvatec	P 100	None
Frenchpark	Sitka spruce	Whole stem	Silvatec	P 100	None
Frenchpark	Sitka spruce	Roundwood	Jenz	None	P100
Swan	Sitka spruce	Whole tree	TP280	P 100	None
Swan	Sitka spruce	Tree section	Jenz	P 100	None
Swan	Sitka spruce	Whole stem	Silvatec	P 63	P63
Swan	Sitka spruce	Roundwood	Jenz	P 63	None
Kilbrin	Sitka spruce	Whole tree	Silvatec	P 100	P100
Kilbrin	Sitka spruce	Whole tree	TP280	P 63	None
Kilbrin	Sitka spruce	Whole tree	Silvatec	P 100	None
Kilbrin	Sitka spruce	Tree section	Jenz	None	None
Foil	Sitka spruce	Energy wood	Jenz	P 63	None
Foil	Sitka spruce	Roundwood	Jenz	None	None
Portlaw	Ash	Tree section	Jenz	P 63	P100
Portlaw	Ash	Whole tree	Silvatec	P 100	P100
Portlaw	Sycamore	Whole tree	TP280	P 100	None
Portlaw	Sycamore	Whole tree	Silvatec	P 100	P100
Bord na Móna	Lodgepole pine	Whole tree	Silvatec	None	None
Bord na Móna	Lodgepole pine	Whole tree	Jenz	None	None
Bord na Móna	Birch	Whole tree	TP280	P 45	None

CHIP QUALITY: BULK DENSITY

Wood chip piles consist of the solid volume of the particles and the empty space around each particle, referred to as bulk volume or loose volume. Bulk density refers to the weight of a particular quantity of wood chip divided by its loose volume, and is expressed in units of kg/m^3. Wood chip bulk density is very useful for estimating transportation and storage needs, where wood chip is traded by volume, and in calculating energy density from the calorific value.

Bulk density is highly variable, influenced by basic density, nominal chip size and particle size homogeneity. Bulk density (as received) is the measured bulk density at a particular moisture content, so the weight includes the weight of moisture. Bulk density (dry weight) is calculated from the bulk density (as received) and the moisture content (as received), and excludes the weight of moisture.

CEN/TS 14961 *Solid biofuels – Fuel specifications and classes* recommends that bulk density (as received) is specified for traded wood chip on a volume basis, according to categories BD200, BD300 or BD450 (200, 300, or 400 kg/m^3). In addition, bulk density is required if the energy density of the traded wood chip is specified. Energy density is the ratio of net energy content, expressed in kilowatt hours (kWh), and bulk volume. In turn, energy content is calculated from the net calorific value and the bulk density.

Method of estimating bulk density

The procedure available for estimating bulk density of wood chip and other solid biofuels is described in CEN/TS 15103 *Methods for the determination of bulk density*. The procedure uses a 50 litre container for determining the bulk density of individual sub-samples. The container is weighed empty, filled with wood chip and reweighed. The weight of the 50 litre wood chip sample is converted to a bulk density (as received), expressed in kilograms per cubic metre (kg/m^3). A minimum of three sub-samples per sample lot are taken and results are averaged. The moisture content of the sample is also derived and bulk density (dry weight) is calculated as follows:

*Bulk Density (dry weight) = Bulk Density (as received) * [1 –(Moisture Content % / 100)]*

Bulk density sampling was carried out at all trial sites, on all assortments and on all chipper types. Some 224 sub-samples were processed. In each case, moisture content samples were collected as part of the study and were used to calculate bulk density (dry weight). Due to time and operational constraints at the sites, it was not possible to sample each wood chip assortment consistently in terms of sample size and sample intensity.

Sitka spruce wood chip bulk density

Bulk density results for the Sitka spruce thinning assortments showing bulk density (as received), which includes the weight of moisture in the wood, and bulk density (dry basis), which excludes the moisture weight are shown in Table 8.11. Results include the site, assortment and chipper and are ranked from the highest to lowest dry weight bulk density.

Bulk density (dry weight) of Sitka spruce wood chip assortments ranged from 124 kg/m^3 to 167 kg/m^3, with a mean of 141 kg/m^3. While there is a general relationship between bulk density (as received) and bulk density (dry weight) the effect of moisture content is important. In several cases, high moisture content inflated the bulk density (as received).

It was difficult to identify significant differences between wood chip produced by different chippers, although the Jenz truck-mounted chipper appears to generally produce higher bulk density chip. Equally, it was not possible to draw clear conclusions on the assortments. The energy wood assortment result, which had the highest bulk density, may not be representative as the sample size was small and was measured at one site only. Bulk density also varied with site: the Swan assortments tended to have highest bulk density, followed by the Cork assortments, with the Frenchpark assortments having the lowest bulk density on average.

Broadleaf wood chip bulk density

The bulk density results of the wood chip assortments of the broadleaf thinning trial at Portlaw, Co Waterford, are given in Table 8.12. Bulk density was measured for both ash and sycamore assortments. The Silvatec chipper and tractor-mounted TP280 chipper were used in both species, while the Jenz truck-mounted chipper operated on ash only. The bulk density (as received) was derived from the average of individual measured sub-samples. Moisture content was sampled specifically for the bulk density samples, as specified by

Table 8.11: Bulk density of Sitka spruce wood chip assortments.

Site	Assortment	Chipper	Bulk density (as received) kg/m³	MC %	Bulk density (dry weight) kg/m³
Swan	Energy wood	Jenz	389	57.2	167
Kilbrin, Cork	Tree sections	Jenz	344	53.0	162
Swan	Tree sections	Jenz	409	61.1	159
Frenchpark	Whole stem	Silvatec	328	51.6	159
Swan	Whole tree	Silvatec	304	51.7	147
Swan	Roundwood	Jenz	306	52.8	144
Swan	Whole tree (Chemical)	Silvatec	297	52.1	142
Swan	Whole tree	TP280	309	54.1	142
Foil, Cork	Whole tree	Jenz	310	54.4	142
Kilbrin, Cork	Whole stem	Silvatec	338	58.1	141
Kilbrin, Cork	Whole tree	TP280	286	51.1	140
Kilbrin, Cork	Whole tree	Silvatec	251	44.6	139
Swan	Whole stem	TP280	334	59.0	137
Frenchpark	Whole stem	TP280	275	50.4	136
Frenchpark	Whole tree	TP280	299	55.2	134
Kilbrin, Cork	Whole tree (Chemical)	Silvatec	239	44.6	132
Frenchpark	Whole tree	Silvatec	290	57.3	124

Table 8.12: Bulk density of broadleaf wood chip assortments.

Site	Species	Assortment	Chipper	Bulk density (as received) kg/m³	MC %	Bulk density (dry weight) kg/m³
Portlaw	Ash	Whole tree	Jenz 700	279	28.3	200
Portlaw	Ash	Whole tree	Silvatec	281	35.0	183
Portlaw	Ash	Whole tree	TP280	303	41.2	178
Portlaw	Sycamore	Whole tree	TP280	284	37.3	178
Portlaw	Sycamore	Whole tree	Silvatec	271	36.6	172

CEN/TS 15103, and bulk density (dry weight) was calculated from bulk density (as received) and moisture content.

The bulk densities (dry weight) of both ash and sycamore were broadly similar, with ash being slightly higher on average. The assortment in all cases was whole tree. In line with the conifer results about, it appears that the truck chipper produced wood chip of higher bulk density.

Broadleaf and conifer wood chip bulk density on cutaway peatland (Bord na Móna) sites

Bulk density was determined for wood chip from the naturally regenerated birch, the Sitka spruce/birch mixed stand and the lodgepole pine stand at Bord na Móna, Boora, Co Offaly. The bulk density of the mixed Sitka spruce/birch stand consisted of wood chip from both species. The lodgepole pine stand was harvested in two separate periods: March 2006 (Lodgepole pine 1) and June 2006 (Lodgepole pine 2) and samples were taken separately from each section. The results are presented in Table 8.13.

The birch stand yielded wood chip of the highest bulk density at 186 kg/m³. The Sitka spruce/birch stand was primarily birch, which explains the high bulk density of this assortment. Interestingly, the June harvested lodgepole pine had a lower bulk density, almost certainly due to retention of needles, whereas the March-felled pine had shed all its needles.

Discussion and conclusions on bulk density variation

Bulk density was primarily related to the basic density of the species. Figure 8.6 illustrates the different bulk densities of sampled species, with Sitka spruce having the lowest bulk density sampled, lodgepole pine higher and the three broadleaves highest.

Table 8.13: Broadleaf and conifer wood chip bulk density on cutaway peatland (Bord na Móna) sites.

Species	Assortment	Chipper	Bulk density (as received) kg/m³	MC %	Bulk density (dry weight) kg/m³
Birch	Whole tree	TP280	297	37.4	186
Sitka spruce/birch	Whole tree	Silvatec	281	35.0	182
Lodgepole pine 1*	Whole tree	Silvatec	232	30.4	161
Lodgepole pine 2*	Whole tree	Silvatec	223	36.2	143

** Lodgepole pine 1 was harvested in March 2006, Lodgepole pine 2 was harvested in June 2006. Both were chipped in August 2006.*

Basic density varies both with and within species. For example, trees of the same species growing on different sites may have different basic densities due to growth rate or growing conditions. Within individual trees, wood density also changes with age, in conifers juvenile wood is typically more dense than adult wood. Even over an annual growth ring basic density varies between early- and late-wood.

Wood chip from different assortments will also differ in bulk density due to varying proportions of wood, bark and fines. The type of chipper used may also have an effect on bulk density, depending on the nominal chip size and homogeneity of the particle size produced. Figure 8.7 indicates the variation in bulk density of wood chip produced by different chippers on the same assortment. Bulk density was highest in wood chip produced by the Jenz truck-mounted chipper. This may be because the Jenz is a drum chipper and produces less homogeneous chips in comparison with the other two machines, with fine particles able to fill spaces around the larger particles. While the tractor-mounted TP280 chipper and Silvatec are both disc chippers, the TP280 had the knives set to produce a finer chip. This may account for the bulk density variation between the two chippers.

Bulk density (as received) of wood chip is highly influenced by moisture content. Moisture adds substantial weight to a given volume of wood chip. High bulk density (as received) can impact on load carrying capacity in transport. A vehicle may carry a full load of seasoned wood chip with a low bulk density, but may be forced to travel with a reduced load if a high bulk density load puts the vehicle over the legal weight.

The example presented in Figure 8.8 illustrates the importance of moisture content. The bulk density (dry weight) of sampled whole tree Sitka spruce wood chip was found to be 141 kg/m³. At 30% moisture content the bulk density (as received) increases to 200 kg/m³ and at 60% moisture content the bulk density (as received) is 350 kg/m³, with the increases due to the weight of water. A curtain-sider lorry with 100 m³ carrying capacity can take a full load of 20,000 kg of wood chip at 30% moisture content. At 60% moisture content, the lorry will be over weight at 36,000 kg. Higher bulk density loads, due to high moisture content wood chip, will reduce carrying capacity, increase transport fuel consumption, and impact negatively on supply chain efficiency.

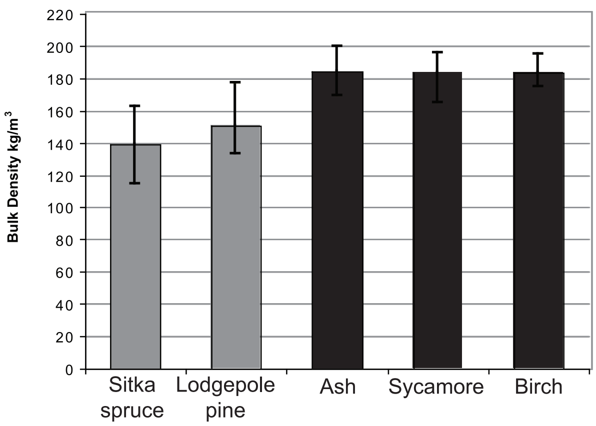

Figure 8.6: Mean dry bulk density by species. Vertical bars are the range.

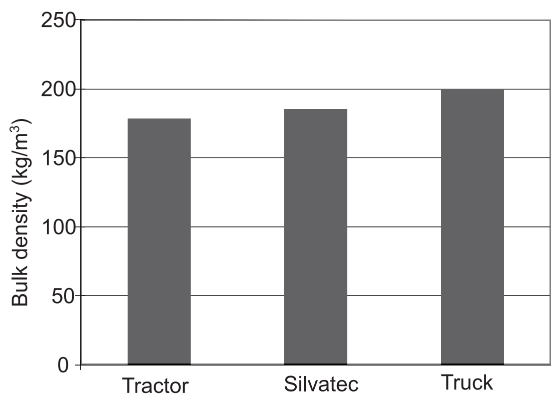

Figure 8.7: Bulk density (dry matter) variation by chipper for whole tree ash at Portlaw.

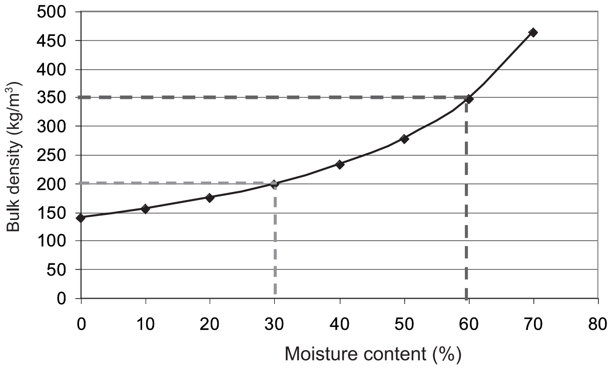

Figure 8.8: Relationship between bulk density and moisture content in whole tree Sitka spruce wood chip.

It was not possible to check the sampled bulk densities recorded against the actual bulk densities, which could be measured off the lorries. Bulk density could be obtained from lorries by measuring the dimensions of the trailer or container unit, and calculating the volume and then recording the load weight on a weighbridge. This would have confirmed the accuracy of the sampled bulk densities. On the other hand, the wood chip load volume will change over a journey as the particles settle. Studying the amount by which a load settles over a particular journey could also be useful.

Bulk density could potentially be used as a method for quantifying wood chip for payment purposes. Payment of wood fuel should always relate to the energy content delivered, and this in turn is largely dependent on the moisture content. It may not be possible to measure calorific value or moisture content directly in every case, particularly at a small scale. Bulk density (as received) is quickly and easily sampled and measured. Assuming a constant bulk density (dry weight) for that species, then the moisture content and therefore energy content of the wood fuel can be estimated from the difference between bulk density (as received) and the assumed bulk density (dry weight) constant for that species.

CHIP QUALITY DISCUSSION AND CONCLUSIONS

The chip quality studies carried out in ForestEnergy 2006 characterised the produced wood chip and provided the datasets that facilitated the estimation of wood energy production costs for each assortment. The European Technical Specifications provided a framework for classifying wood chip from different assortments and also the procedures for measurement of the key quality parameters. Moisture content and bulk density were easily determined in practice, but both the specification for particle size classes and the methods for determining particle size distribution were difficult to operate and did not provide reliable results. These technical specifications are being subject to revision and improvements may result from this process.

Ultimately quality is measured by the ability to perform a function. The objective with the chippers employed was to demonstrate the production of a medium to large chip suitable for a large energy generator. All chips produced in the ForestEnergy 2006 programme were successfully combusted at Edenderry Power.

9. CONCLUSIONS AND RECOMMENDATIONS

The primary goals of ForestEnergy 2006 were:

- to demonstrate harvesting machinery and methods for wood for energy under Irish conditions;
- to document the productivity and costs of the methods;
- to research the drying of felled trees and assortments under Irish circumstances;
- to document the quality of the fuel chips in terms of size distribution and bulk density.

All the goals of ForestEnergy 2006 were fulfilled:

- The harvesting methods and machines were shown to the general public during two series of demonstration days in spring and autumn, which were visited by 800 and 1150 people respectively.
- This report documents the results of all the studies on the machines and methods and allows an estimate of harvesting costs under Irish conditions.
- During spring and autumn samples were taken to measure the drying of the assortments during one summer.
- The quality of the produced wood fuel was evaluated by performing a size distribution analysis on more than 20 samples and the bulk density was measured during the chipping operations.

The main conclusions of the technology transfer programme for conifer plantations are:

- It is feasible to harvest wood for energy as chips from first thinnings under Irish circumstances as long as the terrain is not too soft.
- The least expensive method in conifers was the whole tree method where the trees were felled by chainsaw in a row thinning and chipped by the Silvatec terrain chipper.
- Similar costs were obtained by the tractor-mounted TP280 chipper.
- The productivity of the Silvatec chipper was 2.5 to 3 times as high as that of the tractor-mounted TP280 chipper, but the hourly costs were three times as high.
- The methods where assortments were produced were much more expensive than the whole tree methods, even though the productivity of the Jenz truck chipper was excellent.
- The whole stem method was almost as expensive as the assortment methods.
- A system where the trees are thinned chemically and then felled and chipped by the Silvatec chipper was more expensive than the whole tree methods, but still much cheaper than the assortment methods.
- Seasoning was variable, depending on site and assortment. The whole tree assortment seasoned best, while uncovered roundwood and energy wood assortments did not season at all.
- Particle size classification highlighted a major conflict between the European Technical Specifications on quality classes and what the industry classes as acceptable wood chip. In general, the fines content was well below limits but the oversize content was above the maximum allowance of 1%, in many cases by less than 1%.
- Bulk density (as received) of spruce chip ranged from 290 – 389kg/m^3. This was dependent on moisture content. Excluding moisture, the bulk density (dry weight) averaged 141kg/m^3.
- The average energy density of spruce wood chip was 7.1GJ/m^3. The production cost on an energy basis concurred with the production cost per m^3 solid volume that the whole tree assortment was best at €2.03/GJ.

The main conclusions of the technology transfer programme for broadleaved plantations are:

- The whole tree method with chipping in the stand was the cheapest, but more expensive than in the conifer stands due to the small size of the trees.

- Forwarding whole trees to the roadside after feller-bunching and chipping by truck chipper is expensive due to the low productivity of the feller-buncher and the forwarder.
- Seasoning was species-dependent: sycamore seasoned well, with moisture content reduction of over 10% on average. Ash did not season when stored in the extraction rack. On the other hand, the moisture content of freshly felled ash in March was less than 40%.
- Particle size classification in broadleaves also gave conflicting results: while the chip particle size distribution was very tight (around the 45 mm target), it also did not meet the specification because of proportion of oversized particles.
- Sycamore and ash bulk density (as received) were between 271 and 303 kg/m^3. Excluding moisture, the bulk density (dry weight) was higher than spruce at between 172 and 200 kg/m^3.
- The energy density of broadleaves was higher than that of conifers because of higher bulk density and lower moisture content. This resulted in better than expected production costs per GJ for terrain chipped broadleaves.

The main conclusions for the Bord na Móna clearfell sites are:

- Due to the small size of the trees, the costs are relatively high compared to the conifer stands.
- Costs can be reduced by adapting the harvesting method to only take the bigger trees.
- The feller-buncher needs to be adapted as the felling head with the chainsaw was not suitable for these operations. A felling head with a circular saw would have been better for the small, bunched and crooked trees.
- The assortments at Bord na Móna seasoned better than those in the thinning trials. This was because the trees were clearfelled, creating an open exposed environment for seasoning. Lodgepole pine in particular seasoned well, probably due to the transpiration effect from the abundant needles.
- Particle size classification resulted in one assortment conforming to the P45 specification. Like the other trial sites, the results of other assortments from Bord na Móna did not conform well with the specifications.
- Lodgepole pine bulk density (dry weight) averaged slightly higher than spruce, while birch was comparable with the other broadleaves.
- The energy density of all assortments was high because of the lower moisture content than the thinning assortments. Production cost per GJ for lodgepole pine felled by feller-buncher was comparable with that of the spruce chainsaw-felled whole tree assortment.

In all the stands the additional biomass harvested, compared with standard roundwood assortments, was measured. Results varied from site to site because it was necessary to place some or parts of trees under the wheels of the machines to protect the soil from damage. In some cases this meant that there was less biomass than in the roundwood method. In general, in the whole tree method in the Sitka spruce stands some 50% additional biomass was removed in the form of chips.

It should be noted that the machines used in these trials were not optimally adapted to Irish terrain. The machines should have been equipped either with much wider tyres or equipped with band tracks. This would have reduced the amount of material used in brash mats.

Normally little damage is caused in the rows by the harvesting machines. The main damage to the stands is on the cross racks where most of the transportation and turning takes place. It may be better to thin the cross racks to waste and put all available wood and branches on the ground under the wheels of the machines. The brash mat which is created in that way would last until at least the next harvest.