# Technical Development Woodfuel Research Catalogue 1998-2008

## Summary

This report provides a catalogue of summaries from 28 woodfuel-related reports produced by Technical Development (TD) within the last 10 years. Report summaries are organised into the themes: harvesting, chipping, drying, woodfuel & burner specifications, wood pellets, residues, small scale harvesting, short rotation coppice, supply chain, transport and other subjects.

## Glossary

- **shr** – standard hour – measure of work time which allows for non-productive work and stoppages
- **MC** – moisture content (wet basis)- The wet basis moisture content (MC) of a piece of wood is defined as the weight of water expressed as a percentage of the total weight of the wood.
- **CV** – calorific value- energy value of material, generally measured in joules per unit mass.
- **dbh** – diameter at breast height- diameter measured in centimetres of tree at 1.3 m from the ground
- **odt** – oven dry tonne- material that when fully dried will weigh 1 tonne
- **CCF** – continuous cover forestry- forest management which maintains the forest canopy during the regeneration phase with a presumption against clearfelling
- **IPIN** – Internal Project Information Note, standard Technical Development report format
- **IN** – Internal Note, alternative Technical Development report format
- **TN** – Technical Note, report format approved for general release

# Summary Table of Reports Detailed in this Review

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| Harvesting | Chipping clearfell tops in East Anglia | Murgatroyd, I. R. | 1998 | IPIN | 12/98 | Study of chipping mature, poorly formed, Scots pine tops. Results indicated that inclusion of a greater proportion of stemwood increased chip yield, the productivity of all machines, and revenue. | 1 |
| Harvesting | Woodfuel trial Rivox, Ae Forest District | Saunders, C. J. | 2007 | IPIN | 15/06 | Study of alternative woodfuel and residue product mixes cut from mature Sitka spruce. Different product mixes were found to affect machine productivity and exploit tree portions that were not commercially utilised conventionally. | 2 |
| Harvesting | Rumster Forest Northern Wood Heat woodfuel pilot study | Webster, P. & Price, M. | 2007 | IPIN | 07/07 | Study of cutting a woodfuel product mix with conventional working in mature Sitka spruce and lodgepole pine. In woodfuel cutting machine productivity was found to rise in woodfuel cutting and costs to roadside to decrease. | 2 |
| Harvesting | Woodfuel production from a thinning operation | Webster, P. | 2008 | IPIN | 30/07 | Study of mechanised first thinning of Sitka spruce with comparison of cutting woodfuel and conventional product mixes. Productivity for the woodfuel mix increased slightly for the harvester and decreased slightly for the forwarder. Woodfuel cost to roadside was slightly lower. | 3 |

# Technical Development Woodfuel Research Catalogue 1998-2008

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| Chipping | East Anglia whole tree chipping | Murgatroyd, I. R. | 1998 | IPIN | 11/98 | Study of whole-tree terrain chipping of pine thinnings. Output was found to vary with working approach and tree size, working with rows and semi-systematic work providing highest productivity. | 3 |
| Chipping | Random length smallwood chipping recovery compared to conventional shortwood systems | Murgatroyd, I. R. | 1998 | IPIN | 19/98 | Study of clearfelling in Sitka spruce and lodgepole pine where a larger proportion of stemwood is recovered in the fuelwood treatment than the conventional product mix. Fuelwood working increased volume recovery and harvester productivity but the random cut lengths decreased forwarder productivity. Fuelwood and conventional costs were broadly similar but the fuelwood provided greater revenue and surplus. | 4 |
| Chipping | Chipper review | Webster, P. | 2005 | IPIN | 06/05 | Ten small chippers were reviewed for use with birch and pine shortwood. Fuel consumption, outputs, chip quality and noise levels were recorded. Infeed material dimensions and handling had the greatest effects on productivity. | 5 |
| Chipping | Large chippers | Webster, P. | 2006 | IPIN | 19/06 | Four high output chippers were reviewed. Chip quality, outputs, fuel consumption and chipping costs were recorded. Infeed material dimensions and presentation were found to be most important productivity variables. | 5 |
| Chipping | A Comparison between a | Webster, P. | 2007 | IPIN | 09/07 | Comparison of outputs and costs between a hand loaded and a larger mechanically loader chipper. Unit | 6 |

# Technical Development Woodfuel Research Catalogue 1998-2008

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| | hand-fed and a mechanically-fed chipper | | | | | cost was broadly equal but the larger chipper had higher outputs. Infeed dimensions were found to be an important factor in chipper working. | |
| Chipping | Small scale chippers - standards review | Webster, P. | 2008 | IPIN | 02/08 | Study of birch and pine chips produced from ten chippers. Chips were assessed under the CEN/TS 335 14558-2004 standard and classified as either P45 or the higher P16. | 6 |
| Drying | Small roundwood – pilot drying trials | Webster, P. | 2006 | IPIN | 09/06 | Study of Sitka spruce and lodgepole pine small roundwood air drying whilst in covered stacks at roadside. MC was found to decrease over the 19 month storage from 57.8% to 27.9%. Stacks could be dried further with time. | 8 |
| Woodfuel & Burners | Woodfuel burning systems | Technical Development | 2003 | IN | ODW 12.01 | Summary of the main categories and characteristics of woodfuel burning systems from 2–100+ kW. Identifies fuel specifications, combustion type, efficiency, heat output range, burner arrangements, energy output arrangements and end user suitability. | 8 |
| Woodfuel & Burners | Woodfuel: Relating quality and specification to burner types | Webster, P. | 2004 | IPIN | 05/04 | Study describing the main factors affecting woodfuel quality for logs and woodchips in relation to burning system specifications, and providing best practice guidance on how to achieve suitable fuel quality. | 8 |
| Woodfuel & Burners | Energy value assessment of | Roux, S. | 2007 | IPIN | 14/07 | Study of woodchip qualities produced from 5, 11 and 14 year old pine and birch. Calorific values were found | 9 |

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| | woodchips from trees of different ages | | | | | to be similar for all age groups in both species. | |
| Residues | Presentation of brash for baling from clearfell harvesting | Webster, P. | 2007 | IPIN | 17/06 | Study of three brash presentation techniques in Sitka spruce clearfell and their effect on harvester, forwarder and baler working. Harvester productivity and costs were equivalent or better in the modified techniques compared to conventional presentation felling. Bale production output, cost and solid matter proportion are also given. | 11 |
| Residues | Brown brash baling – (An appendix to IPIN 17/06) | Webster, P. | 2007 | IPIN | 17/07 | Study of bale production for the three brash presentation techniques described in IPIN 17/06 after brash has lain on site for 41 weeks. Outputs and costs are given for baling and forwarding. | 12 |
| Residues | Calorific value of brash bales | McAllister, F. | 2007 | IPIN | 28/07 | Analysis of forest chip derived from bales produced in IPINs 17/06 and 17/07. Bales with a greater percentage of stemwood were found to have higher calorific value and provide higher grade fuel. | 13 |
| Small Scale | An evaluation of small scale forwarding methods in a broadleaf thinning operation | Drake-Brockman, G. R. | 1999 | TN | 40/98 | Study of broadleaved thinning with four tractors. Productivities and costs are given and show that mini-forwarders can compete with larger tractors and that access infrastructure is critical. | 13 |

# Technical Development Woodfuel Research Catalogue 1998-2008

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| Small Scale | Supply of woodfuel from small woodlands for small scale heating | Drake-Brockman, G. R. | 1999 | IN | 8/98 | Study comparing shortwood and pole-length woodfuel extraction in oak. Costs were similar in both cases, the shortwood system being more suitable for longer extraction distances. Cost of chipped timber was around 1.1 p/kWh. | 14 |
| Small Scale | Smallwood extraction sledge | Jones, D. | 1999 | TN | 24/98 | Study of a prototype timber extraction sledge. The trailer was found to work but considerable modifications were still required if the concept was attract commercial interest. No further work has been undertaken to date. | 15 |
| Small Scale | Compact tractors in forestry | Ireland, D. | 2006 | IPIN | 14/05 | A review of compact forest tractors providing guidance for selection, specification and relevant legislation. | 15 |
| Small Scale | Outdoor workshops - Review of small-scale harvesting equipment | Webster, P. | 2007 | IPIN | 08/05 | A review of a range of forest harvesting machinery that could aid small-scale working. | 15 |
| Small Scale | Small-scale systems for harvesting woodfuel products | Hall, A. | 2005 | TN | FCTN 009 | A review of small-scale harvesting equipment and systems. Provides guidance on the selection of appropriate systems for small-scale harvesting operations in relation to woodland type and woodfuel products, site and management constraints, | 16 |

# Technical Development Woodfuel Research Catalogue 1998-2008

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| | | | | | | harvesting system options and extraction machinery options. | |
| Small Scale | Systems for adding value – firewood processors, peelers and pointers | Technical Development | 2003 | IN | ODW 15.04 | A study of a small range of firewood processors, peeler and pointers, providing outputs and costs. | 17 |
| Small Scale | Woodfuel production from small undermanaged woodlands | Technical Development | 2003 | IN | ODW 12.02 | Review providing indicative costs for harvesting, extracting and processing of woodfuel from small and undermanaged woodlands. Provides a range of energy costs for the systems studied. | 17 |
| Short Rotation Coppice | Harvesting and comminution of short rotation coppice | Wyatt, G., *et al.* | 1998 | TN | 8/98 | Study of SRC willow and poplar harvesting using five cut and chip harvester and four billet harvesters. Assessments of machine suitability. outputs and extraction damage assessment are provided. | 18 |
| Short Rotation Coppice | Short rotation coppice harvesting: ground damage and yield effects | Wyatt, G | 1998 | TN | 21/98 | Study of the ground and crop damage effects from SRC harvesting. Includes an assessment of trailers used to extract SRC chip and their impact on the soil. Growth assessment of coppice after harvesting found no relationship between damage and yield. | 18 |

# Technical Development Woodfuel Research Catalogue 1998-2008

| Theme | Title | Author | Date | Type | Ref. | Summary | Page |
|---|---|---|---|---|---|---|---|
| Supply Chain | Developing best practice guidelines to support local small to medium scale woodfuel production | McAllister, F. & Jones, D. | 2007 | IPIN | 18/07 | Assesses the woodfuel resource in Wales. Presents case studies of three woodfuel suppliers in mid-Wales with costs. | 19 |

# Introduction

TD has carried out a considerable amount of woodfuel related research to date, however, there is no list or index compiling and organising the woodfuel publications to date, and no easy way to rapidly access the main findings or conclusions of these reports.

# Objectives

The objective of this project is to identify, summarise and compile the relevant information available in TD woodfuel related publications of the last 10 years.

# Work method

An initial search by title of reports produced by TD since 1998 was used to identify 52 thought to be related to woodfuel. The reports were read and those containing information still relevant to the present woodfuel supply chain situation or other current issues were selected, providing 28 titles. For the selected reports, extended abstracts were written and compiled into a catalogue by theme, year of publication, title, number and type of report.

# Results

## Harvesting

### Murgatroyd, I. R. (1998) Chipping clearfell tops in East Anglia, Internal Project Information Note 12/98

The harvesting and chipping of tops from a p.1928 Scots pine clearfell was studied at East Anglia FD, in a crop with an abnormal amount of forked stemwood. Average tree size was 0.95 $m^3$ ob with standing timber volumes of between 255 $m^3$/ha (ob) and 305 $m^3$/ha (ob). Forking above breast height occurred in 22% of the trees.

Felling and initial processing led to two studied treatments. The 'short tops' treatment chipped the material left after all possible stemwood products up to a minimum top diameter of 6 cm (ob) had been processed from the trees. The 'long tops' treatment chipped the material left after only sawlog material had been processed. Diameters ranged from a minimum of 14–16 cm ob to 35 cm where forking had inhibited sawlog conversion. Different methods of presenting the tops for extraction were also trialled.

Machines used were an Akerman H7/Lako 60 tracked excavator harvester, a 6 wheeled Hemek Ciceron forwarder with extended bunk and a 6-wheeled Kockums 84–35 forwarder fitted with a Bruks 800 chipper.

The crop yielded 43.1 green tonnes/ha of chips at a cost of £11.42/tonne when short tops were processed and between 75.0 and 90.4 green tonnes/ha of chips at a cost from £6.37 to £6.61/tonne when long tops were processed.

Harvester and forwarder productivity increased when cutting long tops rather than short tops.

Chipper productivity increased by 71 to 77% when processing long tops compared to short tops (7.7 to 8.0 $m^3$/shr compared to 4.5 $m^3$/shr), and expected surpluses from the overall clearfell operation were 16 to 22% greater when processing compared to short tops (£30.77 to £32.3/$m^3$ at roadside compared to £26.37/$m^3$).

## Saunders, C. J. (2007) Woodfuel trial Rivox, Ae Forest District, Internal Project Information Note 15/06

The study took place at Rivox, Ae Forest District, Southern Scotland. The crop was p. 1962 Sitka spruce with a mean tree volume of 0.24 $m^3$ and mean stand volume of 380 $m^3$/ha. Harvesting was completed using a John Deere 1270D with a Timberjack 758 head in conjunction with a John Deere 1410D forwarder.

Four treatments were studied, investigating cutting chipper poles at either a specified 2.9 m length or random length between 2.5 and 6.0 m. Chipper pole minimum top diameter remained at 3 cm for both specifications. Also investigated was the cutting of green tops for residue harvesting.

Treatment 1 consisted of cutting all conventional products consisting of logpoles, 3 sawlog types, 2 bar types and fencing as well as 2.9 m x 3+ cm chipper poles.
Treatment 2 replaced fencing material with fixed length chipper poles.
Treatment 3 had the same product mix as Treatment 1 but green tops were also cut.
Treatment 4 had the same product mix as Treatment 2 but the chipper poles were of random lengths.

The harvester outputs from the four treatment types were similar and ranged from 11.26 $m^3$/shr ob to 12.63 $m^3$/shr ob with harvesting costs of £5.40 to £4.80/$m^3$ ob. Cutting random length chipper poles had the greatest detrimental effect on harvester outputs and costs due to handling difficulties within the harvester head. Random length chipper poles produced lesser outputs for forwarder extraction in this case study.

Cutting set length chipper poles increased roundwood recovery by 89 $m^3$/ha ob compared to Treatment 1 when this product type was introduced to the cutting specification which had a fencing product as the only non sawlog product. It is important to note that this significant volume was previously being placed in the brash mat.

Forwarder outputs ranged from 20.70 $m^3$/shr ob to 5.61 $m^3$/shr ob. The highest extraction rates were achieved with large sawlog material at high product density rates and the lowest extraction rates were achieved with small sawlog material at low product density. Smallwood extraction rates were between 8.81 $m^3$/shr ob and 13.61 $m^3$/shr ob. Extraction costs were between £2.10/$m^3$ ob and £7.70/$m^3$ ob.

The forwarder output for green tops was 3.06 $m^3$/shr and this volume calculation is based on main stemwood volume and not branch volume. Extraction costs based on stemwood volume were £14.10 $m^3$ ob. The volume of green tops is estimated at 8.00 $m^3$/ha which is relatively low when compared to the chipper pole volume.

### Webster, P. and Price, M. (2007) Rumster Forest Northern Wood Heat woodfuel pilot study, Internal Project Information Note 07/07

A comparison between clearfell production of conventional products and woodfuel was carried out in unthinned stands of lodgepole pine and Sitka spruce in Rumster Forest, Scotland.

The lodgepole pine stand had an estimated volume of *c*. 355 $m^3$/ha, a mean tree volume of *c.* 0.19 $m^3$ and a top height of 18 m. The Sitka spruce stand had an estimated volume of *c*. 590 $m^3$/ha, a mean tree volume of *c*. 0.41 $m^3$ and a top height of 25 m.

The conventional product mix consisted of 3.7 m log, 2.5 m palletwood and 3.0 m chip in areas of Sitka spruce and 2.5 m palletwood and 3.0 m chip in areas of lodgepole pine. Woodfuel treatments replaced the cutting of palletwood and chip with random lengths of less than 5.0 m and no diameter limits.

Cutting of woodfuel was found to increase volume recovered by *c*. 20% in lodgepole pine and *c*. 35% in Sitka spruce.

Harvester productivity was found to increase when cutting woodfuel by 59% from 7.8 to 12.4 $m^3$/shr in lodgepole pine and by 26% from 12.8 to 16.1 $m^3$/shr in Sitka spruce.

Indicative forwarder productivity study values suggest working is more efficient in woodfuel working by *c*. 20% and *c*. 19% in Sitka spruce. Productivity normalised for an extraction of 100 m for conventional and woodfuel treatments respectively were *c*. 10.14 and 12.92 $m^3$/shr in lodgepole pine and *c*. 11.58 and 13.92 $m^3$/shr in Sitka spruce.

Total costs to roadside in lodgepole pine were 8.80 £/$m^3$ for conventional working and 6.17 £/$m^3$ for woodfuel. Costs in Sitka spruce were 5.95 £/$m^3$ for conventional working and 4.85 £/$m^3$ for woodfuel.

## Webster, P. (2008) Woodfuel production from a thinning operation, Internal Project Information Note 30/07

A mechanised thinning operation in Sitka spruce was studied the Dyfnant forest, Wales in 2007.

The stand of Sitka spruce was 23 years of age, with a density of 2344 stems/ha, an average dbh of 13 cm, average tree volume 0.073 $m^3$ and average volume per ha of 171 $m^3$. The operation was a first thinning in a second rotation crop. One line was removed every 20 m to create access racks for the machinery and selective thinning carried out on both sides of the racks.

The trial compared two cutting specifications, a 'conventional' mix of 3.7 m log, 2.4 m bar, 2.8 m chipwood and 1.7 m stake and a 'woodfuel' product mix of log, bar and 3.0 m woodfuel.

The harvester used was a John Deere 1270D Eco 3 with a 758 HD harvesting head. Forwarding was carried out with a John Deere 1110 D.

Time study data gathered showed a harvester productivity of 2.44 $m^3$/shr for conventional working and 2.91 $m^3$/shr for the woodfuel specification. Forwarder output for a 100 m extraction distance was 13.19 $m^3$/shr for conventional working and 12.06 $m^3$/shr for the woodfuel specification. Costs for harvesting and extraction to roadside were calculated as £28.43/$m^3$ and £25.13/$m^3$ for conventional and woodfuel specifications respectively.

The main conclusion was a smaller harvesting head with a smaller capacity fitted to a specialised base unit would have been more appropriate both for the conventional and woodfuel harvesting, allowing better general manoeuvrability and increased recovery of smaller diameter stemwood for woodfuel.

# Chipping

### Murgatroyd, I. R. (1998) East Anglia whole tree chipping, Internal Project Information Note 11/98

This report describes time studies of whole tree terrain chipping carried out in East Anglia FD in 1998.

The terrain chipper studied was a Hafo GMR21 4WD drum chipper, equipped with an offset Mowi 2255 loader and a Hultdin chainsaw felling head. The loader had an effective reach of 3 m to the off side of the machine and 5.2 m to the near side. The diameter-limit of the felling head was 30 cm.

Seven studies were carried out in stands of predominantly Corsican pine with some areas of Scots pine and broadleaved intrusion. Mean tree volumes varied between 0.10 $m^3$ and 0.14 $m^3$ (7 cm ob). Terrain classification in all stands was 1:1:1.

Stand volume reduction varied between 76.06 $m^3$/ha and 86.10 $m^3$/ha with chip yields ranging between 108.13 t/ha and 123.04 t/ha. Whole-tree tonne to volume (7 cm ob) ratios at 57% moisture content were recorded between 1.39 t/$m^3$ to 1.55 t/$m^3$ for different mean tree volumes and species mixes.

The outputs observed (tonnes per standard hour normalised for a 100 m extraction distance) ranged from 3.93 t/shr (average thinned tree size 0.103 $m^3$ ob, working across the rows, with significant broadleaf intrusion) to 6.19 t/shr (average thinned tree size 0.13 $m^3$ ob, working with the rows, removing of 1 row in 7 and selective matrix thinning).

The offset loader and lack of head rotator necessitated the use of double passes, decreasing productivity.

Thinning, chipping and extraction costs to ride/roadside public road transport bins were shown to vary from £5/tonne to £10/tonne per 100 m extracted depending on crop size, thinning method and machine cost assumptions.

# Technical Development Woodfuel Research Catalogue 1998-2008

## Murgatroyd, I. R. (1998) Random length smallwood chipping recovery compared to conventional shortwood systems, Internal Project Information Note 32/98

Trials were carried out in South West Scotland in 1998 to investigate the possibility of increasing the woodfuel component harvested from clearfells of Sitka spruce (SS) and lodgepole pine (LP) mixed stands.

The trials compared shortwood working for two differing product mixes. Treatments cut a variety of standard log and palletwood sizes but differed in chipwood specifications. Conventional working cut chipwood to a minimum top diameter of 6 cm (ob) whereas unconventional working cut chipwood random length to 3 cm top diameter (ob).

Fourteen studies were carried out in three areas of SS/LP showing different growth, form and levels of windblow. Terrain was classified as either 3:2:1 or 5:2:1, i.e. relatively smooth and flat sites but with moderate to soft soils.

The trial used three JCB 814 Supers; tracked excavators base machines fitted with either Keto 150 or Logset 555 heads. Forwarders used were a Kockums 84-35 six wheeled forwarder on two of the three sites studied, and a Logset Challenger 8 wheeled forwarder on the other site.

The woodfuel material was fed into a Morbark Model 23 Chiparvestor set to cut chips of between 19 mm and 38 mm.

End product recovery (as a percentage of standing volume) was found to be greater by 8 to 30% with the random length method than with the conventional one in all but one case, where it was 3% less. The mean recovery volume as a percentage of standing commercial volume for the unconventional system was 101% and 90% for the conventional system, indicating that unconventional harvesting was removing material of less than 7 cm top diameter. Lower recovery rates were obtained on poorer sites as more stemwood was required for brashmat construction.

Harvester outputs ranged between 9.8 $m^3$/shr and 10.94 $m^3$/shr in conventional working and 9.83 $m^3$/shr and 12.53 $m^3$/shr in unconventional working. Cutting random chipwood lengths increased productivity by a mean of 10% compared to the conventional method.

Forwarder extraction rates, averaged for 300 m, ranged between 12.62 $m^3$/shr and 18.48 $m^3$/shr in conventional working and 9.73 $m^3$/shr and 19.07 $m^3$/shr in unconventional working. The mean extraction rate of the unconventional random chipwood lengths was 77% of that of the conventional fixed lengths, mainly due to the difficulty to accommodate full forwarder loads with random length products.

The Morback chipper had an output of 34.87 $m^3$ /shr (ob) and was underutilised on site.

The total cost of the chipwood system (£7.3/$m^3$ at roadside) were slightly higher than with the conventional method (£7.23/$m^3$ at roadside) due to smaller forwarder loads and additional cost of chipping.

The expected revenues and surpluses, however, were higher for the random length method (average £23.31/$m^3$ income and £16.01/$m^3$ surplus) than for the conventional method (average £19.49/$m^3$ income and £12.26/$m^3$ surplus).

Brash mat structure and condition were similar between both treatments.

## Webster, P. (2005) Chipper review, Internal Project Information Note 06/05

Ten small scale chippers, identified on the basis of collective TD experience and consultation with manufacturers and suppliers, and representing a range of designs, were trialled for the production of woodfuel at the small scale. The selection included 2 drum chippers, 7 disc chippers and 1 screw cone chipper. Maximum feed diameter ranged between 10 and 40 cm. Machine cost ranged between £5000 and £25 000.

Piece size and moisture content of the infeed material was recorded, and sampling of chip particle size was carried out in accordance with CEN/TC 335. Outputs and costs, particle size and machinery safety and operational aspects were assessed.

The material used for the trials was birch and pine shortwood of 2 m length within the diameter range of the chippers trialled, manually or mechanically fed depending on the models.

Chipper fuel consumption ranged from 1.28 to 3.71 l/$m^3$ depending on the chipper model and size of infeed material.

Outputs ranged from 0.7 $m^3$/shr to 5.29 $m^3$/shr, corresponding to costs of between £5.00/$m^3$ and £14.97/$m^3$, although most costs were in the £8–10/$m^3$ range.

Chip quality varied between CEN/TC P45 (80% of particles in weight between 3.15 and 45 mm) and P100 (80% of particles in weight between 3.15 and 100 mm).

The noise levels recorded ranged from 91 to 96 dB, and noise level above 100 dB was recorded from one model, indicating the need for specific ear protection. Due to the amplification effect of the conical shaped infeed chute, noise is noticeably concentrated at the position where the operator stands.

Species was found to have little effect on chip output or quality but mean chip size generally increased with increased material throughput.

The main factors limiting outputs appeared to be the proportion of small diameter material and the material handling time, which also inflicted considerable physical strain on the operator. The orientation, height and presentation of material at the infeed also affected performance and outputs.

*The assessment of the products of the different chippers against the CEN/TC 335 standard has been updated in the IPIN 02/08 – Small Scale Chippers – Standard Review*

## Webster, P. (2006) Large chippers, Internal Project Information Note 19/06

TD investigated four high output (>100 $m^3$/hr of chip capacity as rated by the manufacturer), mechanically fed chippers able to produce desired chip characteristics and with a maximum feed diameter of 400 mm or greater. Chippers were selected from a range operating in Great Britain (GB), these were:

- Heizohack HM 14-800
- Foresteri 4560C
- Jenz 560Z
- Musmax Terminator 8.

Output and other aspects of performance were tested and the main findings were:

- From an infeed specification of 2.8 m lengths with a top diameter range of between 40 and 6 cm the Heizohack and Musmax produced woodchips that conformed to the P16 specification of the CEN/TC 335 standard. The other two machines produced woodchips that met the P45 specification.
- Outputs ranged between 11.39 $m^3$ and 21.10 $m^3$ of solid wood per standard hour. Assuming an expansion factor of 3, this means that none of the machines produced 100 $m^3$ of chip per hour, production ranging from 34.17 to 63.3 $m^3$/shr.
- Fuel consumption ranged between 1.18 and 1.92 litres/$m^3$ of solid wood.
- Chipping costs ranged from between £4.30/$m^3$(solid) and £6.68/$m^3$(solid).
- Presentation of timber for chipping is important and should aim to minimise the need for grapple rotation and boom extension.

- Increasing the diameter of infeed material limits output by building up the volume of chips within the drum and triggering the machine anti-stress devices.

## Webster, P. (2007) A Comparison between a hand-fed and a mechanically-fed chipper, Internal Project Information Note 09/07

This Internal Project Information Note (IPIN) is a report from one of several sub projects carried out by TD for the Northern Wood Heat (NWH) project. It presents a comparison between a manually-fed chipper (Bandit 90W disc chipper) and a mechanically-fed one (Biber 7 Plus Eschlbock drum chipper). The Biber 7 Plus did not have an integral loader and therefore loading of the roundwood was undertaken using a Valmet 6400 tractor with forwarding trailer fitted with a FMV 2500 loader.

Infeed material consisted of two batches of dried Sitka spruce and one of dried lodgepole pine with mean piece lengths of 2.9 m, 3.4 m and 4.7 m and mean piece volumes of 0.033 $m^3$, 0.040 $m^3$ and 0.075 $m^3$ respectively.

Output for the Bandit 90W ranged between 2.72 $m^3$/shr and 3.41 $m^3$/shr and for the Biber 7 between 7.25 $m^3$/shr and 8.53 $m^3$/shr. Output increased with piece length. Unit costs for the Bandit 90W varied between 5.76 £/$m^3$ and 7.22 £/$m^3$ and for the Biber 7 between 5.79 £/$m^3$ and 6.82 £/$m^3$.

All the roundwood chipped had a moisture content (MC) of less than 26%.

Both chippers performed to a satisfactory standard throughout the trial. The output capabilities of both machines indicate they are suitable for different scales of work.

For small-scale operations, for example supplying small quantities of woodchips up to 20 $m^3$ (small roundwood) per eight hour day, the Bandit 90W would be more suitable. It also has the advantage that it is self powered and can be towed between sites using a 4-wheel drive vehicle.

The Biber 7 Plus is capable of producing larger quantities of woodchips and therefore is suitable for large-scale chipping operations. From the output observed in the trial, it is capable of chipping 68 $m^3$ of roundwood per day. Power is provided by an agricultural tractor PTO and, although most modern tractors are fitted with high ratio gears allowing high road speeds, towing the chipper long distances may be uneconomical. In such instances a low loader would be required.

### Webster, P. (2008) Small scale chippers - standards review, Internal Project Information Note 02/08

Woodchips produced from ten small-scale chippers were assessed for particle size variability against the CEN/TC 335 biofuel specification. Sampling was in accordance with Technical Specification 14778-1:2005 and assessment carried out by an accredited laboratory.

Birch and Corsican pine roundwood were used with respective mean moisture content (MC) of 44.41% and 59.16%.

All of the chippers were capable of producing the standard P45 specification (more than 80% fraction in weight between 3.15 mm and 45 mm) and three chippers produced the higher quality P16 specification (more than 80% fraction in weight between 3.15 and 16 mm) from both species.

The results were compared with an earlier particle size assessment carried out in 2005 (IPIN 06/05). Both showed the main fraction from most machines to be within the P45 size category however the earlier results showed a greater percentage of particle sizes in the <1 mm and >63 mm categories.

## Drying

### Webster, P. (2006) Small roundwood - pilot drying trials, Internal Project Information Note 09/06

This trial investigated the rates of MC reduction in Sitka spruce (SS) and lodgepole pine (LP) on two sites in Scotland between May 2004 and December 2005.

The trial sites and short roundwood (SRW) were provided by Forest Enterprise, Scotland (FE) from existing FE harvesting operations. Approximately 100 $m^3$ were made available from each site. Nine stacks of *c*.11 $m^3$ were constructed, three stacks of both SS and LP and three stacks of a mixture of SS/LP on each site. No dead material was included in the trial. Product specification was 2 m in length with an end diameter range of between 4 and 46 cm. To aid drying, stacks were constructed on bearers and covered with impermeable plastic sawn-timber wrapping sheets.

The results show there was a consistent reduction in MC over the nineteen month period of the trial. The starting MC of 61.1% for SS on both trial sites was greater than that of 54.2% for LP. From May 2004 until the first weight sampling in October

2004 SS changed MC quicker than LP. However towards the end of the trial period the rate of MC reduction between the two species overall was similar.

The mean MC for all species at the beginning of the trial was 57.8% (wet basis). This was reduced to a mean of 27.9% by December 2005. No target or equilibrium MC was reached during the trial period (i.e. the stacks were still drying) and therefore no investigations into maintaining MC at a constant rate could take place.

## Woodfuel & Burner Specifications

### Technical Development (2003) Woodfuel burning systems, Information Note ODW 12.01

This Information Note is one of a series forming a guide to woodfuel production from small-scale woodlands.

This note presents information on the main categories of woodfuel burning systems and their characteristics, identifying fuel specifications, combustion type, efficiency, heat output range, burner arrangements, energy output arrangements and end user suitability. The note covers a range of system sizes, from small, simple warm air systems in the 2-10 kW range up to modern commercial sized systems of 100+ kW producing heat, electricity or a combination of outputs.

### Webster, P. (2004) Woodfuel: Relating quality and specification to burner types, Internal Project Information Note 05/04

This report describes the main factors affecting woodfuel quality for logs and woodchips in relation to burning system specifications, and provides best practice guidance on how to achieve suitable fuel quality.

The amount of moisture in wood varies for different tree species (generally greater in softwoods than hardwoods), regions of the country and in different parts of individual trees (greater in the sapwood than in the heartwood). The wet basis MC of a piece of wood is defined as the weight of water expressed as a percentage of the weight of the wood. MC is inversely related to the calorific value of fuel meaning that the drying of woodfuel will increase heat output and therefore its economic value. Six practical methods to reduce MC are discussed:

- Ring barking

- Chemical thinning
- Sour felling
- Felling of dead and dying trees
- Stacking on site
- Stacking at roadside.

Species with a higher density (hardwood generally) will normally have a greater calorific value than species of lower density at equivalent MC, their rate of drying will be slower will require more energy to process into logs or chips.

The dimensions of high-quality fuel should be consistent and linked to the requirements of the burning system. Limits for log wood are recommended as no thicker than 150 mm. Chip size commonly varies between 2 and 50 mm, being highly dependent on chipper type and settings, and infeed material qualities. Chip fuel quality is highly dependent on consistency of particle size.

One of the primary aims of storing woodfuel is to reduce the MC. Seasoning (drying time) is dependent on the wood density, wood dimensions, presence of bark, method of storage and stacking and the required MC. The rate of drying is strongly influenced by air movement, temperature and humidity.

The main recommendations are to dry roundwood to target MC at roadside, stacked on bearers, in an exposed area, and ideally covered to avoid rewetting. Woodchips should be stored at target MC on a concrete floor in a covered heap or barn. Storage of low MC woodchips will reduce the fungal and bacterial growth which can decrease chip calorific value, cause health problems from handling and cause spontaneous chip-pile combustion. Fuelwood (logs or chips) should also be as dry as possible to limit costs during handling and transport.

Transport distance of fuelwood should be kept to minimum as it is a low value commodity. In particular, the low bulk density of woodchip causes transport to rapidly become uneconomic and so the comminution at point of use is preferred.

Woodfuel specifications should be common between both producer and end user to ensure an agreed and suitable quality of the fuel in terms of size, uniformity and MC. The report provides descriptions of fuel source classification, moisture content and particle size and homogeneity in relation to the CEN 335 standard.

The report finishes by describing a range of woodfuel burning systems from small domestic units of 2–25 kW capacity to medium business or community units of 11–200 kW capacity.

### Roux, S. (2007) Energy value assessment of woodchips from trees of different ages, Internal Project Information Note 14/07

Early and pre-commercial thinnings for fuel wood production have been developed in the past twenty years in Scandinavia, and especially in Finland. A central assumption is that the energy value of woodchips produced from such operations is highest when coming from younger and smaller diameter material. As part of the wider Wyre forest project, it was decided to investigate this and to see if recommendations could subsequently be made for woodfuel production.

Assessments of the MC and calorific value of woodchips produced from Corsican pine and birch of 5, 11 and 14 years of age were carried out. The trees were felled with a chainsaw, snedded, and chipped on site.

Moisture content varied between 43.7% and 46.9% in birch and 58.9% and 60.6% in Corsican pine.

The calorific values ranged from 20.03 to 20.10 MJ/dry kg for birch and 20.68 to 20.79 MJ/dry kg for Corsican pine, showing no obvious difference between the calorific values for different ages of these particular species.

Net calorific values were consistent with other values found in literature.

## Residues

### Webster, P. (2007) Presentation of brash for baling from clearfell harvesting, Internal Project Information Note 17/06

This report describes a study of three different methods of presenting brash for baling and the operational issues associated with integrating brash baling into a conventional mechanised clear fell operation.

The study site in Wales was an area of Sitka spruce clearfell. Before felling, the p.1953 crop was stocked at 1210 trees/ha with a standing volume of 546 $m^3$/ha. Approximately 445 dead trees per hectare within the crop provided a further volume of *c*. 39.9 $m^3$/ha. The site had upland brown earth soils and a moderate slope of 14%.

Three brash-presentation treatments were trialled against conventional harvesting where all the brash was incorporated into the mat.

- Treatment 1: 100% branchwood and small diameter tops placed in the brash mat (conventional practice) and every second brash mat baled.

- Treatment 2: Delimbed small diameter stemwood (delimbed tops), equivalent to 50% of available stemwood in tops, placed in a distinct brash zone for baling.
- Treatment 3: Whole small diameter tops, equivalent to 50% of available tops, placed in a distinct brash zone for baling.

Harvesting was carried out by a John Deere 1270D with a H480 head, cutting a mix of logs, bar, fencing and chip. Forwarding of timber and bales was carried out by a John Deere 1110D.

Harvester productivities in Treatments 1, 2 and 3 were 23.35 $m^3$/shr, 22.07 $m^3$/shr and 21.70 $m^3$/shr respectively, compared to 21.57 $m^3$/shr for conventional working. Harvester cost in the three treatments ranged between £2.78/$m^3$ and £3.00/$m^3$ compared to £3.01/$m^3$ for conventional working.

Brash from the different presentation methods was recovered by a John Deere 1490D brash baler and the performance of the brash baling operations assessed.

Bale production in treatments 1, 2 and 3 was 41 bales/shr, 33 bales/shr and 36 bales/shr respectively, exceeding the output of 20–30 bales per hour stated by the manufacturer.

Volume production in Treatments 1, 2 and 3 was 19.23 solid $m^3$/shr, 19.97 solid $m^3$/shr and 16.88 solid $m^3$/shr respectively.

Unit costs per bale were calculated for Treatments 1, 2 and 3 as £1.70, £2.12 and £1.94 respectively and volume costs as £3.62, £3.50 and £4.13 per solid $m^3$respectively.

Forwarding of bales was at the rate of 45 bales/shr and the mean solid volume of the bales produced was 0.513 $m^3$.

Bales produced from Treatment 2 had the highest proportion of solid matter (assessed at 0.605 $m^3$ solid volume per bale compared with 0.469 for the two other treatments) and stemwood, so were deemed likely to have the highest energy content.

### Webster, P. (2007) Brown brash baling - (An appendix to IPIN 17/06), Internal Project Information Note 17/07

This IPIN investigates the baling of brown brash from three different methods of presenting brash for baling. The presentation methods and baling of green brash are described in IPIN 17/06, which should be read in conjunction with this document.

The three treatments were:

- Treatment 1: 100% branchwood and small diameter tops placed in the brash mat (conventional practice) and every second brash mat baled.
- Treatment 2: Delimbed small diameter stemwood ('delimbed tops'), equivalent to 50% of available stemwood in tops, placed in a distinct brash zone for baling.
- Treatment 3: Whole small diameter tops, equivalent to 50% of available tops, placed in a distinct brash zone for baling.

Baling was carried out 41 weeks after clearfelling to allow an estimated 80% of needles to drop.

Baling rate of brown brash for Treatments 1, 2 and 3 was 37, 31 and 41 bales/shr respectively. Unit cost per bale was £1.88, £2.25 and £1.70 respectively.

Extraction was carried out by a John Deere 1110D forwarder. Extraction rates for Treatments 1, 2 and 3 were 46, 57 and 57 bales/shr respectively. Cost of extraction was £0.96/$m^3$, £0.77/$m^3$ and £0.77/$m^3$ respectively.

Total cost to roadside for the 3 treatments was £2.84/$m^3$, £3.02/$m^3$ and 2.47/$m^3$ for 1, 2 and 3 respectively.

In terms of costs to roadside for the operations studied, there was no clear variation between green and brown baling. However current research into calorific value and nutrient content of both green and brown bales should provide indications regarding most appropriate baling method and stage.

Benefits and constraints were summarised as:

Green Baling – benefits

- Baling can be carried out immediately after harvesting, making greater use of the forwarder which is already on site for timber extraction. It is thought preferable to remove the timber first to allow greater stacking space on site for the brash bales.
- Fresh green Sitka spruce brash is better than brown brash for supporting machine movements. However this will reduce over a period of time.

Green Baling – constraints

- Extracting green bales removes a high proportion of needles from the site. This may have a detrimental effect on the nutrient status of the soil and in future growth yields of trees.
- Green bales have a higher MC and therefore are heavier and have a lower calorific value than brown bales.

Brown Baling – benefits

- From observations it was estimated that more than 80% of the needles had become detached from the brash and remained on site. This helps to maintain the nutrient status of the site.
- Brown bales have a reduced MC and a higher calorific value. They weigh less than green bales and therefore are easier for mechanical handling and cheaper to transport.

Brown Baling – constraints

- The forwarder had to be transported to and from site specifically for the extraction of bales at additional cost.
- The brash had broken down, growing thin with bare ground visible in places. On sites with lower ground-bearing capacity brash would have needed to be imported to prevent ground damage. This would be an additional cost to the operation.

## McAllister, F. (2007) Calorific value of brash bales, Internal Project Information Note 28/07

The report is a continuation of work described in IPIN 17/06 and IPIN 17/07 and is an analysis of the energy value of brash bales produced using three separate presentation methods.

The calorific value and major elements contents of brash bales of Sitka spruce produced with three different methods were analysed. The three types of bales contained:

- branchwood and small diameter tops
- small diameter tops only
- delimbed small diameter tops only.

In each case ‘green’ bales (material baled fresh after felling) and ‘brown’ bales (material baled after being left six months on site to dry) were tested.

A random sample of green and brown bales produced from the three brash presentation methods were chipped using a Heizohack HM8 400 drum chipper installed with a 35 x 40 mm screen to produce G50 chips as specified in the Onorm M 7133 standard. Samples of the chips produced from each bale were individually bagged and tested.

The results showed calorific values per dry weight ranging from 17.33 (small tops bales) to 18.51 MJ/kg (delimbed tops bales) for the green bales, and from 16.56 (small tops bales) to 17.74 MJ/kg (delimbed tops bales) for the brown bales.

The brown bales showed a higher initial MC, and therefore a lower calorific value than the green bales, as heavy and persistent rain during summer 2007 led them to re-wet.

The stemwood bales also contained significantly less nitrogen (0.3–0.4%) than either green or brown baled brash (0.6–0.9%), and when burned produced significantly less ash (0.4–0.5% compared with 1–3%).

These results indicate that delimbed stemwood should be preferred for biomass fuel production to branchwood brash, as it allows greater outputs (see IPIN 17/06 *Presentation of brash for baling from clearfell harvesting*), produces bales of greater calorific content, and would have a lesser of an impact on the overall nutrient capital of the site.

# Small scale

### Drake-Brockman, G. R. (1999) An evaluation of small scale forwarding methods in a broadleaf thinning operation, Technical Note 40/98

An evaluation of four different shortwood extraction methods from a broadleaved thinning operation was carried out in Shropshire in 1998.

The mixed broadleaved stand in which extraction was studied was *c*. 80 years old and of generally good form. The site sloped up to 28% with a small area of 35% and had clay soils. The thinning reduced the standing volume from 265 $m^3$/ha to 78 $m^3$/ha, with a mean thinned tree size of 0.21 $m^3$ and a mean thinned dbh of 19 cm. The products extracted were 2.15 or 3.00 m long.

The machines studied were:

- Moheda 11 tonne forwarder trailer and loader pulled by a Valmet 6400 4 WD tractor
- Farma 8 tonne forwarder trailer and loader pulled by a Valmet 6400 (95 hp) 4 WD tractor.
- Star wire loader and 1 tone forwarder trailer with winch, pulled by a Massey Fergusson 265 4 WD tractor.
- Alstor purpose-built 8 wheel drive mini-forwarder with 1 tonne trailer capacity.

The Alstor mini-forwarder achieved outputs of 2.96 $m^3$/shr at a unit cost of £4.59/$m^3$ when extracting 3.0 m produce, had the best terrain capabilities and made the least site impact of the machines tested.

The Valmet /Moheda forwarder unit achieved outputs of 3.69 $m^3$/shr at a unit cost of £4.96/$m^3$ for 2.15 m produce. The Valmet/Farma forwarder unit achieved outputs of *c*. 2.78 $m^3$/shr and a unit cost of £6.26/$m^3$ with 2.15m produce.

The MF265/wire loader had the lowest outputs (0.64 $m^3$/shr) and highest costs, mainly because of the wet soil conditions.

The results show that purpose-built mini-forwarders can provide an economic alternative to the larger agricultural tractor forwarder models.

The trials also showed the critical importance of good access infrastructure within woodlands, the importance of site conditions (terrain and weather) and the necessity of sound choice of machinery and operational planning.

## Drake-Brockman, G. R. (1999) Supply of wood fuel from small woodlands for small scale heating – Case study 4 – Fell and extract 2nd thinning broadleaves using farm tractor based equipment, Technical Note 8/98

A comparison was made between shortwood and pole-length small-scale woodfuel extraction in a 43 year old oak crop thinning. The trial site in Shropshire was level with well-drained sandy loam soils and good access

The shortwood system included motor-manual felling, cross-cutting of trees at stump and extraction to roadside using a farm tractor based forwarder with hydraulic loader. The equipment used consisted of a Husqvarna XP266 chainsaw, forwarder tractor Zetor 9145 and 6 t trailer with FMV crane. The average thinning tree size was 0.15 $m^3$ and product density 29 $m^3$/ha.

The pole-length system included motor-manual felling, skidding to roadside and cross-cutting. The equipment used consisted of a Husqvarna XP266 chainsaw, skidder tractor County 1164 and Fransguard TW3500 winch. The average thinning tree size was 0.07 $m^3$ and product density 30 $m^3$/ha.

The two systems achieved costs of respectively £10.83/$m^3$ (or £10.18/green tonne or £27.18/ tonne at 30% MC) and £10.20/$m^3$ (or £9.59/green tonne or £26.36/ tonne at 30% MC) at roadside. Direct comparison between the two systems is not possible as the tree size processed in the shortwood treatment was double that in the pole-length and it is thought that the shortwood system would prove cheaper for longer extraction distances, whilst the skidder system would prove cheaper for larger tree sizes.

Both systems studied showed themselves capable of delivering chips to the burner at a cost of *c*. £27/air dry tonne (30% MC). On the basis of these costs and an assumed cost of £4/$m^3$ for the standing timber, the energy cost in p/kWh would be around 1.1 p/kWh, not accounting for the appliance efficiency.

### Jones, D. (1999) Smallwood extraction sledge, Technical Note 24/98

This report describes brief trials of a prototype smallwood extraction trailer capable of being winched onto or off sites and able to travel over firm or soft ground. Building, testing and design revisions are described and discussion made of working technique and further development. The trailer was found to work but considerable modifications were still required if the concept was attract commercial interest. No further work has been undertaken to date.

### Ireland, D. (2006) Compact tractors in forestry, Internal Project Information Note 14/05

This report discusses the use of compact tractors in forest operations and provides guidance for the selection of machines in relation to likely applications.

Small-scale compact tractors are commonly used in the UK for horticulture and grounds maintenance. There is, however, a growing interest in their use for forestry applications.

Compact tractors are defined by their compact dimensions, and are commonly below 50hp, although their power to weight ration is comparable to larger machines and more powerful models are available.

Compact tractors offer specific advantages in terms of reduced site impact and maneuverability compared to larger scale tractors, making them well suited to sensitive forest harvesting and management sites, although on very rough sites ground clearance may become an issue.

Compared to other small-scale machinery options, compact tractors offer considerable safety and ergonomic advantages to operators.

Most tractors have a three point linkage and PTO which enables the use of a large range of attachments. Compact tractors can be used for timber processing, extraction, ground preparation, mowing for amenity and conservation, transport of equipment and materials and ongoing management tasks.

Compact tractors are subject to Provision and Use of Work Equipment Regulations 1998 (PUWER) and where applicable the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER). Compact tractors can offer superior operator protection compared to many alternative small-scale machines in terms of Roll Over Protection System (ROPS) and Falling Object Protection System (FOPS). Tractor features are classified by their requirement under legislation or best-practice guidelines.

## Webster, P. (2007) Outdoor workshops - Review of small-scale harvesting equipment, Internal Project Information Note 08/05

The report is a discussion piece investigating harvesting equipment both previously trialled and new to the UK.

Machinery type, advantages and disadvantages are described through four classifications:

- Purpose-built
- All terrain cycle (ATC)
- Agricultural tractors
- Mini/midi tractors.

Brief descriptions, capabilities and purchasing costs are given for a number of pieces of equipment which have been case-studied by TD in the past. The list consists of:

- Mini-forwarders – 2 types
- Mini tractors
- Agricultural tractor PTO attachments – processor, grapple skidder, terrain chipper, wire loader
- ATC attachments – forwarder trailer
- Log chute.

The report also provides brief descriptions, capabilities and purchasing costs for a selection of equipment new to the UK. The list consists of:

- Mini skidder and small 4WD grapple skidder
- Harvesting heads - feller buncher head and disc-cutter heads
- 3WD harvester
- Mini-skyline.

The report concludes by discussing the relevancy of the equipment types to the demands of working in small-scale, farm and community woodlands, CCF systems and the increasing markets for woodfuel.

## Hall, A. (2005) Small-scale systems for harvesting woodfuel products, Technical Note FCTN009

Small woodlands in Great Britain are a potential source of woodfuel for local heating, but there are difficulties identifying efficient harvesting systems. This Technical Note provides guidance on the selection of appropriate systems for small-scale harvesting operations, based on a comprehensive series of case studies undertaken by Forest Research. It considers four factors that influence the overall selection: i) woodland type and woodfuel product(s); ii) site and management constraints; iii) harvesting system options and iv) extraction machinery options.

In broad terms the findings from the case studies are:

- Forwarding tends to be more cost effective than skidding, which is considered to be inefficient for longer extraction distances (>250 m).
- Where difficult sites require maximum manoeuvrability and flotation, mini forwarders should be considered where appropriate.
- Using purpose-built forwarders is likely to cause less ground disturbance on drier sites than skidders and terrain chippers, with small-scale forwarders causing significantly less site disturbance.
- Skyline operations tend to be the most expensive option, their use being dictated by site and setup time constraints.
- System or machine choice must take account of machine availability, machine flexibility, differing machine/labour costs within and between areas, and site conditions.
- In general terms harvesting costs increase when slopes increase, uphill extraction is used, lower volume or product densities are harvested, smaller product volumes or sizes are harvested, poor tree and product forms are worked and produced, access is poor or difficult, extraction is over longer distances.

Key points for working in early broadleaved thinnings were:

- Lower volume returns and higher unit costs, make them the least profitable option.
- Pole length working is generally the cheapest system, but there is often little difference between skidding and forwarding shortwood options.
- Wire loaders are always the most expensive option in terms of hourly production costs, but they are one of the lowest capital cost units.
- On easy terrain a farm tractor-based forwarder is likely to be as cost effective as a larger purpose-built unit, depending on extraction distance.

Key points for working in mixed broadleaved coppice were:

- Choice is likely to be influenced by factors other than cost (availability, capital cost, site constraints).
- On steep sites (>50%), purpose-built forwarders are the most expensive option.

Key points for working with crown wood, scrub and residues were:

- Pre-commercial thinnings are often felled and left on site, however there may be some cost benefit in utilising material as woodfuel.
- Crown wood can be a cost effective fuel resource although the correct harvesting system needs to be adopted, that is, skidding, forwarding (to stump or roadside) or terrain chipping, subject to the correct machine choice.
- There is significant room for improving terrain chipping outputs.

Costs vary widely according to the harvesting system used and are subject to the site factors already mentioned. Generally, costs of extraction in thinning are higher than in clearfelling, with basic costs increasing between £1 and £2 per $m^3$ for every additional 100 m of extraction. Indicative costs for extraction are provided for steep, moderate and easy/flat sites.

Costs for cable-crane systems on steep sites range between £10–25/$m^3$, dependent on processing and working methods.
Costs on moderate sites range between £5–12/$m^3$ using County-type skidders, £3–6/$m^3$ for short distances using portable winches and between £3–12/$m^3$ using forwarders.

Costs on easy or flat sites range between £3–12/$m^3$ using medium/large forwarders, between £5–12/$m^3$ using County-type skidders, between £13–17/$m^3$ using ATCs and between £4–15/$m^3$ using mini-forwarders.

## Technical Development (2003) Systems for adding value - firewood processors, peelers and pointers, Information Note ODW 12.03

This Information Note is one of a series forming a guide to woodfuel production from small-scale woodlands.

Several machines are described, summarised and their operation commented on.

Firewood processors described are the Japa 100, Japa 600, Nokka PK 200 and Technorton Compact. Outputs ranged from 0.49 $m^3$/shr to 2.34 $m^3$/shr. Costs ranged from £9.65 to £31.78 per $m^3$.

Also described is the Neuhauser R1K, a versatile combination peeler/pointer/splitter machine capable of producing a full range of forest fencing products. Outputs measured were 101 peeled and pointed 1.7 m stakes/shr, at £0.24 each and 64 peeled 3.66 m rails/shr, at £0.38 each.

## Technical Development (2003) Woodfuel production from small undermanaged woodlands, Information Note ODW 12.02

This Information Note is one of a series forming a guide to woodfuel production from small-scale woodlands.

A large number of systems are available for the production of woodfuel, some of which are very basic. The economics of using wood for fuel are very dependent on the woodfuel burner/boiler appliances used, the costs of production and the moisture content of the final product. If efficient appliances are used, far higher production costs may be sustained than are acceptable for conventional roundwood markets. Modern woodfuel systems for procurement and use have potential for rehabilitating undermanaged and neglected woodlands.

Indicative outputs and costs are provided for a range of thinning, extraction and processing alternatives. Motor manual felling costs varied between £5.42/$m^3$ and £8.04$m^3$ with cross-cutting costs of between £1.66/$m^3$ and £1.99/$m^3$. Extraction costs for a number of systems are given. Extraction systems detailed include a variety of forwarding and skidding options, winch, log chute, cable-crane and horse methods. Outputs varied between 0.76 $m^3$/shr and 3.3 $m^3$/shr and costs between £3.73/$m^3$ and £25.74/$m^3$. Costs for woodfuel processing varied between £4.35/$m^3$ (solid) and £27.18/$m^3$ (solid).

Total woodfuel production costs per tonne between £18 and £68 are presented. Assuming a calorific value of 14 GJ/tonne for 'air dry' wood, a realised heat cost of between £2.57/GJ and £9.71/GJ with a 50% efficient burner, and between £1.61/GJ and £6.07/GJ with an 80% efficient burner can be expected.

Derived values for heat are dependent on the final moisture content of the woodfuel and efficiency of the burner.

# Short Rotation Coppice

## Wyatt, G., et al. (1998) Harvesting and comminution of short rotation coppice, Technical Note 8/98

Trials of willow and poplar short rotation coppice (SRC) harvesting and comminution were carried out on sites across the UK.

Nine harvesting systems were assessed; five models of 'cut and chip harvesters' and four models of 'stick harvesters'. In parallel, seven models of chippers for the comminution of coppice following a stick harvesting operation were also assessed.

The trials showed that to a greater or lesser extent, all machines would require some modification to fully perform in UK crops, where current stem size, form and spacing did not match the harvesters' characteristics.

Cut and chip system outputs of 0.16–0.56 ha/shr, corresponding to between £7.10/odt and £15.91/odt were recorded. Stick harvesting system outputs of 0.09–0.22 ha/shr, corresponding to between £16.26/odt and £36.69/odt were recorded (including a separate chipping element). These values are indicative as the trials took place in different sites and conditions, with yields between 26 and 35 odt/ha.

Chipper outputs of between 0.91 and 3.30 odt/shr were recorded, providing comminution costs of between £8.36/odt and £38.81/odt. Notes on chipper suitability and chip fraction outputs are also provided.

Ground damage assessments were also made and found that tractors and trailers caused the most ground damage and traction problems limited the harvestable area and that the risk of bogging is high if machinery routes are poorly drained or sited on slopes or soft ground.

Cut and chip units were found to require higher capital investment but allowed lower direct harvesting costs, making them better suited for large scale operations. However, suitable provision needs to be made for subsequent storage of the chips.

Stick harvester systems were identified as suitable for smaller scale operations (individuals or small group of farmers) due to lower capital costs, greater utilisation of existing farm equipment and greater fuel storage flexibility.

The report ends by providing short summaries of all equipment tested and main trial recommendations.

### Wyatt, G (1998) Short rotation coppice harvesting: ground damage and yield effects, Technical Note 21/98

A series of studies were carried out to assess the ground damage and impact on yield resulting from short rotation coppice (SRC) harvesting on four trial sites across the UK.

Five different methods were used to carry out damage assessments:

- Pre and post working ground compaction measurement.
- Rut depths measurement.
- Soil pressure readings at 30 cm depth during working.
- Crop yield assessment (destructive sampling measuring odt/ha).
- Visual assessment of rutting damage.

The results showed that loaded trailers exerted greater ground pressure than the tractors towing them and that tracks exerted less ground pressure than wheels. Consequently, tracks caused less rutting than even low-pressure tyres. Rutting was linked to machine running weight, heavier machines causing more damage.

Ground compaction was found to increase with number of machine passes. On loam soil sites, heavier machinery caused greater compaction than lighter equipment. On the clay trial site there was no similar difference, an effect likely due to the plastic soil being pushed aside rather than being compacted vertically.

Further studies compared wheeled and tracked trailers and concluded that the tracked trailer performed better, creating less rutting and compaction.

Growth assessment one year after harvest on willow crop did not show a yield effect linked to ground compaction or stool damage. No conclusions could be drawn on longer-term damage.

The final recommendations were to minimise ground damage by using the lightest possible tracked equipment, optimise load size, and avoid harvesting during very wet periods.

## Supply chain

## McAllister, F. and Jones, D. (2007) Developing best practice guidelines to support local small to medium scale woodfuel production, Internal Project Information Note 18/07

This report provides an outline of the nature of the woodfuel resources in Wales and presents case studies of woodfuel production in mid-Wales at domestic/community, farm/estate and small-medium supply scales to provide guidance in the development of small to medium scale woodfuel production from Welsh woodlands.

Of the considerable potential woodfuel resource in Wales, little is used. Much of the resource is in broadleaved trees and farm woodland and there are practical constraints on its management for timber or fuel as well as constraints on development in protected areas such as National Parks.

There is a strong and well established demand for log fuel in Wales and the market for woodchip fuel is developing rapidly. Development of a woodfuel supply chain is still at an early stage however.

Cost and output data are presented for cutting and processing woodfuel in three case studies in the mid-Wales area; Llanbrynmair, Penpont and Corris. Costs were £32.57/$m^3$ for processed logs at depot for the Llanbrynmair study, £19.66-28.70/$m^3$ for woodchip at depot for the Penpont study and £8.08/$m^3$ for woodchip at depot for the Corris study. Discussion and costings of woodfuel transport and competitiveness relative to conventional heating fuels is also made, concluding that a delivered chip price of 2.8p/kWh is attractive when compared to oil.

Development of the woodfuel production systems studied had been driven by the availability of grant support, existing farm equipment and infrastructure, raw material supplies and local market developments, although there was a lack of connectivity between these drivers.

The systems studied were small-scale and made opportunistic use of cheap raw material. As the market develops the use of more specialised equipment will become necessary and raw material supply will have to be managed more efficiently.

# Contact

Reports detailed in this review can be acquired in two ways:

TNs are available directly on the web from TD website:

# Technical Development Woodfuel Research Catalogue 1998-2008

http://www.forestresearch.gov.uk/fr/hcou-4u4j9j

IPINs, INs and other report types can be provided on request from:

Forest Research
Forest Resources and Management
Technical Development
Ae village
Dumfries
DG1 1QB

TEL - 01387 860264 | FAX - 01387 860386 | EMAIL - tdb.ae@forestry.gsi.gov.uk

Reference 500S/36/09

Reports generally describe findings of case studies and the findings should be taken as limited to the studied context. The list of products/manufacturers in this report is not comprehensive; other manufacturers may be able to provide products with equivalent characteristics. Reference to a particular manufacturer or product does not imply endorsement or recommendation of that manufacturer or product by Forest Research.