FUEL-WOOD FROM UNDERMANAGED WOODLAND

ETSU B/M4/00487/30/REP

Contractor
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Fuel-Wood from Undermanaged Woodland

Final Report

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Summary

This report examines the potential for the utilisation of currently undermanaged woodland for supply of wood fuel. The potential markets for wood fuel are identified, along with their requirements in terms of fuel specification. Woodland resources currently receiving little or no management are identified, concentrating on broadleaves in lowland Britain. The nature of these resources is discussed, and opportunities/constraints for their management reviewed.

Machinery suitable for these woodland areas is discussed, and the application of this equipment into practical systems is examined in some detail. These themes are developed in two case studies, resulting in a discussion of findings and a range of conclusions.

It is believed that potential exists to extract chipped wood fuel form existing unmanaged woodland areas from £25/gt upwards, including standing value and contractor profit.

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Glossary of Abbreviations

a .... annum, year

Census .... Forestry Commission Census of Woodlands and Trees.

CV .... Calorific value: energy content of a fuel

GJ .... GigaJoules (10^9 Joules)

gt .... Green tonnes: tonnes of material as found, without artificial drying

hp. .... Horse power (1 hp $\approx$ 0.746 kW)

ha .... Hectare, 10,000 m^2 ($\approx$ 2.47 acres)

kW ....kiloWatts (10^3 Watts)

m.c. .... Moisture content (wet basis)

MW .... MegaWatts (10^6 Watts)

MW_{th} .... MegaWatts of *thermal* power

NFFO..Non-Fossil Fuel Obligation

ob ....Over bark: measurement gross of bark thickness

odt ....Oven dry tonnes: mass of material other than water

pa ....per annum

pmh ....Productive machine hour: time during which machine is actually available for work, with operator

PTO ....Power-take-off: drive shaft providing power to implements

TDOB ....Top diameter over bark (smallest diameter for one market)

YC ....Yield class (tree growth rate, units m^3/ha/a)

1. Introduction

It is widely recognised that much woodland is under-managed, this being due to a lack of viable markets for its produce. Such woodland is often the product of many years of man's intervention, for example the case of traditional coppice, and in the absence of this intervention is progressively changing its character. In part due to a recognition of this, and in part due to a desire to revitalise the rural industries associated with such management and to stimulate the concomitant employment, initiatives are being mounted in many areas to encourage the management of neglected woodland.

Coppice and other woodland work was a major source of employment in many rural areas, and provided welcome extra winter work for farm workers. Whilst a return to such conditions is patently unrealistic, any renewed activity in what were once major uses of labour will have some effect on rural employment.

Wood fuel can represent a very significant market for the lower grade products resulting from the management of currently neglected woodland areas, and was a major outlet historically. The harvest and sale of firewood is widespread, but represents an amenity-value market with consequent high unit energy prices. To develop a broader market with volume sales, lower price harvest strategies with the potential to provide realistic alternatives to fossil fuelled heating are required. The opportunity exists for this where the need to manage the woodland for amenity or environmental purposes has been recognised. In such scenarios the full cost of harvesting the wood fuel *may* not be reflected in its price.

This report examines the potential of currently undermanaged woodland to supply fuel by the following steps:

1. Identification of markets: what type of organisations could use wood fuel from these woodlands, and what will their fuel requirements be.

2. Identification of resource: what is the nature of the woodland resource available

3. Management opportunities and constraints: what is and is not possible in the way of management for wood fuel

4. Availability of suitable equipment: what machinery is required to extract and process the wood fuel

5. Systems of Work: how can the equipment be assembled into working systems in order to perform the necessary processes

6. Costings: case studies examining the costs of wood fuel harvesting systems form undermanaged woodland

2. Market Potential

The sectors of the energy market where wood and straw can make a substantial contribution in the medium term are as a domestic/commercial fuel replacing coal or oil, or as an electricity generation fuel under the Non-Fossil Fuel Obligation. The latter option is being very actively pursued by industry, due in no small part to the efforts of ETSU, however uptake of biomass *heating* in the market-place has been slow, despite its potential attractiveness.

The underlying potential for biomass as a source of energy for space heating is well known. This has been identified in "Sustainable Development - the UK Strategy" (p.133), and in "Climate Change - the UK Programme", sect 3.21.

In 1991, out of 109.7 Million Tonnes of Oil Equivalent (MTOE) of non-transport energy used in the UK, 45.9 MTOE, excluding electricity, were used in the domestic sector. Thus about 40% of the non-transport, non-electrical, energy used in the UK is in the form of oil, coal and gas for domestic, most probably space-heating, purposes. Thus the potential market is vast, even if market penetration were limited and only in rural sites.

In the absence of many district heating schemes in the UK, the continental-style large-scale use of biomass for urban heating is unlikely, but will rather be in dispersed, or small cluster installations, in rural areas where fuel supply is close-at-hand. In addition, there are many municipal/commercial properties with substantial space heating loads located in rural areas. Such properties include schools (state and private), colleges, hospitals, prisons. In addition process heat loads occur in rural areas, for example dairies, meat processors, timber dryers.

In a report of this type, it is impossible to give any accurate information on likely fuel prices: these are a matter for negotiation between the vendor and purchaser of fuel. However, for guidance it is suggested that for a fully commercial operation, it is necessary for the wood fuel price (£/GJ) not to exceed two thirds of the oil price (£/GJ). This margin provides for the higher operating and maintenance costs of wood fuel boiler plant, a provides a fair return on capital.

2.1. Market Requirements

In many instances *logs* are likely to form the most obvious and readily available form for wood fuel. Indeed, considerable areas of nominally undermanaged woodland are in fact worked to yield firewood. As a source of energy, firewood tends to be relatively expensive, however clear amenity benefits secure its place in the market.

It is possible to reduce the labour requirements of operating a log-fired system, however if wood chips are available, then considerable automation is possible. The chips are held in a bin or bunker sized to give a refuelling period that fits in with the whole system. An additional holding (*buffer*) store will permit the holding of seasonal stocks, and perhaps allow some degree of drying. An *outfeeding* system will gather chips from the base of the bin/bunker, and pass it to the boiler stoking system from where they are fed by auger into a combustion chamber. Here the intensity of combustion that is so important when burning wood is maintained by having a very small but very intense fire that burns continuously.

Output is controlled in this system by linking the auger, which feeds the fire, to the temperature in the heating system via a thermostat. Once the desired temperature is achieved, the auger switches off. From this point, it simply prevents the fire from going out by pulsing at a set interval until the temperature falls back and continuous running is needed again.

This type of automation is likely to be critical in any commercial application. Increasing the operation costs of wood-fired systems severely prejudices their viability. For this reason, any commercial system will require wood-chips as fuel.

2.1.1.Fuel Quantity

The following *guide* figures are suggested:

Farmhouse 20gt/a

Large country house/small mansion 100-250gt/a

Secondary School 150gt/a

College based in/around stately home 400-1000gt/a

Generally residential premises have far greater fuel requirements due to the need for longer heating periods and the substantial consumption of hot water. Schools have a short occupancy periods and have holidays at the coldest times of the year. Naturally, the above figures should only be used as a rough guide. For any specific sites, professional guidance should be sought to determine boiler size and predicted fuel burn at an early stage.

2.2. Fuel Quality

2.2.1.Particle Size

An ETSU report, number B/W3/00161/REP by FEC Ltd., reviews the practices and standards for wood fuel quality determination in several countries, covering both moisture content and particle size. The report progresses to suggest guidelines for UK wood fuel standards. Accepting the variations in plant tolerance, the recommendations are divided into three bands, relating to plant output.

Comments are then invited from fuel suppliers, users and plant/equipment manufacturers. FEC quite correctly state that oversize material and fines are likely to be the two limiting factors, intermediate size distribution being largely irrelevant: fines are defined as material under 3mm in size.

2.2.1.1. Standards

The British standard for wood-chips relates to children's play surfaces. It is awarded on the presentation and satisfactory testing of a sample. It is not a standard suitable for wood-fuel.

Danska Skoves Handelsudvalg (the Danish Forest Owner's Association Trade Committee) has produced standards for fuel chips, giving two grades. These are based on the grades commonly used in the pulp and particleboard industries. The finer of the two sizes is recommended for small heating plants ($<1mw_{th.}$). To check compliance with the grades, a sample of chips is first weighed, then manually inspected for slivers, which are removed. Slivers are defined as thin pieces of at least 100mm length. Subsequently, the sample is passed through a set of sieves, each sieve separating a fraction.

The separated fractions are weighed, and these weights expressed as a percentage of total sample weight. These results can they be compared with the standard shown to check compliance. Danish experience indicates that attempting to prevent the production of chunks and slivers is possible, but tends to increase the proportion of undersize chips and dust.

Various workers have made understandable attempts to relate chip size to the requirements of the utilisation plant. In many cases a distinction is made on plant output rating lines. Whilst some justification can be made for this, it is rather arbitrary, in that no distinction is made between the requirements of the different plant types existing at one size. In practice, particle size is not often specified in supply contracts, and plants are designed to accept the fuel which is delivered.

2.2.2. Moisture Content

Combustion plant is commercially available, and operating, on moisture contents of over 50%. As moisture increases, so must combustor design alter. The general trend is towards increasing amounts of refractory material, preheated undergrate air, and larger combustion chamber volumes. The cost of the plant may double over that required for "dry" (<25%) fuel, and a full economic analysis needs to be done on the merits of drying vs. more expensive combustion plant.

At the scales of operation likely for rural space-heating systems, fuel moisture contents at the boiler of no more than 50% are required, in many cases less than this. If the felling moisture content is higher than this, some degree of drying is clearly called for.

3. Potential Fuel Resources and Constraints

3.1. Resources

For the purposes of this report, the woodland types considered are those occurring all over lowland Britain: neglected broadleaf woodland and coppice crops suffering from a lack of markets. Whilst some coniferous woodland is doubtless undermanaged, this has not been considered, except insofar as the removal of conifers from e.g. larch/beech mixtures as part of a thinning process.

3.1.1. Neglected Broadleaf Woodland

In this section broadleaf woodland other than coppice will be considered: i.e. high forest, or approaching it. It must however be remembered that, as discussed below, coppice of the right composition can revert to high forest if left unmanaged for a sufficient period, and indeed much virtually has. If the coppice is not of suitable species, then it may revert to scrub.

Broadleaf woodland occurs all over lowland Britain, and much of it is unmanaged. Blocks under Forest Enterprise or estate ownership will tend to receive at least a degree of management. Similarly will woods managed by specialist companies. However, much woodland lies outside these categories. For instance, many if not most farms have at least some woodland area, much of which is poorly managed.

Even recently planted broadleaf woodlands can experience under-management, due to poor returns from pulp and other small roundwood outlets. This may be especially true as distance from the large scale markets, and hence transport costs, increase. In particular, the thinning operations needed to ensure a high quality final crop are often not carried out due to poor returns. These returns are constrained by terrain and access problems, and the frequent small size of woodland blocks.

Thinning is a multi-stage process widely practised in forestry. The prime objective of *commercial* forestry is to produce sawlogs, these being the most valuable bulk product (Veneer is a more valuable market, but *much* more selective). The sawmilling process requires straight logs, and the occurrence of knots is preferably minimised. To achieve this the trees are initially planted at high densities. This suppresses the growth of side branches, and hence knots, and forces straighter stems. After a period of growth, inter-tree competition begins to adversely affect the stem size of the trees. To ensure the development of quality trees, a thinning operation is conducted in order to reduce the stocking density. The first occurrence of this depends on the productivity of the site, the species grown, and other factors, and usually occurs from 15-25 years after planting. The exact timing is often set by the point at which the material being harvested is sufficiently valuable to justify the process.

The thinning process is generally repeated several times before clear-fell occurs. The products of thinning are usually pulpwood and, at later stages, small roundwood and occasional sawlogs. Practical considerations and the increase in handling costs limit the separation of the crop into fractions (other than *sale* and *residue*), and the low value of the saleable products in relation to the costs has inhibited thinning operations for many woodland owners.

Were reliable local markets for the material produced during thinning operations in existence, then the potential would exist for more regular thinning to occur. This has been recognised on some estates, e.g. West Dean (q.v.). Anecdotal evidence from many sources suggests a significant backlog of thinning exists in many areas, due to the poor economics of the operation. Thinning for fuel-wood would be less quality sensitive than for pulpwood, and would not require the separation of species and dead trees.

3.1.2. Neglected coppice

Historically, large woodland areas were managed by rotational cutting, or coppicing. Many broadleaf species regrow well from a cut stump (the *stool*), producing several stems. In time natural competition will cause the death of some stems, and the progressive reversion of the coppice to high-forest or to scrub, dependent on composition. The process of conversion to high forest can, and has been, accelerated manually by selectively removing stems to leave one per stool, as a means of improving the timber value of such woodland. It must, however, be remembered that such timber will never be of the quality that properly managed broadleaf plantations will achieve: in particular the swept butts of coppice-origin sawlogs is a problem.

The neglect of much coppice woodland has indeed caused the natural reversion of large areas from coppice to high forest or to scrub. Such sites may often be amenable to re-coppicing, however the butt diameters of many of the stronger stems can cause chipping difficulties. However, ash, in particular, may yield a proportion of high-quality stems suitable for saw-milling. Such stems should be marked prior to the felling operation to ensure that the are left standing for later harvesting, and not felled and chipped.

Historically, much hazel was managed on a coppice system. The markets were specific for e.g. thatching spars and split stems for wattles/hurdles. When left unmanaged for over 50 years, such hazel coppice degenerates and becomes worthless. Additionally, hazel produces a very large number of stems when coppiced, making harvesting and extraction potentially costly for a given volume.

The lack of management of coppice has resulted in a large volume of material being stored, beyond that which would be expected on the normal rotation. The effect of this will be felt during the first harvest ion two ways:

1. The yield of material will be considerably over that on a normal rotation

2. The maximum diameters will be larger than on a normal rotation

The first harvest may well approximate to a premature clear felling operation of broadleaf forest, with subsequent harvests being of more typical coppice material. In some areas, schemes to restore coppice woodland have found that the high yield of material justifies the clearing operation, whereas later rotational management is harder to justify. A coppice system specifically or mainly for fuel-wood could perhaps nowadays be managed on a longer cycle than was the case historically.

The commercial working of coppice is not widespread nowadays due to the low overall value of the produce: it is analogous to perpetual thinning system that yields no high value sawlogs. As the traditional high value markets for coppice material, such as hop poles for sweet chestnut and hurdles for hazel, have decreased, the only markets remaining are for lower value pulp and firewood. As discussed earlier, the poor economics of thinning results in its not being carried out in many instances. Thus the economics of coppice operation can be presumed poor in areas where thinning of broadleaves is considered to be of low viability.

Of the remaining commercial coppice crops, the most important in recent years was sweet chestnut, in Kent and East/West Sussex. One traditional market was hop poles, however more recently fencing stakes and pulp were major markets. The loss of the market for pulp near Sittingbourne has resulted in extended haulage distances and concomitant high costs.

Hazel coppice was worked on a fairly short rotation of 6-12 years for hurdles, thatching spars and many other purposes. The hurdles were used for penning sheep on the chalk downs. When allowed to grow on for longer, it becomes unsuitable for its normal markets, and due to the large number of small diameter stems is unattractive to harvest for chip or pulp. If left uncut for over 40 years, the stools start to die. Recognising this, Hampshire County Council has been making coppice restoration grants for some time. Fuel-wood opportunities from hazel coppice arise principally from this restoration phase. Longer term uses are due to a revival of interest in hurdles for garden fences, and the demand for 15-20 million thatching spars per annum.

3.1.2.1. Coppice with Standards

This is a two-storey forest, with large timber trees growing from an understorey of coppiced species. Historically a very widespread management (and once compulsory!) system, typically 30-100 trees/ha are kept as standards. The most common standard is oak, representing 95% of standards in the 1979-82 *Census*, being found widely over sweet chestnut, hornbeam and hazel.

The presence of standards alters the economics of the coppicing operation, for to get a high value sawlog crop, the coppice must be prevented from competing with the standards. Immediately after coppicing of the understorey, oak standards will show an increase in growth rate. Additionally, subsequent to sudden changes in light levels, such as when clearing stored coppice, oak has a strong tendency to develop epicormic shoots (lateral shoots up the trunk), which have the potential to greatly devalue the sawlogs due to the presence of knots. Thus there is a considerable incentive to manage the coppice underwood on a consistent basis.

The shading from the overstorey must be managed in order that the understorey does not die out. It is important not only to consider the number of standards per hectare, but also their spread, and thus the total shaded area/hectare. It has been suggested that overstorey shading should be c. one third canopy closure at the commencement of a coppice rotation, and c. two thirds at the end. Naturally, the coppice cut provides the opportunity to thin the overstorey. Leaving a minimum of 10% overstorey cover will preserve some of the visual amenity of the site.

3.2. Constraints

The opportunities identified above are inevitably subjected to various constraints. Much broadleaf woodland provides significant habitat potential, which must be considered when developing a sustainable fuel resource. Additionally, a range of practical constraints must be considered. These points are dealt with below:

3.2.1. Nature Conservation

Coppice management was practised for many centuries in much of England's lowland woods. The application of this system probably contributed to the survival of a wide range of species that would otherwise have been lost during the widespread deforestation of the country. A significant factor in the success of coppice for this purpose is the wide range of growth stages, and the guaranteed repetition of conditions over many years (assuming constant management).

The coppice system, by virtue of its inherent diversity, permits the survival of many species within a small woodland area. Neglect resulting from economic and social changes in the later 19th and early 20th centuries resulted in the loss of many species, and a progressive change in the woodland towards high forest. Some areas of former coppice are suitable for restoration: Kirby (1992) suggests that from a nature conservation viewpoint, c.18,000 ha of ancient semi-natural woodland could be brought back into coppice cycles, using the following selection criteria:

1. The wood should have a history of coppicing, and should have been cut during this century.

2. The region should be one where coppicing was a common management technique

3. Select woods that yield a diverse ground flora after cutting

4. Select woods with a diversity of tree species that will be favoured by coppicing

5. Use coppice restoration to maintain large stools (1-2m diameter or 0.75m high)

6. Use coppicing to maintain open grassland, scrub or heath when these have been lost from the surrounding landscape

7. Do not restore coppice where the wood has developed so far into the high forest stage that much of the species will be lost by coppicing: e.g. wood decomposers needing dark and damp conditions

Generally, coppicing is a more favoured system in the South and East, whereas high forest is preferable in the North and West. There are definite exceptions to this, however.

The great potential for wildlife conservation by the use of coppice management also implies a great risk of lost potential due to bad practises. Kirby, 1994 identifies the following areas of potential concern:

1. The scale of the operation

2. The state and nature of the wood

3. Coupe sizes and layout

4. Time of cutting

5. Extraction Processes

6. Deer Management (see below)

7. Monitoring and control of the work

Detailed proposals by the same author may be found in the appendices.

Whilst harvesting of entire tree volume has attractions, in that it yields a 30% increase in harvested biomass, there are significant concerns about removal of excessive quantities of organic matter and nutrients.

3.2.2. Practical Constraints

In addition to the above nature conservation constraints, there exist a range of practical constraints:

1. Once the sap rises in the spring the moisture content of the timber will rise, falling again in the autumn

2. Throughout the summer, the tree will be in full leaf. If the tops are collected with the fuel-wood, much moisture will also be collected. Chips containing leaves degrade rapidly.

3. Notwithstanding the above point, felled trees in full leaf will continue to transpire, and being disconnected from their source of water via their

roots, will dry out considerably prior to death. This suggests that trees felled in full leaf should be left in-the-round to dry.

4. Many undermanaged woodland sites are very wet, even in summer. Sites on broad ridges can often be on deep clay, and with little fall, drainage is poor. The wetness is often a major factor in the wood having survived agricultural clearances

5. Access both to and within the wood may be poor:

    a. Rides may be non-existent or poorly located.

    b. Rides often are of unimproved soil with poor drainage, hence having low trafficability

    c. Woodland may be well off public and even farm roads, with consequent poor access

    d. Access to many farm woods/copses may only be across stubble fields between harvest and autumn cultivations

6. Some sites may be located on steep slopes, where a combination of gradient and poor soil precluded agriculture.

Such constraints will often act together to limit the period for certain operations. For example, if access is only across stubble fields, then carting of produce can only occur during late summer/early autumn. To avoid summer felling disturbing nesting birds, felling would occur during the previous winter, the produce being stacked at rideside for summer carting. If the woodland floor was too wet in winter, then summer felling would be compulsory. Such compromises are likely where sites have many constraints.

The constraints on sites will limit the operational processes and systems suitable for each site, and inevitably this will impinge on the viability of working many sites.

3.2.2.1. Deer

Deer are widely active throughout UK woodland. They find the tender shoots that appear after a coppice cut especially palatable, and will seriously endanger the coppice regrowth. Deer control of some type is essential, however fencing can be expensive. A traditional method is to use the lop and top from the coppice cut to hedge the edge of the coup, or to scatter it across the site. Such measures make it uncomfortable for the deer to move about the site. Wigwams of sticks over each stool are thought ineffective, as once regrowth occurs the tender tips of the shoots will appear though the wigwam and be bitten off by the deer, who can reach in from the side.

It must also not be forgotten that sheep incursion causes much damage to woodland, and effectively prevents any natural regeneration on sites where such stock have access. For this reason, it is critical that sheep be excluded.

A basic deer fence, using local materials and a single height of wire netting could be erected for as little as £3/m. The netting would be suitable for reclaim and re-use once the coppice had grown above browse height in 2-3 years. A permanent deer fence would cost £5-8/m, if erected by contractor.

3.2.3. Shooting

Perhaps the most significant use for undermanaged broadleaf woodland is for game shooting. This may range from rough shooting of wild game birds to highly organised syndicates or corporate hospitality operations. Whilst this is not a treatise on game shooting, a few points may be mentioned:

1. It is usually desired to maximise the holding capacity (birds/area) of a woodland block. This will be achieved by having dense cover.

2. A preferred management practice is to cut broad rides through dense cover to permit shooting of birds leaving the cover

3. Unbroken highly congested neglected woodland is likely to offer sub-optimal shooting

4. Diverse habitats with plenty of internal edges, areas of deep cover and more open areas for shooting stands are probably desirable

5. For the reason above, traditional coppice offers good game potential, however the coupe size optimal for game cover may be rather smaller than is optimum for economic harvesting.

It may be seen from the above points, that whilst there is some coincidence of requirements between woodland management for game and for fuel production, the details may differ considerably. Notwithstanding this, woodland managed for fuel will offer superior shooting to totally unmanaged woodland, and thus a compromise must be reached.

3.2.4. Management Payments

Where site owners are highly constrained by environmental factors, payments have been made on an agreed management plan basis. Such payments are most likely where the site is classified as a Site of Special Scientific Interest (SSSI), and will assist with defraying the additional costs incurred by constraining operations, for instance not felling at certain times of year. It must be acknowledged that such a mechanism is critical in order that such woodland areas do in fact receive management. The returns from such payments can be credited against the costs of a wood fuel operation, and will assist in reducing their level.

Naturally, it is not possible to quantify such payment here. The advice would be that if individual woodland owners feel constrained by external factors, they should attempt (with professional help if necessary) to negotiate some form of compensation.

4. Processes

The processes discussed here are those of felling the fuel-wood, extracting it from the felling site, converting it to chips, storing and delivering it to the burning site (not necessarily in that order). These processes can be assembled into a range of operational systems to suit particular site conditions and other requirements. This section reviews various options at each stage in the process, and discusses how these interact with each other, and concludes with reviewing a selected number or operational systems.

4.1. Felling

The process of felling initiates the fuel-wood harvesting process by detaching the stems to be felled from their roots. Prior to this it is often necessary to clearly mark/identify any stems to be retained, such as:

1. Standards to be retained until maturity (if in cycle), or initiated (if under restoration);

2. Timber trees for later felling;

3. Any trees to be retained to senescence for conservation processes.

If high-grade labour is available, then feller-selection of trees to be felled or retained offers a significant reduction in management costs. Such systems have found favour on estates with committed in-house staff. The felling options are as follows:

4.1.1. Motor-manual

Motor-manual felling is perhaps the most flexible system, adaptable to most situations. In some cases, however, further mechanisation will lead to reductions in costs. However, this mechanisation will require sufficient work to justify its purchase, and will not be suitable for many coppice types.

Motor-manual felling involves the use of a chainsaw and operator to fell the crop. Motor-manual felling gives the option of felling in advance of subsequent operations. This can permit higher work rates of these operations, and can also provide an opportunity for drying *in the round*. Some woodland managers prefer to see the felled timber extracted very shortly after felling, to permit up-to-date records of volumes to be cut.

A rough *guide* cost for a motor-manual *shortwood* (see below) operation is £6-8/gt using contractors, and £4-5/gt using in-house labour, including snedding (removal of branches), crosscutting and stacking of products. A *tree-length* system might reduce this to £1-1.50/gt. Such figures are based on anecdotal reports of practical experience in these types of woodland, and thus should always be verified locally.

4.1.2. Felling-head

The felling head is a combined grab and chainsaw available in various sizes. It is mounted on a crane and controlled by an operator on a base machine, such as an agricultural tractor or a larger forest machine. Whilst the felling head is capable of fast workrates, there exists a danger with multiple stems of pinching and chain damage. As the operator is located in a cab remote from the cut, he may have a poor view in congested situations.

When cutting stored coppice, it has been suggested to cut high as single stems, and then to cut the combined base off in one cut as a subsequent operation for firewood (logs). This also has advantage that the very large butt-end diameters do not enter the chipping system, though this option may not be practical from the log merchant's point of view! It is considered by some in the industry that the felling head may not be well suited to neglected woodland situations. Indeed, in uniform conifer crops, trials have indicated parity between the overall costs of felling heads and motor-manual systems.

4.1.3. Other Operations

The felled stems may be:

- De-limbed (usually, but not necessarily), cross-cut into the poorest size specification, e.g. 2-metre lengths, *(shortwood)* and extracted thus, or
- Extracted entire as *tree-length/tree section*, or
- Chipped at the stump

4.2. Extraction

Felled material requires extraction from the felling area. Tree-length or tree-section material may be *skidded* - essentially dragged, and tree-section/shortwood *forwarded:* carried on some type of vehicle.

4.2.1. Shortwood

After cross-cutting into shortwood lengths, the crop requires removal from the felling area. This will normally be achieved by stacking them on some type of vehicle and carting out: *forwarding*. The term shortwood can cover a wide range of diameters and lengths of material. It must be remembered that chippers will give the best utilsation on longer feed material, and this combined with thge reduced crosscutting should encopurage the use of longer material than has conventionally been the case. This point is discussed further below.

At its very simplest this could mean manually loading a pickup or trailer with 4-foot cordwood, though the low workrates implicit in this type of system suggest firewood type operations, with low capital outlay but high capital costs. Such systems are, however, widespread and depend on a premium *amenity* price for their products.

In the mid range are various options using agricultural tractors hauling forwarding trailers, a hydraulic crane being mounted either on the three-point linkage, the trailer drawbar, or in specialist conversions, directly on the tractor. Such units are cost-effective and popular on estates, and for smaller contractors. If insufficient work is available to keep the tractor occupied for the whole year, then the possibility exists for use for farm work at some periods. This offers the possibility of spreading costs further than would otherwise be the case, though other uses of the crane and trailer may be limited.

At the sophisticated end, a 6- or 8-wheel drive self-propelled forwarder, using its hydraulic crane to self-load, is the popular option. Such machines are used by larger contractors, and being purpose built have both high workrates and high capital costs. They thus must be kept occupied for a considerable period per annum. In their costings, the Forestry Authority commonly use a figure of 2000 productive hrs/annum for such machines; however this would be high for agricultural-type machines on estates.

Conventionally, shortwood systems operate to a fairly rigid length specification. There may be advantages in relaxing this specification for situations such as where the product is chipped before dispatch. It must be remembered that the efficiency of work of the chipper will increase as pieces become longer, as fewer need to be loaded per tonne chipped. Some imagination will be required regarding working practices, however systems with a variable length of 3-5m have worked successfully. In these cases the feller cross cuts to a top diameter, provided this lies between 3 and 5 metres length, rather than compromising top diameter to maintain length. such systems are well accepted in Sweden.

4.2.2. Tree-length

Instead of cross-cutting at the stump and extracting as shortwood, potential exists to extract either the whole tree, or a least long lengths of roundwood from it: *tree sections*. The costs of snedding and crosscutting are avoided: see motor-manual felling above. The latter can be handled by forwarder as above, or as described below for tree-length. The main constraint on the former option will be the difficulty of stacking at rideside when compared with shortwood.

Whole tree harvesting systems have been promulgated by various workers. In the contexts of previous work these have been defined as systems where an energy component of a crop is harvested in conjunction with conventional roundwood products (sawlogs/pulp). The whole tree is felled and extracted to a suitable site for further processing, in one operation. At this site the tree is separated into its fractions (Mitchell 1993).

In the context of undermanaged broadleaf woodland, it is conceivable that whole tree-lengths could be extracted for chipping in their entirely at rideside, provided that this had comparable viability to the production of pulpwood. In this case, no conventional timber products would be produced. This operation can be termed *whole tree comminution (landing system)*. De-limbed tree-lengths of high quality broadleaf timber are often extracted thus for sawmilling, being too large for forwarding.

Tree-length systems must be applied with care in thinning operations, where damage to the standing crop must be avoided: broadleaves have much stiffer branches than do the conifers where this system has been particularly used. They may thus be more suited to coppice coupes or to clear fell of high forest. Tree-length material is difficult to stack at rideside, and will probably need to be chipped immediately after extraction to prevent a very congested situation arising. If it is desired to make use of the opportunity for transpirational drying, this must be carried out at the stump, with a delay between felling and extraction.

4.2.2.1. Equipment

Tree-length timber is commonly *skidded*: i.e. dragged off-site by a tractor of some sort. An agricultural tractor plus chain is capable of skidding timber, however there is no provision to prevent the timber overrunning when going down a very steep hill. Small grapples that mount on the 3-point linkage are available, and these have the advantages of direct control and a degree of weight addition onto the rear of the tractor, improving traction and reducing the drag from the skidded material. Such equipment is best suited to smaller diameter material, such as coppice, and smoother sites. It will thus be common on small estates.

For larger material, skidder winch conversions of four-wheel-drive agricultural tractors are available, moving on to purpose built frame-steer skidders. Such units normally have twin drum winches, and are fitted with buffing plates on the rear, which prevent timber overrun. Dependant on timber size, several lengths may be skidded, each being attached to the winch rope by means of chain chokers (which tighten around the timber on pulling). Fitting a fibreglass cone over the failed of the winch gives tight bunching of multiple stems, minimising snagging.

More recently, clam-bunk skidders have become available, which are often based on all-wheel-drive forwarder chassis. These units carry a grapple crane and have a pair of hydraulically actuated jaws on the rear chassis. The operator loads the jaws with the butts of trees, closing the jaws whilst moving between collection points. Thus half or more of the tree weight is supported on driven wheels, offering good traction. One manufacturer has recently developed a small version to trail behind an agricultural tractor, which is probably more applicable to undermanaged woodlands than are the larger self-propelled clam-bunk machines. Fitting a felling head to the crane on a clambunk unit gives a *feller-clambunk* machine, capable of felling and extracting trees.

4.3. Chipping

4.3.1. General

Three major chipper types are available:

- The drum chipper
- The disc chipper
- The conescrew chipper

The limited infeed area of the disc chipper makes it more suited to chipping whole trees or logs, where it gives a more even chip size than does the drum chipper. It also has a tendency to allow the final portion of a log to rotate through 90° and pass through unchipped. The drum chipper is better suited to random presentation and to branched material.

The conescrew type is made by only one manufacturer, Sasmo, and is available in a variety of sizes. It uses a tapered screw with a sharp edge to draw the material in, and to shear it against an anvil block. A range of screw pitches are available, giving products from fine chips to large chunks.

For more detail, see Landen 1994.

4.3.1.1. Workrates

Trials work by Aberdeen University has given indicative work rates as follows:

Whole tree chipping in hardwoods:

Tractor powered chippers: 1.75-2.25gt/pmh

Heavy duty trailer mounted chippers: 3.66gt/pmh

Lorry mounted chipper..8.23gt/pmh

Silvatec...8-21.41 gt/pmh

Whilst hand loading of a chipper is possible, to keep even a smaller-sized machine fully loaded is a strenuous task for two men. The addition of a crane will often reduce gang-size to one, and will increase chipper work rate. Manual loading could be seen as a reasonable alternative to hand burning of tree-felling waste on smaller estates, however any serious wood fuel operation will use crane-fed chippers.

4.3.1.2. Capacity

It must be remembered that the amenity type chippers used by tree-surgeons etc. are not designed for continuous heavy-duty forestry work. Whilst they have apparently reasonable nominal diameter capacities, operating at these values for long periods will result in premature wear of the machine, and the risk of blockage. General advice from chipper suppliers is to select a chipper with a nominal diameter capacity 30% greater the average large piece in the feedstock.

Chippers are designed for chipping green, or at least fairly green, material. If dry wood is to be chipped, a considerable increase in power requirements and wear rates is to be expected. Anecdotal evidence suggests that the maximum diameter capacity of a chipper *may* be reduced by a factor of two when chipping fully air-dry roundwood. This is more likely to be a critical factor in the lighter, amenity-type machines rather than the heavier units.

4.3.2. At the Stump

This operation could be carried on in conjunction with mechanised felling, or by a second pass:

4.3.2.1. Self-propelled

At a sophisticated level, specially built harvesters such as the Danish-built *Hafo* and *Silvatec* machines can be used for collecting material from the thinning process. These units have the chipper throat below the cab facing forwards. A hydraulic crane is fitted, which the operator uses to feed the chipper. If this crane is fitted with a *felling head* (see above), then the harvester can be used for line-thinning work in a one-pass operation.

The disadvantage of a one-pass operation is the high moisture content of the material at time of felling. If this is anticipated as a problem, then felling would be undertaken manually, and the felled trees left to lose excess moisture before chipping. This method also has the advantage of permitting a higher harvester work rate, by 20-30%, though overdrying can be a problem in the summer. The fellers must drop the trees so that the butt ends are presented to the advancing chipper.

These machines can also be used for the later selective thinning operations, on a similar basis. The increasing mechanisation of the thinning operations is likely to result in whole trees being chipped for fuel in many instances. Prices in the pulpwood and small-diameter roundwood markets have often been far from buoyant, sometimes not covering the cost of conventional labour-intensive shortwood thinning techniques which only harvest a small part of the felled trees, therefore highly mechanised operations gathering the whole biomass yield may make thinning for fuel an attractive option.

In Aberdeen University trials (ETSU B1273 *Whole tree harvesting Systems for Wood Fuel*), the *Silvatec Chipharvester* achieved the following performance in softwoods:

Tree Size m^3 ob.	Work rate gt/pmh	Costs £/gt
0.02	16.97	3.96
0.03	10.15	6.62
0.08	10.85	6.19
Average	12.66	5.59

The fall-off in performance with increasing tree size may be due to a power limitation: this is referred to in the description of the harvesting trials. *Most* chippers show an increase in performance with increased tree size, due to lower demands on the feed crane system.

In hardwoods the following performance was recorded:

Tree Size m^3 ob.	Work rate gt/pmh	Costs £/gt
0.05	8.00	8.34
0.1	21.41	3.14
Average	14.7	5.74

The fall-off in performance is not apparent in this case. Anecdotal evidence suggest that these machines work well in 6-9" diameter material, though they can cope with occasional 12" pieces with a fall in output.

Some reservation has been expressed about the suitability of such machines for broadleaf wood land. They are probably suited to well-organised hardwood and mixed stands, where the crop is in clear rows. They are probably too cumbersome for situations where stumps/stools occur randomly, with a high risk of punctures. Thus recently planted coppice may be a more attractive proposition than very old coppice. The onus is on those performing the felling to cut the stumps to a height and shape to do minimum damage!

Notwithstanding this, significant areas of coppice in the Weald of Kent/Sussex are worked using such a system. The coppice is motor-manually felled in the spring at or around bud-burst, and left to dry over summer. Chipping is undertaken in the late summer/early autumn before the ground becomes untrafficable.

4.3.2.2. Terrain Chippers

These machines consist of a six- or eight-wheel drive articulated chassis, with cab and engine on the front half. The rear body would originally have mounted a bolster body for carrying of roundwood, with a hydraulic loading crane to load the timber.

The units have been modified, where a chipper and engine replace the bolster body, along with a high-tip bin. A hydraulic crane is used by the machine operator to feed the residues into the throat of the chipper, which extends to one side of the machine. A hydraulically-driven conveyor drags the residues into the feed rollers of the chipper. These control the feed rate of material into the chipping mechanism, and hence the chip length.

These machines have drum-type chippers, driven by an independent engine, though hammer-mills drums have been trialled. The chips are blown by the chipper through a discharge spout into the rear bin. When this bin is full, the operator will back up to a $35m^3$ bin and discharge the load.

Such machines are successfully used for chipping of residues from conifer clear fell, on relatively easy terrain.

4.3.2.3. Tractor-Mounted

At a less specialised level, an agricultural tractor could be fitted with a chipper and crane, with or without felling head. The chips would either be discharged into a trailer drawn by the tractor, or into another trailer.

This system offers the possibility of a one-pass operation at a small-scale, with the option of motor-manual felling ahead of chipping as described above. If the tractor/trailers are shared with other operations, then these costs are spread beyond the wood-fuel operation. The chipper is likely to be bespoke, though the crane may be used for roundwood loading at other times.

4.3.2.4. Systems and Constraints

Chipping at-the stump implies transporting a chipper and power unit, as well a the chip transport system, to the stump. As discussed earlier, the wet nature of many neglected woodland sites will result in low trafficability of the soil. Whilst it may be possible to reduce the chipper unit ground pressure (this being predictable), the trailer is potentially more difficult, the loading varying widely. Due to the need to chip when *not* in leaf (q.v.), it is likely that sites may be wet. Some type of working system will need to be evolved, where either the tractor, chipper and trailer leave the site to unload chips, or where a separate tractor collects full trailers, exchanging them for empties. In either case a risk of low machinery utilisation, and thus higher costs, exists.

With specialist self-propelled chippers, the base unit normally carries a high-tipping body at the rear of the chassis. When this is full, it tips into a tractor/trailer combination, which conveys the chips to hard rideside, tipping into the final transport, often c.35m^3 roll-on/off bins.

Power available from tractors will be a limiting factor regarding chipper work rate and maximum diameter capacity. A six-cylinder four wheel drive tractor will muster 100-120 bhp at the engine, giving perhaps 85-105 hp at the PTO. Whilst larger tractors are available, they are significantly more scarce, and will be found clumsy and heavy in a woodland situation.

Trailer chippers might have 200+ hp., and thus greater capacity, and the only way to get this power to the stump is to use a forwarder mounted chipper. Such units are well suited to conifer clear-fell sites on easy terrain, but not to wet or rough conditions, and may be found large, heavy and clumsy in some neglected woodland. If such equipment were required, then it would be highly desirable to select a low-ground pressure forwarder unit as the base: the chipper/bin being independent from the forwarder chassis. An eight-wheel drive bases unit with suitable tyres would tend to do less damage off-road than an older six-wheel drive unit.

If at-stump chipping is being considered careful evaluation must be made of the nature of the site, and the effect of the proposed traffic on the soil structure. It must also be remembered the wet conditions will cause movement difficulties, and potentially bogging of machinery, incurring extra costs.

At-stump chipping is probably best suited to rotational harvest of coppice, rather than to the special conditions obtaining when bringing such areas back into management, and to the thinning of broadleaves/mixtures. Concerns have been expressed regarding the *excessive* removal from the site of biomass, and hence nutrients, when the crown is chipped. Despite this, many woodland owners wish the sites to be left clear of lop and top, especially where shooting access is an important consideration. A compromise option would be to flail delimb at the chipper infeed, with all the branch/leaf material being returned to the forest floor or sold as mulch. Such an option will require the development of a low cost flail delimber, which does not need to produce to the whitewood product specification applying to the current machines.

4.3.3. At rideside

Following extraction as shortwood or tree-length, the fuel-wood may be chipped at rideside. This option can have advantages in that opportunity exists for buffer storage, especially of shortwood, between extraction and chipping, unless direct chipping is opted for. The former permits decoupling of the extraction operation and the chipping operation, and also allows drying to occur *in-the-round*. A disadvantage is that stacking/unstacking equipment and labour will be required. Also, the chipper requires loading, unless this operation is undertaken by the forwarder crane in a shortwood direct chipping system. If this forwarder is not available (e.g. if the system is tree-length, or if extraction by forwarder was contracted out), then a crane, operator and base unit will need to be costed in. A self-loading chipper complete with crane would be the popular option.

Large chippers may be hired in for the required period, these being capable of taking large-diameter material, being powered by an engine of 150-250 hp. Such machines often have a feed table onto which the wood is placed by the crane. Thus the crane is freed from the feeding operation, and can return to the stack for the next load, improving productivity. A smaller estate/contractor owned machine will be less capital intensive, but will also have lower work rates/diameter capacities (see note regarding amenity machines above). To fully utilise the capacity of a large machine it is critical that an uninterrupted supply of feedstock is available. This can only be achieved by either very high - probably unreasonably so- extraction rates, or by stockpiling material adjacent to the chipper site. The latter options provides buffering, and will be much more workable than the former. In the case of skidder extraction, stacking is not possible, suggesting in the case of clear fell, extensive areas of long material which must be gathered. Conversely, a skidder extract rate is reasonably close to a smaller chipper work rate, so this system may be more feasible. Additionally, it is necessary to confirm that the infeed mechanism of the chipper is capable of sustaining the necessary feed rate on the raw material under consideration: it may be optimised for another raw material type.

It is suggested that large capacity chippers are best suited to chipping pre-stacked shortwood from thinning or clear fell, or less appropriately to chipping skidded thinnings. In the former case, the product specification will affect the chipper workrate: smaller stems sizes being more demanding on the crane, operator and feed system. In the latter case, however, the chipper will need to move along rides to gather material, requiring it to be trailed behind, probably, the crane tractor. Similarly, the chip carting trailers must follows the chipper along the rides, increasing the damage potential; however, this damage will be restricted in area, and in chosen/predictable places.

It must be remembered that skid/clambunk systems will cause a fair degree of soil/stone contamination to the bark, and hence risk of chipper damage. If the end combustion process is tolerant, then a shredded or hammermilled product may offer advantages of a chipped one. However, whilst power station sized plant can, most smaller combustion systems will not accept such material.

4.3.4. At-plant

The potential exists to locate the chipper at the utilisation plant, with roundwood being delivered to that site, the chipping approximately following the demand for fuel, rather than the felling pattern. A particular advantage is the relative ease of achieving a payload of roundwood as compared with chips. If chipping is undertaken at the utilisation plant, then the scope for alternative utilisation of the chipper may be limited. Additionally, harvesting and extraction is likely be constrained to a shortwood system, due to the need to stack for longer-term buffer storage, with relatively high costs for these stages.

At-plant chipping will, as with any of the other chipping locations, require a chipper of capacity adequate for the largest diameters occurring, which may imply quite a sizeable machine. Such a unit will inevitably have a throughput capacity in excess of that needed for the fuel burn of that plant. The unit will thus suffer form low utilisation, with concomitant high capital costs per tonne chipped. The chipper will be based on a drum/disc machine, perhaps with a power-feed log table.

If a large chipper is hired in for a short period, then either roundwood must be stockpiled at the utilisation plant, or arrangements made to transport it to the utilisation plant at a rate to match that of the chipper, which may prove difficult. In all cases a significant buffer of chipped material must be maintained, to cover for chipper outages.

4.3.5. Central Depot

If a number of heating installations are located in one area, then a centralised chipping facility may be set up. Fuel-wood would be transported in-the-round to this plant, where a large chipper with a good utilisation would be employed. This option is used in some instances in Finland, with the roundwood transport distance being maximised and the chip transport minimised, due to the ease of transporting greater loads of the former. Efforts are being made to further reduce costs by pre-processing, such as flail delimbing roundwood in the forest, and conveying a tree-sections. Such clean stemwood will achieve higher payloads than branchy material. The applicability to broaleaves is not clear.

Such facilities offer the potential to perform screening and drying operations on the wood fuel, improving the quality control of the end product. Such an approach may be necessary where the boiler operation risk is being taken by a third party. Naturally, such operations suit many source: many use situations, perhaps a cluster of heating plants drawing on a number of sources, or one large central use, such as a power station. Chip quality is likely to be enhanced due to improvements in feedstock uniformity resulting from pre-processing, as discussed above

4.3.6. Summary: Systems of Work

Three general systems of work have been identified, incorporating various of the above processes. Some variants of the systems are identified:

1. Fell-Chip-Cart-Store-Burn .... System 1

   This system involves chipping at-the stump, avoiding the extract stage. If this work is undertaken when the trees are not in leaf, then the ground conditions may be wet on many sites. Such systems are best suited to clear fell sites, such as coppice coupes in a regular rotation, or to clearing residues after clear fell of or thinning of high forest. They are not well suited where large diameter material may be encountered, such as in coppice restoration.

   Some form of chip extraction system will be required. To keep chipper downtime to a minimum, a chip shuttle system separate from the chipper is often employed.

2. Fell-Extract-Stack-Unstack-Chip-Cart-(Store)-Burn .... System 2

   This system implies extracting to a hard rideside where the chipper is located, with intermediate buffer storage in-the-round. Such systems are relatively flexible, but less attractive where much small diameter material needs to be collected. Extraction is likely to be as shortwood by forwarder, though if sufficient space exists at the chipper site, tree section systems could be considered.

If the *stack-unstack* stage, i.e. the buffer of in-the-round storage, is omitted:

Fell-Extract-Chip-Cart-(Store)-Burn .... System 2a

then, if no operation is to run under capacity, the extract work rate must match the chipper work rate. Additionally, no drying in-the-round will be possible, however the cost of unstacking is avoided. The *cost* of stacking is unavoidable, as a crane will still be required to feed the chipper, unless the scale of operation merits only hand feeding. Such systems are *potentially* suited to tree-length extraction, or to shortwood extraction. If tree-length extraction is selected, then if the *chipper* workrate exceeds the *skidder* work rate, the skidding must be well ahead of chipping so as not to *hold-up* the chipper. If the reverse is true, then the skidder will leave material at rideside ahead of the chipper. In either case, it is essential that, due to the limited stacking capacity, sufficient space exists to leave skidded material at rideside ahead of chipping, implying wide rides or low volumes. Such systems thus may be more applicable to thinning than clear fell situations, unless a high output machine such as a feller clambunk is available. Stacking potential can be improved by using a pole length system, where the skidder uses its dozer blade to push up the stack.

Hired-in trailer chippers will have high workrates and high costs. To minimise the cost per tonne chipped, it will be necessary to fully utilise the chipper capacity. Thus the feed system must match the chipper work rate.

A smaller chipper, perhaps estate owned, will have a more compatible workrate with a skidding system, but will lack the robustness and diameter capacity of the hired machine. This indicates that this option may be more appropriate for the harvesting of fuel-wood from in-rotation coppice where no large butt diameters are encountered.

3. Fell-Extract-Stack-Unstack-Cart-Chip-Burn .... System 3

This system is that used at West Dean (q.v.). A benefit, shared with system 2, is that of drying-in-the round. The extraction will be a shortwood system. A dedicated chipper is required at the utilisation plant, with limited opportunity for sharing this equipment with other activities. A large chipper could be hired-in if transport or storage can be arranged to give an unbroken supply of feedstock.

4.3.6.1. Suggested Options

Coppice restoration .... System 2 or system 3

Broadleaf clear fell.. System 2 or system 3
If clambunk available System2a

In-cycle coppice..System 1 or system 2a

Broadleaf thinnings:...........Small diameter....................System 1 or system 2a
Large diameter .... System 2 or system 3

Clear fell residues... System 1

4.4. Working Practices

When a tree is felled, it can be separated into various fractions. The point of separation will depend on the relative economics of marketing each of those fractions. Fractions might be:

- Waste
- Pulp or logs for firewood
- Fencing stakes/rails¶
- Sawlogs, including pallet wood¶

¶: different product specifications, e.g. for fencing rails vs. posts, tends to lead to increased fractionation.

In practice, separation of individual trees into more than three fractions, e.g. sawlog, pulp, waste, is unlikely. The point of separation is usually defined as a top diameter (*TDOB: top diameter over bark*), which indicates the smallest diameter for that market. Whilst the market might tolerate smaller diameter, the economics of working small diameter wood will dictate the TDOB for that market. Thus if prices rise for say sawlogs, then it will become worthwhile to cut to a smaller TDOB for pulp at the expense of the next market down e.g. pulp or fencing.

Tree from has a great effect on fractionation and cutting lengths for various systems. Clearly stag-headed oaks will require much more cross-cutting than straight oaks. Market appetite will individually constrain the volume to be cut of each product, and this will change dynamically.

4.4.1. The Effect of Buffers

Generally, systems with a degree of buffer storage between stages are less prone to interaction between stages. Where this cannot be provided, two operations that must run together will be constrained to the workrate of the slower operation. If this constraint is considerably below the potential workrate of that step, then a significant rise in costs in likely. Against this must be set the double handling costs of buffer storage.

5. Case Studies

Case studies have been used in this report as a means of developing an understanding of specific situations. By picking differing cases it is hoped that sufficient understanding has been developed to permit the construction of representative models. Such models allow the lessons learnt from individual cases to be extrapolated to wider use. By identifying sensitive variables, attention can been drawn to those factors needing close inspection in each case.

5.1. Selection of Areas

Case study areas have been selected on the following basis:

- ❑ Existence of, or potential for, heat-load with opportunity for wood-fuel utilisation: in the case of the first, an actual operating system.
- ❑ Availability of suitable woodland resources
- ❑ Significant level of interest in the utilisation of the woodland resource
- ❑ Individual characteristics, as far as possible allowing a breadth of coverage between cases, for example:
  - Differing woodland types
  - Differing environmental constraints
  - Differing fuel quantities

The case-studies selected are as follows:

1. West Dean Estate, Chichester .... College and outbuilding heating
2. Gamlingay Wood, Cambridgeshire .... Mansion heating

5.2. Modelling Methods

For both of the case study areas, operational systems have been devised and costed out. Several variants have been explored, however these should not be considered as exhaustive. To assist those exploring the models, notes are provided below on the costing methods employed.

5.2.1. Labour Costs

The labour costs used in the modelling are based on the Agricultural Wages Board craftsman's rates. These stipulate a 39 hour working week, with a minimum wage. A degree of regular overtime has been assumed, and an allowance made of holiday. Adding an allowance for in-kind benefits, such as a tied cottage etc. yields annual and weekly net employee costs. An addition to this, the employer must meet his National Insurance (NI) obligations, and these are tabulated below the rate calculations.

Adding the weekly net cost to the weekly employers NI gives the gross employment cost. This is further increase by making an allowance for the management time required to supervise that worker. Based on survey work done by others, this is calculated at 6% of employee time, and is charged for at a management rate of £41/hr.

The labour costings are presented in Appendix 2. As with the machinery costings below, those reading the table are invited to substitute their own figures and assumptions.

5.2.2. Machine Costs

Machinery costings, which are detailed in Appendix 3, make various assumptions, not least that *the machinery is all purchased new at the outset of the project*. In this way, a worst-case estimate of the costs is made. In practice, many operators will use older machines, or will wish to charge for lightly used equipment at marginal cost. Such scenarios are very case-specific, and thus difficult to model. For an example of the effect on costs of using an older machine, see the Discussion section.

A portfolio of machines has been costed out, and these are assembled into the required process for each case study. It should be noted that for dedicated machines, such as the chippers, the annual utilisation varies with the case study, whereas for wider use machines it is constant.

Those viewing the models are invited to substitute their own data into the matrices provided, and to draw their own conclusions as to costs within the overall framework provided. To assist those wishing to do this, a brief explanation of the methods used is provided below. These methods are fairly standard for basic machine costings, and whilst more elaborate methods exist, these are not useful where inadequate data on all the variables is available, as is the case here.

5.2.2.1. Fixed costs

A purchase price representative for each type of machine has been assumed, along with an operating life and a salvage value. The last two figures have been based on the practical experience of the authors: tractors at 10,000 hours, chippers at 8,000 hours, chainsaw at 1,000 hours and trailers at 3,600 hours. An annual usage figure has been set for each machine type: for those used exclusively for the wood fuel operation it is based on the tonnage throughput, for those with wider application, based on experience in the field. The machine is assumed to fall in value (depreciate) on a straight line basis from the purchase price to the salvage value over the operating life. The duration of the depreciation period in years is calculated as the operating life divided by the annual usage. Thus it is possible to calculate the average annual depreciation and interest charges as follows:

1. Average annual depreciation as: purchase price, less salvage value, divided by depreciation period.

2. Average annual interest as: average of purchase and salvage prices, divided by depreciation period in year, multiplied by annual interest rate.

(The interest method is often referred to as *interest on half capital*.)

Totalling 1 and 2 above along with allowances for road tax, insurance and shelter (1% of capital pa. each) yields the annual fixed costs.

5.2.2.2. Running Costs

The running costs are calculated on the basis of fuel and oil burnt, and repairs. The repair charge is a fixed percentage of the new cost, and the other two are calculated based on the fuel burnt multiplied by its cost, the former being evaluated based on engine power and a utilisation coefficient.

5.2.3. Transport Costs

The final page of the Appendices presents the simple models used for costing the delivery of wood chips from a chipper to the utilisation plant. It is only employed for the Gamlingay Wood case. The models assumes a load size, vehicle speed and catchment area. By applying a *wiggliness* factor to the last of these, the single haulage distance may be approximated. By allowing for loading, unloading and waiting time, the effective work rate may be calculated. by applying the machine and labour costs to this, the annual and one-off costs of the delivery operation are evaluated.

5.2.4. Note

The following assumptions have been used throughout the case study calculations:

In all cases, green tonnes are calculated on the basis of 37.5% m.c.

m^3 solid timber are calculated on the basis of 0.96gt/m^3.

m^3 of loose chips are calculated on 7.4m^3/odt, ($\equiv$ 4.6m^3/gt).

5.3. Case Study 1: West Dean Estate

5.3.1. Market

West Dean College is a residential establishment situated within the Estate. When replacing life-expired boiler plant some years ago, the decision was made to install a large wood-fired heating system using the Estate forestry as a fuel resource. More detail on the scheme may be found in ETSU report B/M5/00488/05/REP.

The current fuel consumption of the system is about 1000-1,200 gt/annum, at a nominal 37.5% mc. For the purposes of this case study the following characteristics have been assumed:

	odt	gt	m^3 solid	m^3 chipped	GJ
Net CV: GJ per....	18.1	11.3	10.9	2.4	
Burnt,........per annum	647	1,035	1078	4790	11,734

5.3.2. Scale of Resource

Fuel-wood is principally obtained from the West Dean Estate, and from neighbouring farms and estates. Woodland is variable in type and composition, however the principal commercial resource is beech, usually with a conifer nurse crop some larch/beech, some Douglas fir/beech. The longer-term effects of the storm of October 1987 on the availability of thinnings have resulted in the need to work some areas of neglected coppice to supplement the supply from the commercial woodland.

The estate has 800ha of woodland, of which 600ha is productive and actively managed. Of this area, two thirds is broadleaves - 400ha, and one third conifer - 200ha.

5.3.3. Management Opportunities

Fuel-wood comes from thinnings, especially removal of conifers from mixed stands. One particular advantage cited is that the chipwood is not species-particular, as a result during thinning conifer and broadleaf, and even dead stems, can be mixed at will.

The West Dean woodland is managed on a conventional thinning system, where *on average* 70% of the accumulated annual increment is removed when thinning. In practice, thinning is undertaken every five years: at a notional increment of 10m^3/ha/a (YC10), this would yield 35m^3/ha on thinning.

On the sites available, beech will yield YC6-8, giving an equivalent annual production of thinning over the woodland area of 4.2-5.6m^3/ha/a giving 1,680-2,240m^3/annum. Pines will achieve YC8-10, and Douglas Fir YC14-18: at an average of YC10 giving 1,400m^3/annum. Two thirds of this will be of sufficient quality to be sold for other purposes, giving a net available for fuel of 462m^3/annum.

Broadly speaking, the *green* solid density of beech is about 1.03t/m^3, and conifers such as larch/Douglas fir 0.89t/m^3. Thus the total green weight felled per annum will be at a minimum 1,680 x 1.03 + 462 x 0.89 = 2,141gt/annum. Even allowing for loss of weight due to drying between felling and combustion, the wood fuel resource on the Estate can clearly match the annual demand of 1,200gt/a.

5.3.4.Equipment

The estate owns two MB-Trac based machines:

1. A forwarder unit, consisting of tractor with mounted crane, drawing a tandem axle bolster trailer, used for fuel-wood and other shortwood.

2. A skidder unit consisting of tractor with winches etc.

This type of machine has been found to offer significant advantages over previous units, in that the sprung front axle of the MB-Trac allows rapid return trips of a forwarder unit from stack to forest. At the boiler plant is situated a Jenz drum chipper, complete with log table. The chipper is driven by a dedicated diesel engine, and is loaded by the forwarder crane. The chipper discharges into a chain-and-flight conveyor, which fills the boiler bunker.

An unusual item of equipment is a large trailer-mounted log splitter, which can be used to reduce very large pieces to a size suitable for chipper feedstock. This item has proved very useful for dealing with windblown timber. The hydraulic power comes from the forwarder's external hydraulic system, and loading/unloading is by the forwarder's crane.

5.3.5. Systems and Cost

The basic current system of work is as follows:

1. Motor-manual felling
2. Snedding and crosscutting
3. Extraction by forwarder to hard rideside after minimum delay, and stacking
4. Storage in-the-round
5. Loading and carting by forwarder to boiler plant
6. Unloading and chipping directly into boiler bunker

This system complements the other forestry operations, in that it utilises the same equipment and personnel. The haulage of the fuel-wood in-the-round was found to give a superior payload to chips, and permits the use of the forwarder when it returns to base after a day's work. Such usage makes best use of what would otherwise be unproductive downtime.

For the purposes of modelling, a costing has been made for a materials handler to push up chips into a storage bunker. This is felt to be more replicable than the current system at West Dean, where the conveyor discharges into a conveyor. Notwithstanding this, the materials handler make very little difference to the fuel cost.

Modelling of the Estate's system using the machine and labour costing data in the appendices gives the following results:

Note how the costs of felling and chipping dominate the wood fuel costs. Shortwood felling is labour-intensive, requiring length control during the frequent crosscutting. The chipper has no other use, so its full cost is borne by the wood fuel operation. In the discussion the sensitivity of the wood fuel price to the chipper cost is explored further.

The above costs may be found tabulated on the next page.

The table below shows the modelled costs for West Dean using an approximation to the current system:

	Solid m^3/hr	Hours/pa	Hourly Costs	Total Cost	per odt	per gt	per solid m^3	per loose m^3	per GJ
Felling	0.7	1540							
Chain saw			£0.97						
Labour			£9.10						
Felling Total			£10.07	£15,506	£23.98	£14.99	£14.39	£3.24	£1.32
Forwarding	10	108							
Forwarder			£8.27						
Labour			£9.10						
Forwarding			£17.37	£1,872	£2.90	£1.81	£1.74	£0.39	£0.16
Forwarding to Plant	19.06	57							
Forwarder			£8.27						
Labour			£9.10						
Total			£17.37	£982	£1.52	£0.95	£0.91	£0.21	£0.08
Chipping	4.0	269							
Forwarder			£8.27						
Labour			£9.10						
Chipper			£69.53						
Total			£86.90	£23,417	£36.21	£22.63	£21.73	£4.89	£2.00
Clamping	19.8	54							
Materials Handler			£7.72						
Labour			£9.10						
Clamping Total			£16.81	£915	£1.42	£0.88	£0.85	£0.19	£0.08
Total Cost				**£42,694**	**£66**	**£41**	**£40**	**£8.91**	**£3.64**
Total Oil Cost				**£17,142**					**£1.46**

The wood fuel cost resulting from the above system is c.£41/gt, which compares with the figure of £46/gt quoted by Ward and Alexander (1995).

5.4. Discussion

It is critical to appreciate that the West Dean Estate owns both the fuel resource and the heat load, and hence can take a view on the pricing of fuel. In common with many charitable trusts, the Estate has aims that may be rather different to those of a commercial company. In particular there may be attractions to investment in internal infrastructure and the creation or preservation of local employment.

For this reason, whilst the Estate forms an excellent *practical* demonstration, the direct replication of its achievements is unlikely. Rather, it forms the basis for some explorations as to how things could be done alternatively under different conditions. Additionally, the Estate, like any woodland management organisation, already has investments in certain equipment, a situation that presents particular difficulties when case study modelling. To ensure a *level playing field*, it is customary to cost-in new machinery, which is patently unrealistic in this case.

At this point, it must again be stressed that, whilst the above uses West Dean as the realistic basis for a case study, the intention is not to show how it could be done better, but rather to draw out ideas of use to potential future developments elsewhere.

5.5. Case Study 2: Gamlingay Wood

5.5.1. Scale of Resource

Gamlingay Wood, located in East Cambridgeshire, is one of a number of woods owned or managed by the Beds and Cambs. Wildlife Trust, totalling between them c.1000 acres (c.400ha). It occupies an area of 118 acres (48ha), and is composed largely of hazel and ash coppice with oak standards, with some later planting of conifers and aspen.

The site is level, with chalky boulder clay soil of the Hanslope series. Mixed broadleaves on such a site will yield 4-6m^3/ha/a (YC4-6).

5.5.2. Potential Market

For the purposes of this report, a notional potential market has been assumed. The Trust do have a long term plan for a visitor's centre, which they would like to provide heat and hot water for using their own resources. This project is, however, at no more than an outline stage, and will be pursued when funds permit.

To maximise the relevance of this case study, it has been decided to use the example of a large mansion house on a local estate. This option is considered relevant, because there are numerous examples of estates with both large houses and considerable areas of woodland. A fair proportion of such houses are now used a schools and colleges, or as offices/conference centres. As they are located in rural areas, have substantial space heating loads and if residential, have large hot water usage, they may be ideal candidates for wood-fuel heating.

The fuel use for this site exceeds the production capacity of Gamlingay Wood, however wood fuel is assumed to also come from the Trust's other woods, which as noted above occupy c. 400ha. This case study examines the potential of Gamlingay wood to contribute to this fuel supply as part of a larger operation.

For this purposes of this case study, a fully modern heating system with computerised controls has been assumed. This system gives the following fuel requirements:

Wood Fuel	odt	gt	solid m^3	chipped m^3	GJ
Net CV: GJ per....	18.1	11.3	10.9	2.4	
Burnt,........per annum	540	864	900	4001	9799

5.5.3. Management Opportunities

The general silvicultural objective is to increase the production of hazel coppice, including layering to give new stools, and not to increase the production the ash coppice, but still to manage it. The coupe size is very variable, dependant on conditions. The hazel is used for thatching spars and hurdles, and once in rotation can be assumed not to be available for fuel-wood.

The ash coppice is cut on a 15 year rotation, however the markets are weak, and not differentiated by species, such as firewood. Firewood is cut from mixed species, including the ash, and extracted to 5cm TDOB as cordwood by agricultural tractor and trailer forwarder, the product being processed on site into logs.

Currently some coppicing work is carried out using volunteer labour, however given the scale of the woodland their impact is small. Beyond this the trust will permit others to work the woods, provided that the management constraints are adhered to. Whilst the woodland is not commercial, the Trust does have expenses, and therefore seeks to make some return from the woods. For this reason a standing sale value of £2-3/gt has been assumed. In practice this correlates with the low level of payment necessary to secure opportunistic thinning of unthinned broadleaf plantations in private ownership, providing a cushion against costs arising form the work (e.g. fence damage etc.).

For the purposes of this case study, the mixed hardwoods have been assumed to average YC6. On this basis, using the tables for ash after 20 years $57m^3$/ha will be available to 7cm TDOB. This translates to a production of 44.5 gt/ha at harvest, or 2.2gt/ha/a. On this basis, c.390ha of woodland would be required. If the tops were harvested as well, then an additional 30% of fuel-wood would be extracted, at the penalty of requiring deer fencing. This would increase the yield to 2.9gt/ha/a, and reduce the area to 300 ha. The yields quoted above are probably low for coppice, however given the variable nature of the sites and the constraints, they are felt to be reasonable figures.

5.5.3.1. Constraints

Felling between March and July is strongly discouraged, due to disturbance of nesting birds.

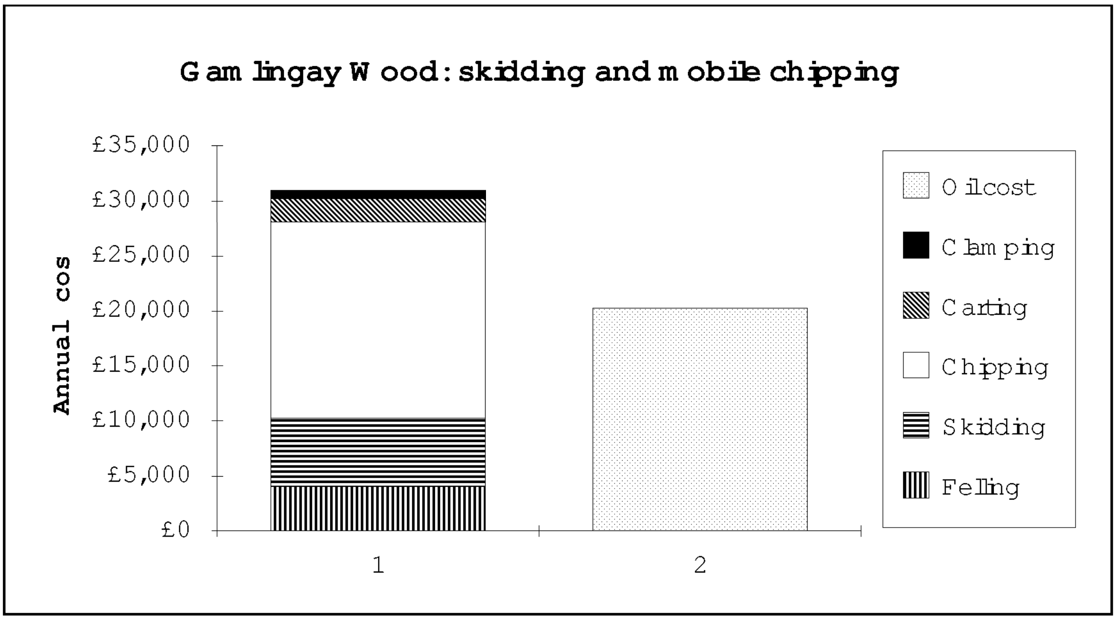
In winter, in common with many woods in the area, ground conditions off-ride become very wet. For this reason, the maximum vehicle size allowed off-ride in winter is an ATV (such machines can however do significant damage). Timber felled and requiring extraction during this period would need to be winched off-site. It must be emphasised that these constraints are individual: on some sites it might be possible to take larger machinery off-ride. The site owner's attitude is critical.

Muntjac deer are active on-site. The method used to-date to restrict their activity is to build a brash wall around the coupe. However, it is acknowledged that as with any fence this is only as strong as its weakest point, and hence that a even scattering of brash might be better.

5.5.4. Modelling: Systems and Cost

Several scenarios were modelled, and the one giving the least wood fuel cost is shown below. The cost of oil to provide the same amount of delivered heat is displayed alongside.

The site requires restoration to in-rotation coppice, and therefore large diameters will be encountered in stored material. Hence the suggested extraction system is by forwarding or skidding to rideside during the late summer. Chipping would be by hired-in chipper in the autumn. For the purposes of the modelling, System 2a: skidder extraction in late summer/early autumn with mobile chipper at rideside has been selected, giving the following results:



Note how the felling cost is proportionately much lower than at West Dean. This is due to the far lower demands placed on the fellers. However, the chipping cost remains high, an indeed contributes the bulk of the wood fuel cost.

The table on the next page shows the modelled costs using the skidding system:

	Solid m^3/hr	Hours/pa	Hourly Costs	Total Cost	per odt	per gt	per solid m^3	per loose m^3	per GJ
Felling	2.25	400							
Chain saw			£0.97						
Labour			£9.10						
Felling Total			£10.07	£4,028	£7.46	£4.66	£4.48	£1.01	£0.41
Skidding	3	300							
Tractor			£9.00						
Hydra-tongs			£2.63						
Labour			£9.10						
Skidding Total			£20.73	£6,218	£11.52	£7.20	£6.91	£1.55	£0.63
Chipping	1.7	540							
Tractor			£4.84						
Chipper			£19.25						
Labour			£9.10						
Chipping Total			£33.18	£17,919	£33.18	£20.74	£19.91	£4.48	£1.83
Carting	8.25	109							
Tractor			£4.84						
Trailer			£5.23						
Labour			£9.10						
Carting Total			£19.16	£2,090	£3.87	£2.42	£2.32	£0.52	£0.21
Clamping	19.8	45							
Materials Handler			£7.72						
Labour			£9.10						
Clamping Total			£16.81	£764	£1.42	£0.88	£0.85	£0.19	£0.08
Total Annual Cost				**£31,020**	**£57**	**£36**	**£34**	**£7.75**	**£3.17**
Total Oil Cost				**£20,252**					**£2.64**

The delivered fuel cost on the basis of all-new machinery is £36/gt, however it is clear that using older machinery will cut this significantly.

6. Discussion

The best opportunities for the use of neglected woodlands for fuel perhaps exist where management operations are constrained by high haulage costs to the existing markets. This is especially true where management was carried out until relatively recently. There is no doubt that estates, especially those managed by charitable trusts, are in a unique position to implement wood-fuel programmes. A competitive scenario might be competing at the landing with pulpwood, if this below £15 gt on-lorry (£10+ transport cost). Pulpwood prices are volatile, however. At 37.5% m.c., the delivered fuel costs from the case study modelling were:

West Dean, static chipping £41/gt

Gamlingay wood, skidding and mobile chipping £36/gt

In both cases the cost of the wood fuel exceeds the cost of the competing oil fuel. However, as discussed earlier, the models assume *full new purchase costs* for all machinery. In many situations older machinery will be used, and in others some may be charged to minor activities at marginal cost.

By way of example, if a second hand chipper was employed in the West Dean scenario, costing £30,000 rather than £75,000, then the hourly machine cost would fall from £69.53/hr to £33.12/hr. The effect of this cost would be to reduce the delivered fuel cost to from £41/gt to £31.75/gt or £51/odt. This is a very significant reduction in overall wood-fuel costs, of the order of 25%. The chipper is particularly sensitive to such changes, as its annual utilisation in terms of hours run is quite low. Clearly, maintenance costs on an older machine may well be higher, however similar cost reduction effects would apply if the machine costs could be spread over other activities, with new instead of second hand purchase.

It must be remembered that purchasing older machinery which is expected to have a high utilisation, using the methods employed here costs may not be lowered by the degree expected: the reduced remaining life of the machine will compensate for the lower purchase price and to some degree maintain the hourly costs. In these cases, spreading of the machine costs over several activities may be preferable to buying second-hand, whereas in the case of the chipper, the low annual utilisation indicates a fair number of years of useful life remaining, and thus low hourly costs.

Subsequent to the above modelling being undertaken, discussions were held with contractors active in the pulp/mulch markets regarding at-stump chipping of in-rotation sweet chestnut coppice: *system 1*. The conclusion of these discussions was that the following costs were more reasonable than might be expected, when considered as part of a large-scale operation:

Felling[§]..£1.50/gt

Chipping at stump[§]..£10/gt

Shuttle off-site[§]..£1.50/gt

Delivery[¶]..£2.42/gt

Pushing up into store[¶]..£0.88/gt

Total..£16.30/gt

§: Anecdotal report from contractor.

¶: from modelling conducted as part of this work.

Using the format of the case studies, the above figures may be presented as follows:

Costs	per odt	per gt	per solid m^3	per loose m^3	per GJ
Felling	£2.40	£1.50	£1.44	£0.32	£0.13
Chipping at stump	£16.00	£10.00	£9.60	£2.16	£0.88
Shuttle off-site	£2.40	£1.50	£1.44	£0.32	£0.13
Delivery	£3.87	£2.42	£2.32	£0.52	£0.21
Pushing-up	£1.41	£0.88	£0.84	£0.19	£0.08
Total	**£26.08**	**£16.30**	**£15.65**	**£3.52**	**£1.43**

Assuming a standing value of £4-5/gt, and an acceptable profit, this indicates that wood fuel from in-rotation coppice should be available at < £25/gt (c.£2.20/GJ), for reasonable quantities.

Part of this apparently low cost is due to the benefits of the at-stump system, and partly due to the benefits of attaching to a larger contractor operation. Further investigation of this option was not possible during the scope of this study, however a deeper examination may be justified. The benefits of such a highly mechanised system on a large scale are clear.

6.1. Chipping

Of all the equipment reviewed earlier, the chipper is the most specialist. This applies from the basic amenity-type machines, right through to the self propelled units. The principal reason for this is the lack of alternative uses: whilst wood-chip is produced and traded for mulch and pulp, the majority of timber is sold *in-the-round*. Hence, whilst the fixed costs of the chainsaws, forwarder, skidders etc. can generally be spread across several tasks, the chipping is much more restricted. As a result, unless significant tonnages of fuel are produced, the annual operating hours of the capital-intensive chipper are likely to be constrained by the quantity to be chipped as fuel.

There are several potential strategies to overcome the chipper cost problem, either by increasing the number of hours worked per annum, or by restricting the capital cost:

1. Hire-in large capacity chipper

2. Purchase second-hand chipper, or amenity-type (with restricted diameter feedstock)

3. Couple to contractor organisation with mulch/pulp markets to justify chipper, as per example above.

Whilst chippers may be hired on a day or week rate, their availability outside the main forest areas is likely to be limited, not least by the delivery cost. In fact, there are only a limited number of large chippers in the UK. If a trailer/truck mounted machine is hired on this basis, then the onus rests on the user to provide a sufficient supply of feedstock to fully utilise the chipper. As discussed earlier, this probably necessitates a shortwood system, with chipping at the rideside from a stack.

The second option will be operation specific, and dependant on the abilities of those running the operation. Whilst there is evidence that the use of second-hand machinery can form the basis of a viable business, it does require good workshop facilities and a high degree of engineering expertise to keep older machines operating. Amenity chippers are being used successfully to produce fuel-wood chip, on a domestic scale. It is necessary to devise a system that separates large diameter material for use a logs prior to chipping. Such a system may work on a farm/small-estate scale using wood from hedgerows/small copses.

The third option has potential for larger projects, and is indeed the type of operation that was examined for large-scale fuel supplies when bids for NFFO-3 were being prepared. Contractors are in a good position to spread machinery fixed costs over a range of activities, and this combined with specialist knowledge should put them in a position to produce fuel at a realistic prices.

7. Conclusions

1. There exists a vast reserve of wood fuel in neglected woodlands. This is partly as stored crops awaiting clear fell or thinning, but importantly also on a sustainable rotational basis.

2. The benefits of bringing neglected woodlands into management are accepted, from shooting, wildlife conservation and amenity points of view.

3. Severe damage sustained by woodland during wood-fuel harvesting operation is to be avoided as far as possible, as it will negate many of the above benefits.

4. For the above reason, it is preferred that felling does not occur during the nesting season, and that extraction does not occur under very wet ground conditions. Similarly, the programme of work must fit in well with the other estate enterprises and sporting activities.

5. Notwithstanding this, tight constraints on operations will raise costs and inhibit woodland management. For this reason a compromise must be reached. One suggested option is to work relatively small non adjacent coupes in coppice, so that adjoining zones buffer the work in progress. This option may also be desirable for shooting.

6. Where operations are constrained due to environmental reasons, payments to cover additional costs *may* be available.

7. Management of otherwise untouched woodland is likely to increase its potential as a shoot, however the optimum management system for shooting may not coincide with the optimum for fuel.

8. However, the benefits to shooting from management for fuel should be capitalised on and credited against the harvesting cost.

9. Deer control is essential, especially on coppice sites. Sheep control will be necessary in some areas

10. Several systems of work may be identified. The application of these will depend not only on the nature of the crop and site, but on the practical availability of equipment and contractors within a sensible distance.

11. The chipping stage is the most specialist. For large tonnage throughputs, heavy duty machines are required. Such equipment requires large throughputs to be sustained in order to chip at an acceptable price, requiring in turn robust supply chains.

12. If large diameter material is to be chipped, then the most cost-effective route is probably to hire-in a large chipper, fed with shortwood from a rideside stack. Such chippers are available for hire with operator, but are located in the main forest areas. Transport to other areas may be costly.

13. Once in rotation, coppice crops are probably best worked by felling in the spring, transpirationally drying over the summer and chipping during the late summer/early autumn using line-thinning type machines. Some compromise may need to be reached regarding felling during the nesting season, if this is indeed done.

14. The above system can produce wood chips at under £25/gt delivered into store. Using new machine costs, other systems require a maximum of between £36-41/gt delivered-in. Where older machines are employed, or machines can be used at marginal costs, these last figures will be considerably reduced: perhaps to £30/gt or less.

8. References

The following freely available documents or parts thereof have been used in the preparation of this report, and may be found useful by those wishing to explore the subject further:

FEC Ltd .... Wood Fuel Quality Standards: ETSU B/W3/00161/REP

Forestry Commission.................. Census of Woodlands and trees, 1979-82 (Currently out of print awaiting new census)

Kirby, K, 1994............................. English nature's Natural Areas - a Different Look at the Countryside, in ETSU Proc 5, Wood Fuel the green Debate

Landen, 1994.............................. Handling and preparation of Wood-Fuel at the Utilisation Plant: ETSU B/M3/00388/28/REP

Landen and Sandars, 1995 .... Interactive Economic Analysis of Small-Scale Heating Plant: ETSU P/01/00260/00/00

Mitchell, CP, 1993 .... Whole Tree Harvesting Systems for Wood Fuel: ETSU B1273

Mitchell, CP, 1990 .... Wood Fuel Supply Strategies, vols 1 and 2, ETSU B1176 P1 and P2

Oxford Forestry Institute, 1987 .... An Evaluation of the Methodology for Managing Existing Broadleaved and Coniferous Woodland for Timber and Energy Production, ETSU B1156

Ward and Alexander, 1995.......... The West Dean Wood-Fuelled District heating Scheme: ETSU B/M5/00488/05/REP

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Appendices

APPENDIX 1. Assessing the nature conservation implications of large-scale coppice restoration to produce wood chips for fuel.

This section is taken directly from a paper presented by Keith Kirby of English nature at the *Wood Fuel - the Green Debate* conference, Hatfield 18-19/10/94.

The following sorts of information are likely to be needed about the scheme.

1. Location and size of combustion plant; any works associated with it such as storage areas for chips.
2. Levels and nature of emissions.
3. How much wood is needed, expressed (roughly) in terms of hectares of coppice cut per annum.
4. Catchment area for chip supply and any major blocks of woodland already targeted.
5. How a continuity of chip supply (if needed) is to be obtained, e.g. through over-chipping in autumn/winter and storage of chips, over-cutting in autumn/winter and storage of poles with chipping delayed until needed; cutting for as much of the year as is allowed; or switching to other sources (e.g. mill waste) when coppice chips are not available.
6. Minimum quantity of chips (or wood) that is acceptable as a 'load', converted into hectares, i.e. what is the minimum that must be cut at a time in any one wood.
7. Any preference (or dislike) for particular species or sizes of coppice.
8. Who will be doing the cutting; will the proponents of the scheme do the cutting; will they have established long-term contracts with particular cutters; or will they take any material that comes in at an acceptable price?
9. How will cutting be done (standard chainsaws or specialised machinery); how and where will the chipping take place; if in the wood, what sort of machinery is involved, will it be restricted to rides or move into the stands; how will the chips or poles be removed from the wood (what size of lorry etc.)
10. What is the expected longer-term requirements for coppice chips from ancient woods? It could be expanding/stable if the scheme is successful;

or declining if existing coppice is seen as a filler until (possible) cheaper willow chips from new planted energy coppice comes on stream.

The following sorts of details are likely to be required for potential supply sites:

1. Site name, location, area.
2. Ancient woodland or not?
3. Soil type.
4. Coppice composition.
5. Coppice history, in particular when last cut, whether standards present or not and, if available, any information on previous patterns of cutting.
6. Ground flora composition, with at least the major dominants.
7. Major variations in d, e and f across the site.
8. Nature and state of ride system at present.
9. What changes to the ride system, creation or chipping glades storage areas etc. may be needed in wood?
10. Information on birds (especially warblers and nightingales), invertebrates (especially butterflies) and mammal interest (dormice, badgers) in wood.
11. Level of deer browsing within the wood and what protection or control measures are envisaged for recently cut areas.
12. Pattern of cutting proposed in terms of size of coupes, and sequence and distribution of coupes across the wood.
13. Rotation length.
14. Season of cutting and extraction of the wood.
15. How much of the wood will be cut over during the whole rotation, i.e. are there parts to be worked as high forest or minimum intervention as well
16. The next sections explore some of these issues in more detail concentrating on what we want to see happen in the woods and the factors that may determine whether this is achieved in practice.

Coppice working should be designed to try to achieve a varied structure, as follows:

1. Some recently cut area always present in the wood and (consequently) a range of other age classes.

2. A permanent "open space" network of rides and glades that helps to link up the temporarily open areas. (Detailed ride management recommendations are available but these are less necessary in a worked coppice than in wood managed as high forest).
3. Some standards, areas of high forest or minimum intervention that provide large trees and other habitats/conditions not found in worked coppice.
4. Coupe size and layout should reflect the particular interests of a site, but the following guidance may be useful:
5. Coupes should generally be in the range 0.5 - 2.0 ha, the smaller the wood the smaller the coupe.
6. Small coupes (less than 1 ha) are best arranged adjacent to one another, larger ones should be staggered in time or space.
7. Where the size of the wood is such that an annual cut in the preferred size range is not possible, it is better to cut a larger area every 2-3 years that cut annually and then have several years break with no cutting at all.
8. No wood should be cut in less than 3 coupes in total.
9. Where woods are larger, so more than 2 ha could be cut on a sustainable basis each year, ideally establish separate periodic blocks in different parts of the wood. If this is impractical offset areas cut in some year to avoid them coalescing as single block.
10. Maintain corridors of mature growth through woods to allow for dormice to move easily round and through large open cut areas. Pinch points in wide rides are desirable for the same reason.

Adjust the season of cutting to when it will cause least damage, preferable September to March

1. The Wildlife and Countryside Act (1981) makes it illegal to intentionally disturb nesting birds: and this is likely to be the case with any cutting between late March and July. The coppice will be at its most leafy and highest moisture content at this time also.
2. Avoid cutting in spring and summer by storing chips, chipping winter-cut poles, or using and alternative source of wood during this period.
3. Close to the main breeding season select sites for cutting that are likely to be poorest in breeding birds, e.g. pure stands of simple chestnut coppice (or simple hazel coppice) and those on acid soils and avoid mixed species stands or coppice-with-standards on base-rich soils which are likely to be richer in bird life (and in other species).

Keep disturbance to rides and stands from machinery low

1. Some disturbance to the ground vegetation and soils on both rides and in the stands can be beneficial in nature conservation terms, but large-scale damage (more than 20% of the surface) is not.

2. Restrict machinery to rides and keep it out of the stands

3. Limit the number of extraction routes used by heavy machinery as it is generally the first pass which creates the main damage.

4. Consider making up one or two rides if this significantly reduces the pressure on the rest of the wood

5. Concentrate working of sensitive soils (particularly base-rich clays) to periods when these are very dry (e.g. early autumn) or frozen hard;

6. Classify sites according to the likelihood of soil damage and adjust cutting schedules accordingly.

Operator of power plants should be encouraged to buy from responsibly harvested timber only.

1. Mechanisms to promote this could include:

2. A code of conduct for contractors

3. Requirements that chips must come from a wood with an approved management plan, e.g. under WGS.

4. Encouraging long-term relations between operator-contractor-woodland owner so it is not in contractor (or owner) interest to cut irresponsibly.

5. Support for responsible operators who do not use contractors who have complaints laid about their methods of working.

Operators, contractors and woodland owners must be aware of the potential deer browsing problem and be encouraged to:

1. Assess the likely problem before cutting takes place.

2. Cut in ways that may reduce the damage (relatively large coupes, using brash at edge to discourage deer).

3. Carry out deer control.

Appendix 2: Labour Costs

Labour Costings				
Working week	39	hrs		
Basic pay	£172.89	£/week		
Overtime	5	hrs		
Overtime rate	£6.65	£/hr		
Working weeks/yr	48	wks		
Days holiday year	20	days		
Daily holiday pay	£43.22	£/day		
Benefit in kind	£3,000	pa	House, firewood, council tax etc.	
Total cost	£13,759	pa		
Average weekly cost	£265			
National Insurance Bands	From	To	Employer rate	Cost
Employees weekly income	£0.00	£55.99	0.0%	£0.00
	£56	£94.99	4.6%	£0.00
	£95	£139.99	6.6%	£0.00
	£140	£194.99	8.6%	£0.00
	£195	£419.99	10.4%	£27.52
	£420		10.4%	£0.00
Employer National Insurance				£27.52
Total average weekly cost	£292			
Total average hourly cost	£6.64			
Management and admin. rate	£41.00			
Percentage time	6%		Exeter Labour use pilot study estimates Managerial input at c. 6-10% of Production based labour	
Inclusive average hourly cost	£9.10			

Appendix 3: Machine Costs

Machine	Chain saw	
Purchase Price	£660	
Life (yrs)	1	
Salvage Value	£0.00	
Depreciation		£660
Interest Rate	10%	
Inflation Rate	5%	
Interest		£17
Tax & Duty		£0
Insurance	5%	£33
Shelter & Neglect	1%	£7
Total Fixed costs		**£716**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	3	
Power utilisation	55%	
Annual Hours	1000	
Fuel & Oil		£156
Repairs	15%	£99
Total Running costs		**£255**
Total Cost		£971
Total Hourly cost		£0.97

Machine	Tractor	
Purchase Price	£36,000	
Life (yrs)	10	
Salvage Value	£3,600	
Depreciation		£3,240
Interest Rate	10%	
Inflation Rate	5%	
Interest		£900
Tax & Duty		£135
Insurance	1%	£360
Shelter & Neglect	1%	£360
Total Fixed costs		**£4,995**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	90	
Power utilisation	45%	
Annual Hours	1500	
Fuel & Oil		£5,270
Repairs	9%	£3,240
Total Running costs		**£8,510**
Total Cost		£13,505
Total Hourly cost		£9.00

Machine	Hydra Tongs	
Purchase Price	£3,500	
Life (yrs)	10	
Salvage Value	£350	
Depreciation		£315
Interest Rate	10%	
Inflation Rate	5%	
Interest		£88
Tax & Duty		£0
Insurance	1%	£35
Shelter & Neglect	2%	£70
Total Fixed costs		**£508**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	0	
Power utilisation	0%	
Annual Hours	1000	
Fuel & Oil		£27
Repairs	8%	£280
Total Running costs		**£307**
Total Cost		£815
Total Hourly cost		£0.81

Machine	MB Trac Forwarder	
Purchase Price	£35,000	
Life (yrs)	10	
Salvage Value	£3,500	
Depreciation		£3,150
Interest Rate	10%	
Inflation Rate	5%	
Interest		£875
Tax & Duty		£135
Insurance	1%	£350
Shelter & Neglect	1%	£350
Total Fixed costs		**£4,860**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	75	
Power utilisation	45%	
Annual Hours	1500	
Fuel & Oil		£4,398
Repairs	9%	£3,150
Total Running costs		**£7,548**
Total Cost		£12,408
Total Hourly cost		£8.27

Machine	Chipper-Static	
Purchase Price	£25,000	
Life (yrs)	10	
Salvage Value	£2,500	
Depreciation		£2,250
Interest Rate	10%	
Inflation Rate	5%	
Interest		£625
Tax & Duty		£0
Insurance	2%	£375
Shelter & Neglect	1%	£250
Total Fixed costs		**£3,500**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	135	
Power utilisation	65%	
Annual Hours	625	
Fuel & Oil		£2,912
Repairs	9%	£2,250
Total Running costs		**£5,162**
Total Cost		£8,662
Total Hourly cost		£13.86

Machine	SASMO mobile chipper	
Purchase Price	£30,000	
Life (yrs)	10	
Salvage Value	£3,000	
Depreciation		£2,700
Interest Rate	10%	
Inflation Rate	5%	
Interest		£750
Tax & Duty		£0
Insurance	2%	£450
Shelter & Neglect	1%	£300
Total Fixed costs		**£4,200**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	135	
Power utilisation	65%	
Annual Hours	540	
Fuel & Oil		£3,495
Repairs	9%	£2,700
Total Running costs		**£6,195**
Total Cost		£10,395
Total Hourly cost		£19.25

Note with the dedicated chippers the hourly charge rate varies from case-to-case depending on the required hours of utilisation.

Machine	Materials Handler	
Purchase Price	£30,000	
Life (yrs)	10	
Salvage Value	£3,000	
Depreciation		£2,700
Interest Rate	10%	
Inflation Rate	5%	
Interest		£750
Tax & Duty		£135
Insurance	1%	£300
Shelter & Neglect	1%	£300
Total Fixed costs		**£4,185**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	80	
Power utilisation	45%	
Annual Hours	1500	
Fuel & Oil		£4,689
Repairs	9%	£2,700
Total Running costs		**£7,389**
Total Cost		£11,574
Total Hourly cost		£7.72

Machine	Tractor	
Purchase Price	£17,000	
Life (yrs)	10	
Salvage Value	£1,700	
Depreciation		£1,530
Interest Rate	10%	
Inflation Rate	5%	
Interest		£425
Tax & Duty		£135
Insurance	1%	£170
Shelter & Neglect	1%	£170
Total Fixed costs		**£2,430**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	56	
Power utilisation	45%	
Annual Hours	1500	
Fuel & Oil		£3,294
Repairs	9%	£1,530
Total Running costs		**£4,824**
Total Cost		£7,254
Total Hourly cost		£4.84

Machine	Trailer	
Purchase Price	£6,400	
Life (yrs)	10	
Salvage Value	£640	
Depreciation		£576
Interest Rate	10%	
Inflation Rate	5%	
Interest		£160
Tax & Duty		£0
Insurance	1%	£64
Shelter & Neglect	2%	£128
Total Fixed costs		**£928**
Fuel Price (£/l)	£0.14	
Oil Price (£/l)	£1.25	
Engine size (kW)	0	
Power utilisation	0%	
Annual Hours	300	
Fuel & Oil		£0
Repairs	10%	£640
Total Running costs		**£640**
Total Cost		£1,568
Total Hourly cost		£5.23

Input Data		
Volume to be transported	7.4	m^3/hr
Catchment area	5.0	km Radius
Wiggliness' factor	1.5	Decimal ratio
Average speed	25.0	kmh
Percentage dead time	35%	
Load size	22.0	m^3
Load time	178.2	mins
Unload time	15.0	mins
Hourly charge for Tractor	£4.84	
Hourly charge for Trailer	£5.23	
Hourly charge Labour	£9.10	
Distances		
Theoretical haulage distance	3.6	km
Average haulage distance	5.3	km
Average round trip	10.7	km
Times		
Turn round times	3.2	hrs
Haulage time	0.6	hrs
Round trip time	3.8	hrs
Machine hours	3.8	hrs
Labour Hours	0.85	hrs
Cost		
Annual charge	£8,312	
Round trip charge	£43	