Proving of Woodfuel Harvesting in Undermanaged Woodlands in the East of England

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Contents:

Executive summary

This report sets out work undertaken by Econergy Limited to develop harvesting systems that will allow undermanaged woodlands and what might be termed 'undermanaged forestry' within the Eastern Region to be accessed economically for the production of woodfuel. The continued decline in both pulpwood markets and in the value of higher-grade forestry products is currently re-enforcing a long-term trend of declining woodland and forestry management. Though by no means a panacea, the energy market is widely perceived as having the potential to provide an important alternative market for low-grade material and, thereby, in helping to redress this decline.

The re-introduction of positive management to the large 'neglected' or 'undermanaged' woodland estate in the region would bring a range of benefits that relate directly to the England Forest Strategy (EPS) and the Regional Assembly / Sustainable Development Round Table Sustainable Development Framework, including:

- income generation
- employment
- improvements in quality and future economic value
- significant enhancement of wildlife / habitat value
- improved value for sporting and other amenity uses

Econergy began pilot woodfuel production operations in the region during 2001 based on a highly mobile chipping unit (the *Surefire* harvester) that is able to access relatively small blocks of woodland economically. However, while these operations have demonstrated the 'win-win' opportunities offered by woodfuel production, they have also led to the identification of a number of issues that highlight a need for ongoing development work. Of these, this report addresses two key aspects:

1. Systems of work for the chipping operation require further refinement to maximise chipper productivity and overall supply chain costs, with a particular emphasis on felling systems and on logistics development.
2. Related to the above, there is unsurprisingly a lack of experience among felling contractors of the systems of work involved in woodfuel harvesting that has produced tangible operational issues.

The structure of the report comprises two elements:

1. Presentation of two case studies: Hall Farm, Garboldisham, and Rougham Estate, Rougham.
2. Presentation of the results of techno-economic modelling work.

Key conclusions:

1. Presentation: the presentation of pre-felled material has a fundamental impact on chipper productivity. The optimum presentation of material is directly in-line with the chipper, or at an angle of less that 20° to either side with all the butts facing towards the chipper throat. It is very often not possible to achieve the accuracy of presentation required using motor-manual felling, presenting a significant issue for many hardwoods and for multi-stemmed (coppice) material in particular.

2. In-wood logistics: once chipper productivity reaches acceptable levels, efficient in-wood logistics become essential to achieve optimum efficiency of the overall system. Specifically, in a terrain-chipping context this involves transferring the chips from the chipper high-tip bin into a separate carting unit. Although an agricultural tractor and trailer combination offers a starting point, the limited terrain capability of such a configuration is a significant constraint and a dedicated and more terrain capable shuttle that can approach the chipper directly is required - such a machine is being developed by Econergy during 2002.

3. Moisture content: unlike traditional pulp markets, the issue of moisture content is often an important one for the energy market. Experience during the operations (and subsequently) has highlighted the fact that the process of drying is not well understood - the degree of variation in moisture content at the second case study site (Rougham), together with it's apparent unpredictability, was particularly striking. No detailed conclusions could be drawn and without further work the best rule of thumb available is one established from Danish experience, i.e. that achieving reliable dying of this type of material (whole trees or whole tops left in situ after felling) requires it to lie for at least one summer.

4. Chipper productivity and chipping costs: a cost model has been developed allowing chipper productivity to be correlated with chipping cost. A standard case figure of 2.75 odt's per hour provides a chipping cost of approximately £16.50 per odt for the chipping itself (i.e. excluding all other costs). This is a cautious rate reflecting an aggregate productivity for the Surefire over the whole of the work period, which was also the proving period for the machine. It has been exceeded in good working conditions - the maximum spot productivity achieved is a chip-bin fill time of 6 minutes, equivalent to c.7.5 odt / hour, believed to be approaching the maximum productivity of the machine. The implication is that there is still significant loss of productivity in the system and there is a continued emphasis on addressing the key productivity issues - presentation and in-wood logistics (above). Other systems of work also merit attention, particularly fell and extract systems.

5. Harvesting systems cost-benefit: one of the factors to have emerged from the operational experience gained is the degree to which reduced processing time for each stem in a woodfuel recovery context can impact on the productivity of the solid wood harvesting operation, and allow that productivity to be focused on the higher value products. Under present market conditions in

the Eastern Region, cutting shortwood pulp is marginal at best and will often be loss-making. The advent of an energy market may allow this material to be diverted to woodfuel production, and in appropriate circumstances the cost-benefit to the harvesting operation can be significant. A spreadsheet model has been developed to assess this benefit on a site-by-site basis.

Areas for future work:

The work undertaken was limited in its scale and ambition and has highlighted areas of follow-on work which would certainly assist in the further development of the woodfuel sector in the region, including:

- work on mechanisation of felling of hardwoods and multi-stemmed material
- work on in-wood logistics (being addressed by Econergy's development of a dedicated chip shuttle during 2002)
- work on passive drying
- trials of alternative supply chain routes
- work studies to assess the productivity benefits for conventional harvesting offered by woodfuel recovery of whole stems or whole 'long-tops'

1 Introduction

This report sets out work undertaken by Econergy Limited to develop systems of work that will allow undermanaged woodlands and what might be termed 'undermanaged forestry' within the Eastern Region to be accessed economically for the production of woodfuel. The work builds on previous technical development work by Econergy to design and construct the *Surefire* Woodfuel harvester[11]. The *Surefire* was built to have a high degree of versatility to enable it to produce chipped woodfuel utilising low-grade material derived from woodlands in the region, including the many undermanaged woodlands (see Annex I for technical specification).

The re-introduction of positive management to the large 'neglected' or 'undermanaged' woodland estate in the region will bring a range of benefits that relate directly to the England Forest Strategy (EPS) and the Regional Assembly / Sustainable Development Round Table Sustainable Development Framework, including:

- income generation
- employment
- improvements in quality and future economic value
- significant enhancement of wildlife / habitat value
- improved value for sporting and other amenity uses

Woodfuel will be produced for sale to the increasing number of end-users in the region, including both power stations and heating plants, providing a valuable new source of income to woodland owners and to existing forestry contractors.

The financial assistance provided by the Forestry Commission East of England Conservancy to support this work is gratefully acknowledged.

[1] The Surefire harvester build project was partly financed by the European Agricultural Guidance and Guarantee Fund and by the DTI's new and Renewable Energy programme.

2 Technical background

2.1 The woodland sector in East England

The Eastern Region has a substantial woodland resource - in Norfolk and Suffolk alone (the primary catchment for Econergy's initial woodfuel operations) there is approximately 84,000 ha of woodland. Although the public estate managed by Forest Enterprise (FE) is substantial, FE nevertheless manages just 28% of this total, with 72% of the woodland area privately owned[2]. The former is mainly accounted for by Thetford Forest, the largest lowland forest in the UK. However, although Forest Enterprise runs a large-scale commercial operation in Thetford, in the current climate in British forestry the viability of timber production is reduced even for this operation, and private woodland in the region suffers from significantly worse problems. Thus, of the total woodland estate, it is estimated that 50%, or 42,000 ha in Norfolk and Suffolk, is largely unmanaged, all of this being in the private sector, i.e. approximately 70% of the private woodlands are undermanaged. In this context, a survey of woodland owners in the region conducted by Anglia Woodnet identified lack of economic return as the single most commonly cited reason why woodlands are unmanaged).

Although the highly depressed state of the timber market as a whole makes the problem particularly acute at the present time, this picture of neglect is a long-term one driven by a number of complex and inter-related factors. A result of this history of neglect is a significant decline in the quality of standing material, which then produces a self reinforcing trend:- reduced quality ► reduced value ► further neglect ► further reduction in quality and so-on.

While this applies particularly to the relatively small blocks of mainly mixed or broadleaf woodland that are a ubiquitous feature of farms and estates in the region, it also applies to many ostensibly more 'commercial' plantations, some of which may remain unthinned 40 or more years into rotation. This means that any attempt to re-introduce positive management has to deal with a standing crop of predominantly low-grade material. However, the region is remote from the major pulp markets in the UK, which are anyway in decline, so that haulage costs have a detrimental effect on prices obtained at roadside. This situation very often results in the cost of harvesting roundwood exceeding the price obtained from pulp buyers. In better crops and in better market conditions the net cost of harvesting low-grade roundwood is subsidised by return from higher value products. Even in good times this erodes the return from sale of sawlogs and bars and the price that can be paid for standing timber, but at the present time market conditions are such that more and more woodland is slipping into economic unviability, generally with an attendant loss of wildlife and amenity value.

With returns from higher grade products significantly diminished but nevertheless generally profitable, the degree to which the limited market opportunity for low grade material represents a major constraint on improving woodland management can hardly be over-stated. It is in this

[2] Source: The England Rural Development Plan for the East England Region (2000-2006). Based on Forestry Commission data (1998)

context that woodland owners, managers and contractors in the region are all eager to see new, local markets of the type represented by the energy market.

2.2 A new market opportunity- biomass energy development

2.2.1 NFFO plants

The development of biomass energy plants has begun to create a new market for lower-grade wood products in the region. Hitherto, the main driver behind this process has been the Non-Fossil Fuel Obligation (NFFO), a support programme for renewable power generation set up under the 1989 Electricity Act. The Minister of State used the powers granted to him by the Act to lay an 'order[1] that obliges the twelve Regional Electricity Companies (RECs) to purchase electricity from renewable generation plants up to a given capacity in MegaWatts. Contracts were awarded via a competitive tendering process in rounds or *tranches* during the 1990's, with successful bidders securing a price that is greater than the prevailing market price for electricity. The price is guaranteed and index linked for 15 years.

The Fibrothetford power station seen from the A11

Under the NFFO a number of contracts were awarded to biomass fuelled power stations in the Eastern Region:

- The 38MW$_e$ FibroThetford plant based on combustion technology and using mainly poultry litter as fuel. This plant was commissioned in 1998 and consumes up to 480,000 tonnes of fuel annually. Currently somewhere in the region of 10-15% of the fuel used is woodchip creating an annual market of perhaps 50-70,000 tonnes.
- The 31MW$_e$ Elean plant at Sutton, Ely based on combustion technology and mainly straw as fuel has been operating since July 2001. Straw supply problems mean that the plant is seriously considering the introduction woodchip co-firing during the next year which would require in the region of 40-50,000 tonnes per annum.

- The 5.5MW_e Novera project at Eye based on gasification technology will use exclusively wood as a fuel. Construction is due to begin in 2002 and on completion in 2003 the annual requirement for woodfuel will be 65,000 tonnes.

In addition to woodfuelled power plant located in the East of England the following power stations are expected to source at least some proportion of their fuel from within the Region.

- The 8MW_e Project ARBRE in Yorkshire using gasification technology will mainly use forest / woodland derived material for its first 3-5 years of operation, switching increasingly to locally sourced Short Rotation Coppice (SRC). The plant is undergoing commissioning trials and seeking start-up fuel from the East of England.
- A 31MW_e project in Corby based on combustion technology and using a third to a half woodfuel is nearing financial close and is expected to be commissioned in 2003/4 with an annual woodfuel requirement of up to 100,000 tonnes.

2.2.2 The future

Bidding for NFFO contracts was withdrawn in January 2000 to be replaced by a *Renewables Obligation* created by statutory instrument under a framework provided by the Utilities Act on the 1st April 2002. This will provide a significant additional market stimulus to biomass electricity generation, including both new-build plant and co-firing of biomass into existing generation plant. It is also further supported by a number of other fiscal and regulatory measures that will also create more diversified opportunities for biomass heating and CHP:

- the Climate Change Levy (CCL) which imposed a tax on fossil fuels from April 2001 (excluding oil, which is covered by existing duty arrangements);
- Enhanced Capital Allowances (ECA's) which provide tax relief on investments in eligible low carbon technologies;
- a DTI sponsored UK Emissions Trading Scheme (ETS) which came into effect in March 2002;
- substantial pump-priming funding that will be available for biomass later in 2002 under a range of measures including capital grants for heat, CHP and electricity generating plant (the Bio-energy Capital Grant Scheme) and also for fuel supply infrastructure.

Although for the next several years the main market driver will remain the demand for woodfuel created by electricity generation plants, the development of wood heating sites such as the EcoTech Centre at Swaffham also provides a small but growing market for woodfuel that will develop under the stimulus provided by these measures. While individual heating plants are smaller than electricity generating plant, the market for heating and process fuels in the UK is larger than that for electricity (approximately 45% of total energy use). In addition, woodfuel heating is probably *the* lowest cost of all renewables, and in this context the wood heating (and in some degree CHP) sector is set to grow rapidly. In those European countries where energy from wood is already integrated into the energy supply infrastructure, the largest proportion of woodfuel is used to generate heat. It is expected that this will increasingly become the pattern in the UK as the wood energy industry matures.

2.3 Woodfuel production

Currently, the major sources of wood-chip in the East of England that can be drawn on to satisfy the fuel demands of these plants are coniferous clearfell residues, and line and selective thinning of larger conifer plantations. However, comparing the likely level of demand with the currently accessible fuelwood resource indicates a significant excess of demand over supply in the medium term, by a factor of perhaps 1.5 or 2:1. It is likely that SRC production will be established to partially meet this demand[3], but the intrinsic lead time involved means that substantive fuel supply from this source will take 5-10 years to mature. Thus, alternative fuel sources must be developed in the short-medium term and, in the longer term, continuous development of biomass energy will ensure ongoing and increasing demand for woodfuel from all sources.

2.3.1 Meeting the demand

Against this background, there is a clear market opportunity to bring currently undermanaged woodland and 'undermanaged forestry' back into more productive use to provide the woodfuel that will be needed to satisfy increasing demand. The low-grade material produced from this type of woodland is well suited to this market, and increased management would bring important and tangible benefits - economic, environmental and social. However, accessing these woodlands economically presents significant challenges.

2.4 Early operational lessons / technical challenges

Econergy began pilot woodfuel production operations in the region during 2001[4]. Based initially on a highly mobile chipping unit that is able to access relatively small blocks economically, this has shown early success in achieving tangible impacts in just the first few months of operation:

- >50ha of woodland harvested (mainly delayed thinning) in blocks down to 1ha;
- in excess of 5,000 tonnes of material processed much of which had previously been rejected by conventional contractors with positive income generation for owners (up to £2.00 per tonne);
- significant quantities of conventional product (sawlog, bars) liberated that would be otherwise uneconomic to recover;

[3] A fledgling 'producer group' for energy crops is being established in South Norfolk / North Suffolk with the aim of planting SRC to respond to market demand. An initial area of approximately 75ha has been established on 5 farms.

[4] In the latter part of 2000, Econergy reached agreement with FibroThetford to supply an initial 5,000 tonnes of woodchip to their plant at Thetford for the purposes of carrying out trials on the Surefire woodfuel harvester and proving of systems. The price obtained was for woodchip at roadside and within a 20-mile radius of the power station, thereby setting the geographical limits to the initial operations. Anglia Woodnet and the Norfolk County Council Forestry Officer gave invaluable assistance in providing contacts with owners of under managed woodlands in this catchment. This factor enabled Econergy to successfully begin a rolling procurement process that is now ongoing based on a 6-month forward programme of purchase, felling and chipping.

- implementation of previously stalled Woodland Grant Schemes (WGS);
- implementation of conservation management schemes backed by English Nature;
- full-time employment created for 2 machinery operators.
- employment created for 2 existing contractors for felling work.

However, while these operations have demonstrated the 'win-win' opportunities offered by woodfuel production, they have also led to the identification of a number of issues that highlight a need for ongoing development work:

1. There is a lack of detailed knowledge of the resource: valuable support has been received from Anglia WoodNet and the County Woodland Officers in identifying potential woodlands, but is apparent that the resource far exceeds that which is 'on the books' of these and other organisations. This was confirmed by a recent Woodland *Assessment Project* undertaken by Anglia WoodNet.
2. There is a lack of understanding or experience of forestry operations among many, even of those owners who have a pre-existing interest in bringing their woodlands into management. Among the large body of owners that have hitherto hardly considered their woodlands this will be even more so. The result is a lack of confidence in entering into contracts for management operations and an ongoing need for reassurance and 'handholding'.
3. Systems of work for the chipping operation require further refinement to maximise chipper productivity and overall supply chain costs, and therefore ensure the viability of the operation, with a particular emphasis on felling systems and on logistics development.
4. Related to 3., there is unsurprisingly a lack of experience among felling contractors of the systems of work involved in woodfuel harvesting, particularly: whole-tree felling without processing or with only limited processing; operation of mechanised harvesting machinery in a small woodland context; bona fide silivicultural thinning in woodland contexts that would rarely otherwise be managed in this way. This has produced tangible operational issues including, in some quarters, a high degree of caution in quoting for costs of work and an insistence on a high degree of marking and ongoing supervision rather than pure feller-select operation.

The Forestry Commission funded work undertaken within the scope of this project relates specifically to 3 and 4, above[5], and the structure of the remainder of the report comprises two elements:

1. Presentation of two case studies:

- Hall Farm, Garboldisham - the first site to be harvested using the *Surefire* from where a number of lessons were learned; and

[5] Separately funded DTI projects will begin to deal with further mechanisation / equipment development requirements: development of a dedicated chip shuttle for chip extraction from the compartment; and development of an onward logistics system based on developing self-loading large (>70m^3) containers for the roadside - transport interface. The results of the current work will provide feedback that will be input to the detailed specification of these developments. It is also possible that future support may be sought for the development of dedicated felling

- Rougham Estate, Rougham - the most recent site to be harvested where some of the lessons learnt at Garboldisham were used to adapt the pattern of work.

2. Presentation of the results of techno-economic modelling work drawing on the experience of operating woodfuel systems gained to date.

These are followed by a number of summary conclusions.

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machinery.

3 Case studies

3.1 Case Study 1: Hall Farm Woodlands, Garboldisham

3.1.1 Description

The first woodfuel harvesting operations undertaken took place in woodlands belonging to Hall Farm, Garboldisham. Hall Farm is an arable farm of 242 hectares, located 9 miles to the west of Thetford in Norfolk. The soil is a light sandy loam of loess origin overlying glacially deposited boulder clay on chalk bedrock. Aquifers in the chalk provide irrigation water for the root, cereal and herb crops grown on the farm.

In common with other farms in the area, shelterbelts have been established to reduce wind erosion of the light soil. Thus, the woodlands at Hall Farm are divided into 12 separate compartments ranging in size from 0.12 to 3.80 ha and covering a total of 16.74 ha. The majority of the plantings date from 1953 to 1964 and consist of a mixture of conifer and broadleaved species. Naturally regenerated broadleaved trees of coppice and self seeded origins are present throughout, presumably encouraged by low levels of post planting maintenance. Virtually no thinning had been carried out since planting and almost no management of any kind had taken place since the gales of 1987.

As well as their role as shelterbelts, the woodlands are also used to provide cover for game birds and rental of the shoot to a local syndicate provides a modest annual income from the woodlands[6].

Econergy made contact with the owner of Hall Farm, Mr. Stephen Collet, for whom a WGS application had been prepared by Norfolk County Council's Woodland Officer working under the aegis of Anglia WoodNet. The plan of operations within the approved WGS prescribed a thinning to improve the quality and vigour of the trees, and to prevent the conifer element from suppressing the broadleaved species. The thinning was also intended to stimulate development of ground flora, creating a much improved shrub layer and understorey within the woodlands and thus increasing both their environmental value and their capacity to hold game birds.

The small scale and fragmented nature of the woodlands combined with the very poor quality of the standing timber meant that the costs of a conventional harvest operation outweighed any return from the sale of product. This resulted in the owner being unable to find a contractor who could carry out the thinning and provide a positive financial return. Thus, prior to reaching agreement with Econergy, the owner had not signed and returned the approved WGS.

[6] As an important aside, the syndicate that rents the shooting at Hall Farm expressed some considerable concerns at the planned operations and actively sought to dissuade the owner from proceeding. This reflects the limited experience most people have of forestry operations and a commonplace but ill-conceived perception that thinning operations will 'damage' the woodland. In practice, the drawn-up, 'draughty' undermanaged woodland lacking an understorey or shrub layer is a relatively poor environment for game birds and the effects on its sporting value of a properly specified and implemented thinning will generally be beneficial.

3.1.2 Woodfuel harvesting operations

Introduction

Several factors effectively determined the sequence of operations on the site:

- the FibroThetford plant for which the woodfuel from Hall Farm was destined requires material to be delivered at <45% moisture content;
- the woods contained a proportion of saleable solid product that was to be recovered;
- the scope of the thinning required that hardwoods not readily felled using a mechanised harvester should nevertheless be thinned.

Based on these requirements, the sequence of operations was as follows:

1. mechanised felling of conifers and separation of solid product
2. forwarding of solid product to a roadside landing
3. motor-manual felling of hardwoods
4. forwarding of poplar sawlogs to roadside landing
5. remaining material (>65%) left *in-situ* to partially dry prior to chipping
6. terrain chipping within the compartments using the *Surefire* harvester; chipped material extracted as produced to a stacking area adjacent to the largest woodland block, initially in the harvester's own high-tip bin, latterly in a tractor and trailer
7. chips loaded into bulkers using the farm telehandler and delivered to the power station at Thetford in batches of > 100 tonnes

Thinning methods

14.21 ha of the total 16.74 ha of woodland on the farm were thinned. GNF Forestry Services, a local forestry contractor, were engaged by Econergy to carry out the felling, and they also marketed the saleable solid product. Sample areas in each compartment were marked for thinning by Econergy forestry staff to act as a guide for the contractor who then carried out the bulk of the work on an operator select basis.

Conifers

Where conifers predominated in a stand (in over 65% of the area worked) thinning was carried out using a Logset 555 harvester head on a tracked 180 hp JCB base unit. Access racks were cut at 12m centers with a light silvicultural thinning between the racks. The harvester cut sawlogs and fencing bars from the larger stems, which were forwarded to roadside and sold. The remaining portion of the tree was left stacked in the racks to be chipped by the Surefire Harvester.

Thinning of conifers started on 17 April and was completed on 26 April 2001

View down a rack towards the harvester in distance

Whole tops left in the rack for 2nd pass chipping

Harvester tipping @ stacking area prior to use of shuttle

Stacked solid product prior to removal

Hardwoods

In the hardwood blocks a two man felling gang was employed to fell selected trees and cut the larger branches to facilitate the chipping operation. A small quantity of poplar sawlogs (P. 1929) was extracted from one of the compartments. The remainder of the hardwoods were left where felled. Preparation for the chipping operation entailed cutting off butt end sections of the logs where the diameter was > 350 mm and cutting large branches to facilitate passage of the tree through the chipper.

Thinning in the hardwoods began on 10th May and was completed on 24th May 2001.

Timber products

The following weights of high-grade timber were sold from Hall Farm:

Conifer sawlogs	56 tonnes
Conifer fencing bars	165 tonnes
Poplar sawlogs	50 tonnes
Total	271 tonnes

Thinning operation: commentary

Although not readily quantifiable, the first and most apparent lesson was the speed with which the mechanised operation was able to be completed, with the contractor's immediate reaction being that this was substantially faster than a conventional thinning operation (spending perhaps as little as 50% of the time on-site that would normally be expected). The forwarder in particular was on-site for just 3 days.

The speed of work achieved was notwithstanding the second lesson learned from the site, viz. that the excavator-based harvester was a clearly limiting factor in terms of productivity. The machine, which is somewhat better suited to clearfell contexts, was not really 'at home' in this small woodland setting, with specific constraints on manoeuvrability and speed of work including:

- base machine width;
- the tailswing that is a feature of all tracked machines; and
- limited off-side operator vision.

Note: GNF Forestry have subsequently replaced this harvester with a wheeled machine, the decision to move from tracked to wheeled base unit being substantially driven by the requirements of working in a thinning context, and in some degree informed by the potential of the woodfuel market to generate increased amounts of such work.

Woodfuel harvesting

Following extraction of round timber products, the remaining poorer quality stems (including all of the hardwoods bar the poplar sawlogs) and all of the tops were left un-snedded in the woodland to reduce in moisture content prior to the chipping operation. A central area for stacking woodchip for onward shipment was arranged with the owner adjacent to the largest woodland block.

The woodfuel harvester began work on 18th June after the felled trees had been drying for between 6 and 8 weeks. This operation was essentially the commissioning trials period for the machine. Thus, although the *Surefire* worked for a total of 50 man-days on site, this figure cannot be used to calculate output rates due to the modifications, adjustments, improvements and associated downtime that took place during this time. However, some 'spot' productivity figures have been estimated based on observations of individual bin filling and tip cycles[7].

Working methods

The *Surefire* began chipping in the plantation nearest to the stacking area, driving into the wood to carry out the chipping by driving along the racks. The cut stems were fed into the chipper with the timber grab, the woodchip being conveyed from the chipper directly into the 10m^3 high-tip bin mounted on the rear of the Unimog chassis. When working close to the stacking area, full bins were tipped directly onto the stack by the *Surefire.* As the chipper worked further from the stack, the high tip bin discharged directly into an agricultural tractor/trailer unit, which shuttled the material to the stack.

[7] Production rates are expressed in tonnes per hour calculated using records kept at the time. The production rate includes time taken shuttling the material to the stack or to a tractor trailer at the woodland edge. Calculations are based on a bin capacity of 10 m^3, and a bulk density for chipped woodfuel of 0.24 tonnes per m^3 obtained from weighbills and measurements taken off bulker lorries used to transport the material to FibroThetford.

Due to the unacceptably low rates of production obtained in the hardwood blocks (see below) a set of hydratongs mounted on a 2 wheel drive farm tractor was brought in to arrange the stems prior to chipping. Stacks of cut stems were formed at rackside or where convenient for chipper access within the wood.

Woodfuel harvesting: commentary

As indicated above, the harvesting operations at Hall Farm were the first undertaken with the *Surefire* harvester and a number of invaluable lessons were learned from the operations there. Overall productivity of the machine varied from a lower extreme of c.1.35 tonnes per hour in the worst of the hardwood blocks to as much as 10.5 tonnes per hour when working material that had been re-presented with the hydratongs. What became apparent is that in this type of context the ability of the chipper itself to chip material presented to it was not a limiting factor. Instead, two factors are key and will be elaborated below:

1. The first variable that has a fundamental effect on productivity is the rate at which the timber grab can feed material into the chipper. While the speed of operation of the crane (based on operator performance, crane specification and hydraulic specification) could be a limiting factor, experience showed that the actual limiting factor was a combination of a) presentation of the felled material with; b) the long length of many stems (which were essentially whole trees or large portions of trees) and; c) the limited lifting and turning ability of the crane when fully extended to recover material that could not be directly approached (e.g. between the racks). Several facets to this were observed:

    a. The motor-manually felled hardwoods produced an essentially random presentation of material in whole-tree lengths in, across and between the racks. This material was extremely difficult to chip at all and certainly resulted in wholly uneconomic levels of productivity (as low as 1.35 tonnes per hour).

    b. It was the poor presentation of the hardwood material in particular that led to the deployment of the hydratongs on the site. This in turn demonstrated the high production capability of the machine when working with well-presented material (>10 tonnes per hour). Indeed, the hydratongs could not keep pace with the chipper, which generally carried on working less well presented material while the 'tongs' were used to accumulate further material[8]. However, while use of the hydratongs proved worthwhile on this operation given the circumstances, introducing a third item of equipment and an additional crew member to the harvesting gang is not viable in the long-term. From this it is apparent that alternative working methods to motor-manual felling must be developed for this kind of material.

[8] Learning from this lesson, on other harvesting contracts in the area, including a heathland clearance hardwood clearfell at East Wretham, hydratongs were used to arrange the cut stems before the chipper arrived on site.

c. In the conifer thinnings the contractor had used the harvester head to stack logs and bars on one side of the thinning rack for extraction by forwarder, and material for chipping had been stacked on the other side of the rack. However, even in the better-organised conifer material left behind by the harvester, presentation of material remained an issue that limited productivity - typical outputs were between 3 (uneconomic) and 7 (just viable) tonnes per hour. The specific issues that arose were:

- it was only once on-site that it became apparent that the angle at which the stems lie relative to the rack / harvester approach is extremely important - essentially, the crane feeds the chipper most effectively when pulling it in from a relatively tight ark in front of or immediately in front and to the side of the machine; once material was at a more oblique angle or placed between standing trees, it became much more difficult to feed;

- related to the above, the ability of the harvester to push sterns through the head meant it could effectively put them beyond the recoverable reach of the crane - long lengths of material presented at 90° to the rack were extremely difficult and time-consuming to feed.

2. The second key variable dictating overall productivity is the speed with which the harvester can discharge a full bin of chips and return to work, this combined with the actual chipping giving the complete cycle time. For much of the early part of the work, it was lack of basic chipper productivity that dominated, however it was recognised from the outset that once productivity was improved (for example through use of the 'tongs') removal of the chip to the stacking area would become the next key limiting factor to productivity.

   As indicated above, the harvester worked on its own during the initial stages of the operation, primarily because this was essentially a machine shakedown period. However, once through the initial period, and when the areas closest to the stacking area had been chipped, a tractor and trailer 'shuttle' was introduced to the system. The unit used was hired from the farmer and, while it was effective enough given the other limiting factors at Garboldisham, it was apparent in high productivity situations that turn-around time on the shuttle could clearly become limiting. The limited terrain capability of conventional farm tractors and the limitations of reversing tractor and trailer combinations in a woodland context were also manifest. However, this issue is explored further in the next case study, where it was looked at more carefully.

In total 498 tonnes of woodchip was produced from the thinning, representing c.65% of the total amount of material recovered from the operations. This is a larger quantity than would have been obtained had the material been processed into pulpwood, since the tops and branches are also utilised in the woodfuel harvesting operation. Moisture content measured at the FibroThetford power station varied from 35-44%, averaging 40% overall, within the maximum of 45% acceptable to the customer.

Note: although not the subject of this report, it is worth remarking that the remaining crop at Garboldisham (the thin having removed c.35% of the individual stems) showed an immediate response during the following growing season. The initial reaction of the owner to the work carried out was some degree of alarm at the apparent starkness of the woodlands, and there were indeed substantial gaps in the hitherto continuous canopy. However, this is clearly the point of carrying out a thinning operation and, even by the autumn following the operations, the remaining trees had shown a tangible response to the reduced competition, with the racks having ail-but closed over in many places. Although the long-term neglect that has affected these woodlands means that they will never produce a high quality timber crop, there is no doubt that the operations carried out have stimulated increased rates of growth among the remaining stems, having also removed the poorest quality stems, and there is every prospect of returning to these woods in the medium term and releasing further value to the owner.

3.2 Case Study 2: Rougham Estate

3.2.1 Description

The first site at which some of the lessons learned from early operations began to be addressed was at Rougham Estate located 6 miles north of Swaffam in Norfolk. The soil is a clay loam with flint, deriving from boulder clay and loess deposited over chalk bedrock during and following the last glacial period. Drainage is less good than on the Breckland soils with water lying on the surface in wet periods, although the site remained readily trafficable throughout both the felling and chipping operations.

The Estate contains 161 ha of mixed coniferous woodland. There is one large block of 58 ha located 1 mile to the south west of the village of Rougham; the remainder is in outlying plantations ranging in size from 2 to <10 ha. The woodland was essentially planted in two phases:

- The largest part of the woodlands were planted during the 1920's, following their acquisition by the Forestry Commission, replacing hardwoods felled in the First World War. These plantings consist of a mixture of Scots Pine, Douglas Fir, Corsican Pine, Norway Spruce and Silver Fir. Hardwood species have regenerated within the plantings including Sycamore, Oak, Lime, Sweet Chestnut and Birch. Many of these are sub dominant within the canopy, their form is generally good although girth is slight.
- The second tranche of planting took place during the 1970's and 1980's. The range of species planted more recently is limited to Scots and Corsican Pine with some Norway Spruce in the outlying blocks. Less regeneration of hardwoods has taken place in these plantings.

The woodlands have generally benefited from a fair level of management and the most recent thinnings were carried out in the mature stands in 1988.

Management policy

Ownership of the woodland passed to the present owner, Dr Peter North of Rougham Hall, in 1997. He wishes to gradually restore the woodland to a hardwood mixture while maximising the return from the conifer crop, and the wildlife conservation value of the woodlands enjoys a high priority. However, prior to Econergy's approach, he had been unable to find a contractor able to undertake the thinning work economically.

The owner has no personal interest in shooting and, while he allows his tenants rough shooting rights over the land, forestry operations are not constrained by consideration of sporting interests.

Econergy made contact with Dr. North via his agent, Mr. Tom Little of Savills. The pre-existing WGS required renewal as the prior difficulty in finding a contractor willing to undertake the work at an economic price meant it had languished for quite some time. A plan of operations was agreed with the owner for a thinnings operation in blocks representing the two age classes on the estate:

1920's plantings

Within the 1920's plantings the objectives of the thinning were to favour hardwoods of good form and to thin the conifers to final crop spacing, favouring Douglas and Silver Fir. A total of 58.06 ha, in 5 blocks, were thinned to existing racks with 4 rows between the racks. Approximately 30% of the conifers were removed in the thinning. With Dr North present, Econergy forestry staff marked sample blocks of trees to be removed as a guide for an operator select thinning.

Later plantings

Blackground Plantation, a 7.7 ha block of Corsican Pine planted in 1976, was identified for a first thinning. The specification for this operation was for a line thinning to remove 1 row in 6.

3.2.2 Woodfuel harvesting operations

Introduction

As at Hall Farm, the work was carried out using a Logset 555 harvester head on a tracked 180-hp JCB base unit operated by GNF Forestry Services. A key goal was to improve the presentation of felled material for the second-pass chipping operation by:

- avoiding placing chip material into the remaining crop by shooting it through the harvesting head;
- ensuring all butts faced a common direction towards the approach of the chipper (which was not possible for the motor-manually felled hardwoods at Hall Farm);
- placing chip material as near parallel to the rack as possible;
- where possible, placing chip material into the centre of the rack, lying parallel with it.

As at Hall Farm, the intention was to leave the material for some months to dry prior to the chipping operation.

1920's plantings

The thinning was carried out over an 18 working day period between 23rd July and 15th August 2001. Mean volume of the felled trees was estimated at $0.35m^3$. Sawlogs and bars were processed from the felled trees and stacked to one side of the rack, then forwarded out to roadside for sale. The remainder of the tree, comprising that portion of the stem that would otherwise have been processed into pulpwood together with the top, was stacked on the opposite side of the rack to the logs, as at Hall Farm but with a greater attention to the presentation (see above). The size of the material prevented it from being left within the rack, but every effort was made to leave it at a tight angle to the rack in order to minimise and simplify the subsequent chipper crane movements.

Later plantings

The thinning was completed in 3 working days in August. Mean volume per tree was $0.04m^3$. A limited quantity of fencing bars was produced and laid to one side of the rack for forwarding to roadside. The remainder of the trees, comprising the larger majority of the material, was laid in the centre of each rack. The size of the stems meant that the harvester, and subsequently the forwarder, was able to straddle the felled trees as they drove down the racks. Although some of the branches were compressed into the litter layer, the mineral soil does not appear to have adhered significantly to them, and generally there was sufficient clearance to allow the machinery to work unhindered.

Above: harvester at work, Garboidisham

Right: rack with pre-felled chip material at Rougham

Timber products

The total tonnage of log material produced from Rougham is as follows

Conifer sawlogs	381.22 tonnes
Conifer fencing bars	606.66 tonnes
Total	988.32 tonnes

Of this total, an estimated 40 tonnes of bars were produced from the line thinning at Blackground Plantation, leaving a figure of 948 tonnes produced from the older stands.

Thinning operation: commentary

As at Hall Farm, the contractor reported that the harvesting operation was substantially faster than would normally be expected. Importantly, the increased attention to presentation was not believed to have had any detrimental impact on productivity. Equally, the experimental approach of placing the smaller stems in Blackground Plantation into the centre of the racks where the machinery straddled them also proved essentially unproblematic. However, it was clearly not appropriate for the larger and more heavily branched older material.

Once again it was apparent that the excavator-based harvester was not really the optimum unit for working in this type of relatively constrained context (see above).

Woodfuel harvesting

Following extraction of round timber products, the remaining poorer quality stems and tops were left un-snedded in the woodland to reduce in moisture content prior to the chipping operation. Use of a stacking area for woodchip was agreed with the owner at a former sawmill site approximately 34 mile from the woodlands at their nearest point. This dictated use of a tractor-trailer chip shuttle to ferry chips away from the chipper unit to the stacking area from the outset of the chipping operations.

The woodfuel harvester began work on 13th December after the felled trees had been drying for c. 15-21 weeks, according to felling date. From the outset there were concerns that the drying period had not encompassed sufficient of the warmer summer period to generate the level of moisture loss required by the Fibrothetford power station (max delivered moisture content 45% wet basis). However, the operations went ahead, partly in order to honour the commitment made to the owner.

Working methods

The *Surefire* began chipping in Blackground Plantation, operating in essentially the same way as previously, i.e. chipping the pre-presented material in the racks. However, as indicated above, the distance to the stacking area meant that a chip shuttle was required from the outset. The unit used was a 4wd MF tractor with forestry guarding combined with a 10m^3 dump trailer. The hydratongs which were used to re-present some of most poorly presented material at Hall Farm (particularly the motor-manually felled hardwoods) were not required at Rougham.

Production

Approximately 315 tonnes of woodchip have been produced from Blackground Plantation to date, with an estimated 315 tonnes of material remaining to be chipped in this block in addition to the 40 tonnes of bars that were recovered. In the older stands, 948 tonnes of log material was obtained, clearly a far higher proportion, reflecting the relative maturity of the crop. At the time of writing, the chipping had not been undertaken here but it is estimated that the volume of chip material comprises 20% of the total felled. The current best estimate of woodchip to be obtained from these stands is therefore 237 tonnes.

Summary:

Blackground Plantation, 7.7 ha line thin	315 tonnes woodchip produced
	315 tonnes material to be chipped
Mature stands, 58.06 ha final thin	237 tonnes material to be chipped
Total woodchip on completion	867 tonnes

Woodfuel harvesting: commentary

Productivity

As indicated above, the intention at Rougham was to build on the earlier experience at Hall Farm in order to improve the productivity of the system by improving the presentation of the material. In the event, productivity was also improved by having an extremely experienced operator on the chipper unit[9]. (Note: anecdotally his comment was that the material in Blackground Plantation was as well presented as any he had encountered.)

Productivity inevitably varied, particularly in the first few days on the site. However, once the crew established a rhythm, productivity was up to 22 bins per day, equivalent to c.176 m^2 or in the order of 50-55 tonnes per day, and over a 7-day period it averaged approximately 45 tonnes per day. Note: at the time the material was being chipped, working hours were constrained by the limited daylight.

This is clearly a significant productivity improvement over Hall Farm. However, observations of the working pattern indicated very clearly where productivity was being lost. Specifically, the limited terrain capability of the shuttle meant that the chipper was reversing out of the racks to rideside in order to transfer chips the shuttle trailer. The time taken to accomplish this operation varied according to the layout of the compartment. However, as a rule of thumb, a 10-12 minute bin fill time when working in good material translated to a 20-25 minute duration for the full chip and transfer cycle, with at least as much time being spent coming out of the rack as spent chipping.

[9] Michael Farrow, who has previously spent several years operating a *Hafo* front-fed chipper for MI Edwards.

This is a substantial loss of productivity and Econergy had already identified that use of a shuttle with a greater terrain capability represents a next step in refining the system (see also above). Indeed, DTI funding has been secured to develop a prototype machine that will be constructed and proved during 2002. Experience at Rougham vindicated this belief and modelling using time trial data recorded on the site (undertaken as part of the specification process for the prototype) indicates that productivity in excess of 30 bins per day should be achievable with similarly well presented material if the shuttle can approach the chipper for the chip transfer[10].

Note: for reasons outlined below, the chipping at Rougham Estate was halted in early January 2002 by which time no chipping had taken place in the main block of 1920's planting. Thus, the extent to which the improved presentation in this context (i.e. where it was not possible to place the material into the rack) will produce improved chipper productivity is not yet known. However, the assessment by the chipping team is that it will certainly be much improved over Hall Farm.

Other lesser factors effecting productivity were also noted during the observations made of the operations:

1. The machine suffered a greater degree of downtime than desirable (perhaps 15% or greater). Clearly, the woodland environment is a relatively aggressive one and downtime is an inevitable fact of life. In addition, some of the downtime related to elements such as the hydraulic controls that were still being shaken down from the proving process for the machine. Nevertheless, a number of steps are actively being taken to seek to minimise time lost due to breakdown:
   - improved recording of faults and breakdowns to assist in pro-active steps to avoid recurrence
   - improved operator training
   - introduction of a more formalised maintenance procedure and schedule
   - a review of guarding and other protection on the machine
2. The second observation that was made is more minor but is nevertheless subject to ongoing review. Specifically, it was observed that, perhaps unsurprisingly, the element of the chip material that slowed the chipper infeed was the very top of the stems, where they are bushiest. These regularly required assistance from the crane to push them into the chipper throat. This not only indicates lost throughput of itself but, as importantly, it inhibited the operator from retrieving the next stem to be chipped which, in ideal circumstances, would be presented to the chipper throat while the previous stem was still being drawn through.

[10] Based on shuttling distances of ½ a mile up to ¾ of a mile.

Although the recovery of tops is clearly one of the benefits offered by a chipping system in both increasing yield from the site and leaving a 'clean' site, where the tops are relatively unwieldy consideration is being given to either:

- roughly snedding to give a pole; or
- removing the very top of the tree

This will be mailed under appropriate circumstances in the future. Although this will incorporate processing such material for terrain chipping, as at Rougham, it will also be undertaken in conjunction with a trial of an alternative to terrain chipping based on felling and extracting prior to chipping at a landing. In this instance, the objective will be driven by the need to maximise forwarder payloads / productivity as much as by chipper productivity. Trials of such a system are outside the scope of this report, but it is viewed as a potentially important complement to terrain chipping and one that could yield extremely high productivity where circumstances allow.

Moisture content

Although the productivity improvements made at Rougham were very positive, the second less positive aspect to the operational lessons learned at Rougham related to the drying process. As indicated above, the material was felled during the latter part of July / August, and even though the material chipped to date (i.e. from Blackground Plantation) was felled towards the end of that period, it had nevertheless been lying for at least 15 weeks prior to chipping. However, clearly it had been lying for only a portion of the warmer, drier summer period.

As soon as the chipping operation was properly established, samples were taken for moisture analysis. These indicated that the material was very wet - in excess of 55% moisture content (wet basis), up to 60%, which was already evident from the feel of the chips themselves (see also Table 1 below). This probably equates to something near the freshly felled moisture content of this material and implies that no appreciable drying had taken place during the period the material had been lying.

A decision was taken to continue with the chipping even though this material was too wet to send into Fibrothetford. This was partly to show willing with regard to the commitment to the owner to clear the site promptly and partly to see whether it was possible to achieve any degree of drying in a clamp. Thus, approximately 315 tonnes of material (c.35% of the total) was chipped and placed into a clamp at the former sawmill site (the limit of the capacity of this storage area). Chipping was then halted with the intention of leaving the remaining material until early summer 2002 to see whether further drying was achieved.

Subsequent to the termination of the chipping operations, a programme of moisture sampling was initiated, both of the chipped material and of discs removed from the lying material. This indicated a wide range of variability, as set out in the table below:

Sampling	Species	Status	MC%
21-Dec	Soft Wood	Chip off clamp	60
21-Dec	Soft Wood	Chip off clamp	57
03-Jan	Soft Wood	Disc sample	60
03-Jan	Soft Wood	Disc sample	63
03-Jan	Soft Wood	Disc sample	63
04-Jan	Soft Wood	Chip off clamp	52
04-Jan	Soft Wood	Chip off clamp	53
04-Jan	Soft Wood	Chip from chipper	56
05-Jan	Soft Wood	Chip from chipper	55
05-Jan	Soft Wood	Chip from chipper	57
05-Jan	Soft Wood	Chip from chipper	55
09-Jan	Soft Wood	Chip off clamp	53
10-Jan	Soft Wood	Disc sample	32
10-Jan	Soft Wood	Disc sample	31
10-Jan	Soft Wood	Disc sample	63
10-Jan	Soft Wood	Disc sample	57
10-Jan	Soft Wood	Disc sample	47
10-Jan	Soft Wood	Disc sample	37
10-Jan	Soft Wood	Disc sample	32
10-Jan	Soft Wood	Disc sample	48
10-Jan	Soft Wood	Disc sample	35
10-Jan	Soft Wood	Disc sample	34
10-Jan	Soft Wood	Disc sample	34
10-Jan	Soft Wood	Disc sample	33
10-Jan	Soft Wood	Disc sample	33
10-Jan	Soft Wood	Disc sample	55
10-Jan	Soft Wood	Disc sample	52
10-Jan	Soft Wood	Disc sample	33
10-Jan	Soft Wood	Disc sample	34

Table 1 Moisture Content Samples, Rougham

Clearly the moisture sampling was conducted in the context of an operational situation and was therefore in some degree *ad hoc* - it was certainly not set up as a formal trial. Thus, it is simply not possible or appropriate to attempt an elaborate analysis or to draw any detailed conclusions. However, the key rule of thumb that has been reinforced is one established from Danish experience, i.e. that achieving reliable dying of this type of material (whole trees or whole tops left *in situ* after felling) requires it to lie for at least one summer. Although many issues spring to mind, such as whether it was the Causican Pine in Blackground Plantation that was a particular problem (which some anecdotal evidence might suggest), it would be rash to make any more firm inferences. Indeed, it is believed that the whole issue of passive drying is one that still requires substantial further work conducted on a much more formalised basis, something that might be pursued through Technical Development Branch.

4 Techno-economic modelling

Using the experience gained from the operations undertaken, two elements of techno-economic work were undertaken, the results of which are set out below.

4.1 Chipper productivity and chipping costs

A host of factors effect the overall delivered cost of woodfuel, and clearly it is important to optimise the whole supply chain in order to produce woodfuel cost-effectively and competitively. There are a series of challenges in this regard, including felling systems, in-wood logistics, control of moisture content and storage, onward haulage and so-on, and it is beyond the scope of this report to offer solutions to all of these issues. However, at the heart of the operation, achieving a high degree of productivity for the chipper itself is clearly an essential starting point, and during the operational period covered by this work the priority was therefore to evolve an efficient working system for the *Surefire* harvester.

In order to allow for a degree of benchmarking and goal setting, a techno-economic model was constructed to relate chipper productivity to chipping costs. This is now actively used as a management tool by Econergy, who are gradually refining the core inputs and wrapping the other elements in the supply chain around it to give a comprehensive supply chain model. This core chipping cost-productivity model is set out below (note: the yellow boxes are input cells in the original spreadsheet; blue boxes are key output cells).

General assumptions

One green tonne fresh material (gt)	@	50	mc
	equates to:	1.0	m3 solid volume (sm3)
		0.5	oven dry tonnes (odt's)
		4.00	m3 of chipped material

Machine availability & work pattern

Weeks worked / year	48	
Days / week in operation	5.5	
Number of shifts worked	1	
Shift 1		
Working day when harvesting	9	hrs
Time off during day	0.75	hrs
Machine hours per day	8.25	hrs
Standard working day	9	hrs
Overtime on active days	0	hrs
Shift 2		
Working day when harvesting	0	hrs
Time off during day	0.75	hrs
Machine hours per day	0	hrs
Standard working day	0	hrs
Overtime on active days	0	hrs
Total machine working hours	8.3	hrs

Productivity

Machine working hours		8.3	per day
Downtime inc. routine maintenance		12.5	%
Net machine working hours		7.2	per day
Chipper productivity		2.75	odt/day
	equates to:	5.50	sm^3 or gt/hr
		22.0	m^3 of chips/hour
	output / working day:	19.9	odt/day
		40	sm^3 or gt/day
	weekly productivity:	109	odt/week
		218	sm^3 or gt/week
	yearly productivity:	5,341	odt/year
		10,482	sm^3 or gt/year

Machinery costs

Capital cost	£150,000	
Cost of capital	9.5%	
Write down period	6	years
Residual value	20.00%	
Utilisation	85%	

PLUS provision of service van

	£ / month	£ / week	£/day	£/mach	£/sm^3 or	£/odt
Chipper	2,659	614	111.58	15.46	2.81	5.62
Service van	124	29	5.19	0.72	0.13	0.26
Total	2,783	642	116.77	16.18	2.94	5.88

Other costs

Labour cost

		8.00	£ / man-hour, standard time
at standard time times	1.0	8.00	£ / man-hour, overtime
	equates to	72	£ / working day / person, shift 1
	and	0	£ / working day / person, shift 2
	(represents	396	£ / week / person working shift 1)

gang size / shift		1	
labour cost shift 1		72	£
labour cost shift 2		0	£/day
additional motor-manual cutter		0	£/day
foreman / spare man		0	£/day
total labour cost / working day		72	£/day
	equates to	9.97	£/machine hour
		1.81	£/sm^3 or gt
		3.63	£/odt
		396	£/week
		19,008	£/year

Fuel cost

@	30.00	l / machine hour
@	0.19	£/l
	5.70	£ / machine hour
	1.04	£/sm^3 or gt
	2.07	£/odt
	41.15	£/working day

Maintenance

226	£ / week
5.50	£ per machine hour
1.00	£ / sm^3 or gt
2.00	£ / odt
39.70	£ per working day
218	£ per week

Insurance

0.63	£ / machine hour
0.11	£/sm^{3}or gt
0.23	£/odt
4.55	£ / working day
25.00	£/week
1200	£ / year

Cost summary

@	85%	utilisation
@	0%	o'head / contingency
@	20%	margin

	£ / week	£/hour	£/sm3 or gt	£/odt	
Machinery cost	642	16.18	2.94	5.88	fixed
Fuel cost	226		1.04	2.07	variable
Maintenance cost	218		1.00	2.00	variable
Labour cost	396		1.81	3.63	variable
Insurance cost	25		0.11	0.23	fixed
Subtotal	1,508	37.98	6.91	13.81	
O'head / contingency	0	0.00	0.00	0.00	
Subtotal	1,508	37.98	6.91	13.81	
Margin	302	7.60	1.38	2.76	
Totals	**1,810**	**45.58**	**8.29**	**16.57**	

odt/hr	sm3 or gt/hr	odt / day	sm3 or gt/day	£/sm3 or gt	£/odt
1.50	3.00	11	22	15.19	30.38
1.75	3.50	13	25	13.02	26.04
2.00	4.00	14	29	11.39	22.79
2.25	4.50	16	32	10.13	20.26
2.50	5.00	18	36	9.12	18.23
2.75	5.50	20	40	8.29	16.57
3.00	6.00	22	43	7.60	15.19
3.25	6.50	23	47	7.01	14.02
3.50	7.00	25	51	6.51	13.02
3.75	7.50	27	54	6.08	12.15
4.00	8.00	29	58	5.70	11.39
4.25	8.50	31	61	5.36	10.72
4.50	9.00	32	65	5.06	10.13

Table 2 Sensitivity of chipping costs to chipper productivity

Commentary

Table 1 provides a summary of the effect of varying productivity on the cost of chipping. The standard case assumption of 2.75 odt's per hour is a reasonably cautious rate reflecting an aggregate productivity for the *Surefire* over the whole of the work period covered by this report, which was also the proving period for the machine. This translates into a cost of approximately £16.50 per odt for the chipping itself (i.e. excluding all other costs, although allowing for a 20% margin).

Already, this rate has been regularly exceeded in good working conditions, and the maximum spot productivity achieved is a chip-bin fill time of 6 minutes, equivalent to c.7.5 odt / hour. This occurred when working in circumstances that provided a combination of high volumes of material in one location optimally presented for the chipper, and it is believed to be approaching the maximum productivity of the machine. The implication is that there is still significant loss of productivity in the system, and this is indeed born out by relatively simple observations on-site, i.e. listening to the amount of time that the chipper is actually chipping - estimated to be no more than 40%. In improving this, the experience from the case study sites has shown that two key factors impinge on how near to the theoretical maximum level of productivity it is possible to get on a sustained operational basis:

- Presentation - this has been addressed within the work undertaken and efforts to improve presentation continue on a site-by-site basis. It is expected that chipping will be undertaken on a number of clearfell sites during 2002, where it is planned to windrow the 'long tops' to provide a very high density of uniformly presented material and, it is hoped, optimum work rates. One area that does suggest itself for further work is a more thoroughgoing review of harvesting mechanisation options and the potential for development of dedicated felling equipment. In particular, multi-stemmed material and other hardwoods, where conventional harvesters are limited, remain problematic.

- In-wood logistics - although a tractor-trailer combination chip shuttle was used during the work undertaken, one of the key findings is that once chipping productivity reaches acceptable levels it is the in-wood logistics that become limiting. The specific requirement identified is for a terrain capable shuttle that can approach the chipper directly for chip transfer. The part-DTI funded shuttle under development by Econergy will represent the next major step forward in this direction, and should be on trial during the autumn of 2002.

Overall, there is a continued emphasis on addressing these productivity issues in the ongoing operation of the *Surefire* harvester. In the medium term (i.e. once the dedicated chip shuttle is operational), the goal of the operations is to achieve 50 tonnes per day productivity, reducing chipping costs to approximately £13 per odt.

Alternative systems

Although alternative chipping systems are not the subject of this report *per se,* it is recognised that the terrain chipping system set out herein is not the only model for woodfuel recovery. One other model, in particular, is believed to warrant further investigation as offering the potential to provide an extremely cost-effective route for woodfuel recovery in a large-scale commercial clearfell context. This would entail extraction either of unsnedded 'long-tops' or of rough-snedded pole length material to a landing for subsequent chipping by a much larger, higher throughput chipper than can be worked in-wood. Such a system entails a whole set of it's own operational issues, including extraction systems and logistics, and the logistics of managing the landing operation (particularly chip removal). However, in the right circumstances it could offer an important supply chain option.

4.2 Harvesting systems - cost benefit analysis

If the market opportunity represented by woodfuel is to be realised in practice, it is clearly essential to be able to access raw material by offering some financial benefit to both owners and to the harvesting contractors that do the felling to liberate the chip material. Very often, the initial reaction by both parties is to seek a price comparator for conventional pulp material. However, it is the author's belief that this is a fundamentally flawed way of viewing the opportunity, which involves significantly modifying the whole system of work for undertaking the management operations (whether thinning or clearfell) and a quite different cost structure to such operations. Specifically, processing and extracting traditional 'shortwood' pulp is a relatively costly operation undertaken to recover the lowest value part of the stem. One of the key potential benefits of a woodfuel system is in avoiding much of this processing cost and, at the same time, increasing the productivity of the harvesting of the more valuable solid products which are where both owners and contractors make their return.

In order to assess this approach, a relatively simple cost-benefit model was constructed and is set out below. The figures presented are broadly drawn from the site at Garboldisham presented in Case Study 1, above, and certain of the inputs (such as standing price etc) reflect that site in particular and are not intended to reflect the wider market.

Inputs:

Standing volume to 7 cm TDOB		550	m^3
		550	gt
Top, branch & other non-recoverable material as % of standing vol	15%	81	gt
Out-turn based on woodfuel recovery		631	gt

Sale prices (rideside)	**Sale price**	**Standing cost**	
Sawlogs	£34.00	£10.00	gt
Bars	£28.00	£5.00	gt
Pulp	£8.50	£1.00	gt
Woodfuel (in rack)	£2.00	£1.00	gt

Conventional job inputs

Total cost of being on-site		£8,400	
	days	12	
	@	£700	per day
	equals	£15.27	per gt
	and	46	tonnes per day productivity

	Proportion %	Tonnes (gr)	Gross r'side value	Standing cost	Process & extract cost	Margin @ roadside
Sawlogs	10.2	56	£1,904	-£560	-£855	£489
Bars	30.0	165	£4,620	-£825	-£2,520	£1,275
Pulp	59.8	329	£2,797	-£329	-£5,025	-£2,557
		550	£9,321	-£1,714	-£8,400	-£794

	Total	Av/gt
Overall margin for site (roadside)	-£794	-£1.44
Margin for sawlog (roadside)	£489	£8.73
Margin for bars (roadside)	£1,275	£7.73
Margin for pulp (roadside)	-£2,557	-£7.77

Job inputs in woodfuel scenario

Total cost of being on-site		£4,900	
	days	7	
	@	£700	per day
	equals	£7.76	per gt
	and	90	tonnes per day productivity

Include in woodfuel:	
Sawlogs	n
Bars	n
Pulp	y
Residue	y

	Proportion %	Tonnes (gr)	Gross r'side value	Standing cost	Process & extract cost	Margin @ roadside
Sawlogs	8.9	56	£1,904	-£560	-£435	£909
Bars	26.1	165	£4,620	-£825	-£1,281	£2,514
Pulp	0	0	£0	£0	£0	£0
Woodfuel	65.0	410	£821	-£410	-£3,185	-£2,774
		631	£7,345	-£1 ,795	-£4,900	£649

4.3 Commentary

No single snapshot such as that presented above can pretend to be definitive, and the intention is to provide an illustrative picture only. However, the picture presented is relatively clear nevertheless: - a potential loss approaching £800 explains why the site was previously unmanaged by conventional means; under the woodfuel scenario, this is turned into a modest surplus for the contractor of £650 *and a* return to the owner of £1,795, whilst providing raw material for the chipping operation at a relatively competitive cost of £2.00 per gt (£4.00 per odt).

The key to this scenario is the productivity improvement made in the harvesting - in this instance reducing 12 days on-site to just 7 days for the harvesting gang. Many contractors are intuitively aware that cutting pulp is tantamount to being a waste of time and money under present market circumstances, but relatively few operate the kind of detailed cost-management systems that will allow them to formalise this in the way presented above. Equally, in the absence of an energy market, there has hitherto been little option other than to cut shortwood for the pulp market.

Although early days this situation is now beginning to change. However, as the section set out above illustrates, it is essential not simply to view the energy market as an alternative outlet for conventional shortwood pulp (short lengths are anyway far from optimum for chipper crane feeding). Instead, the key to realising this opportunity for the existing forestry industry is in a) recognising the substantial productivity benefits that can be gained in appropriate circumstances by reducing the time spent processing each stem; and b) focusing the productivity of the primary harvesting operation on producing the higher-grade material (sawlogs etc) that are profitable.

5 Summary and conclusions

The continued decline in both pulpwood markets and in the value of higher-grade forestry products is currently re-enforcing a long-term trend of declining woodland and forestry management. Though by no means a panacea, the energy market is widely perceived as having the potential to provide an important alternative market for low-grade material and, thereby, in helping to redress this decline. It is in this context that Econergy Ltd have sought to develop systems of work that will allow unmanaged woodlands / under-managed forestry to be accessed economically for the production of woodfuel. Key conclusions of the work undertaken are:

1) Presentation:

From the outset of the chipping operations it was recognised that the presentation of the pre-felled material has a fundamental impact on chipper productivity. The optimum presentation of material is directly in-line with the chipper, or at an angle of less that 20° to either side with all the butts facing towards the chipper throat. Where it is possible to accumulate concentrations of such material, for example in a clear-fell context, chipper productivity can be extremely high - as much as 7.5 odt's per hour.

Even with experienced cutters, it is very often not possible to achieve the accuracy of presentation required to achieve an acceptable level of chipper productivity using motor-manual felling. This presents a particular issue for many hardwoods and for multi-stemmed (coppice) material in particular.

2) In-wood logistics:

Once the primary chipper productivity reaches acceptable levels, the immediate down-stream requirement is to evolve efficient in-wood logistics. In most circumstances, the loss of productivity entailed in extracting the woodchips by driving the chipper itself to a landing / stacking area makes use of a 'chip shuttle' cost-effective. This involves transferring the chips from the chipper high-tip bin into a separate carting unit. Experience has shown that an agricultural tractor and trailer combination offers a clear improvement over having no shuttle, but the limited terrain capability of such a configuration is significantly constraining. In particular, it means that in a thinning situation, the chipper has to come out of the rack in order to transfer chips to the shuttle, entailing substantial downtime. Thus, Econergy are currently constructing a part-DTI funded dedicated shuttle vehicle which, it is hoped, will offer a further productivity improvement when it becomes operational in the autumn of 2002.

3) Moisture content:

Unlike traditional pulp markets, the issue of moisture content is often an important one for the energy market. In the context of the operations reported on herein, the FibroThetford power station for which the chipped material was destined has a maximum allowable moisture content of 45% for woodfuel. Experience during the operations (and indeed subsequently) has highlighted the fact that the process of drying is not well understood. The moisture content sampling undertaken was somewhat *ad hoc,* but the degree of variation in moisture content at the second case study site in particular (Rougham) and it's apparent unpredictability even to the operational team who were on the ground was striking.

Without a better-defined programme, it is not possible or appropriate to attempt to draw any detailed conclusions. However, the key rule of thumb that has been re-inforced is one established from Danish experience, i.e. that achieving reliable dying of this type of material (whole trees or whole tops left *in situ* after felling) requires it to lie <u>for at least one summer.</u>

4) Chipper productivity and chipping costs:

From the cost model that has been developed for the chipping operations, it is possible to correlate chipper productivity with chipping cost. A *standard case* figure of 2.75 odt's per hour provides a chipping cost of approximately £16.50 per odt for the chipping itself (i.e. excluding all other costs, although allowing for a margin). This is believed to be a reasonably cautious rate reflecting an aggregate productivity for the *Surefire* over the whole of the work period covered by this report, which was also the proving period for the machine. Already, it has been exceeded in good working conditions - the maximum spot productivity achieved is a chip-bin fill time of 6 minutes, equivalent to c.7.5 odt / hour. This occurred when working in circumstances that provided a combination of high volumes of material in one location optimally presented for the chipper, and it is believed to be approaching the maximum productivity of the machine. The implication is that there is still significant loss of productivity in the system and there is a continued emphasis on addressing the key productivity issues - presentation and in-wood logistics - with the introduction of the dedicated chip shuttle in October 2002 regarded as being the next major step-forward. Other systems also merit attention, particularly fell and extract systems where it is the logistics of the forwarding operation and of managing the landing that become key.

5) Harvesting systems cost-benefit:

One of the factors to have emerged from the operational experience gained is the degree to which reduced processing time for each stem in a woodfuel recovery context can impact on the productivity of the solid wood harvesting operation, also allowing that productivity to be focused on the higher value fraction of the stem. Under present market conditions in the Eastern Region, cutting shortwood pulp is marginal at best and will often be loss-making. The advent of an energy market may allow this material to be diverted to woodfuel production, and in appropriate circumstances the cost-benefit to the harvesting operation can be significant. The spreadsheet model developed to assess this illustrates how an otherwise wholly unviable site at Garboldisham could be worked profitably by recovering just the best material as a solid fraction and thereby minimising the time the harvester and forwarder were on-site.

5.1 Areas for future work

The work undertaken was limited in its scale and ambition and represents only a starting point. While a valuable exercise in its own right (and operation of the *Surefire* harvester is continuing), it has highlighted areas of follow-on work which would certainly assist in the further development of the woodfuel sector in the region. Briefly these include:

- a more thoroughgoing review of felling mechanisation options and the potential for development of systems and even machinery appropriate for multi-stemmed material and other hardwoods in particular;
- work on in-wood logistics (being addressed by Econergy's development of a dedicated chip shuttle during 2002);
- more structured work to assess the variables relating to passive drying and to refine working 'rules of thumb' in this regard;
- trials of alternative supply chain routes, particularly fell and extract systems;
- Work-studies to assess the productivity benefits for conventional harvesting offered by woodfuel recovery of whole stems or whole 'long-tops'.

Annex 1 *Surefire* outline specification

Chipper Specification

econergy

Base Unit:

Unimog U2150 214hp,
with selectable hydrostatic ground drive

Chipper:

Erjo 7/45 special

Maximum diameter 340mm

Crane:

Kronos 4000XL 8m reach 3.9kNm lifting moment

Bin:

$10m^3$ high-tip at 3.2m

Hydraulics:

Ground drive: closed loop 70cc/400bar

Crane/chipper load sensing 63cc/130l/min/200bar

2-lever joystick controls

Parker IQAN digital control system