ENERGY FROM BIOMASS

Summaries of the Biomass Projects carried out as part of the Department of Trade and Industry's New and Renewable Energy Programme

VOLUME 2: WOOD FUEL SUPPLIES AND SUPPLY CHAINS

ETSU BM/04/00048/REP/2

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INTRODUCTION

These volumes of Summaries provide easy access to the many projects carried out in the Energy from Biomass programme area as part of the Department of Trade and Industry's New and Renewable Energy Programme.

The Summaries in this volume cover contractor reports on the subject published up to December 1997.

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1. WOOD FUEL SUPPLIES

1.1 The Supply Potential

Report No: ETSU B 3124 A   Publication date: 1978

THE POTENTIAL OF FOREST BIOMASS AS A SOURCE OF ENERGY (WITH SPECIAL REFERENCE TO TREES WITH SINGLE-STEMMED HABIT OF GROWTH)

Department of Forestry, Aberdeen University

Background

Past deforestation of UK forests resulted in the early development of silviculture based on the artificial establishment of plantations. Public sector forests are owned and controlled by the Forestry Commission and account for about half of the total. The remaining private sector forests are in the hands of private woodland owners and forestry companies. The area of productive forest in the UK was 1.69ha in 1977. Within woodlands managed by the Forestry Commission, the area of coniferous planting is 16 times that of broadleaved species. In the private sector, conifers again predominate but occupy only 1.5 times the area of broadleaved trees. The private sector manages a larger area of coppice and coppice with standards than the Forestry Commission.

The demand for timber in the UK is increasing and, by the year 2000, 14-15% of the total could be provided from the present forest area. To increase this proportion will require a significant afforestation programme, particularly in the uplands and on unused or marginal agricultural land.

Because rotations are typically 60-90 years for conifers and 100-150 years for broadleaved trees, management systems are designed to provide interim yields and revenue. This involves close initial planting and subsequent thinning at intervals, releasing large quantities of small timber (short roundwood) into the market for use as pit wood, wood pulp, fibreboard, woodwool etc. This strategy, combined with substantial imports of cheap wood pulp, has saturated the market, reduced returns and made thinning uneconomic. An alternative outlet for short roundwood is needed, and the wood-for-fuel industry could meet this need.

Project Objectives

- To identify alternative strategies for producing forest biomass for conversion to fuel.

- To assess the land potentially available for new plantings and the ecological implications of such planting.

- To examine current harvesting procedures.

- To make recommendations for future work.

Findings

Strategies identified

Five strategies have been identified for the production of forest biomass for fuel:

1. The residues from conventional forestry represent an immediate and readily available source of biomass for conversion to fuel. About 30% of branches, foliage and tops is currently harvestable, and this is expected to rise to 75% by 1996. In addition, about 20% of total root and stump arisings should be harvestable. The total tonnage is estimated at 469,000 dry tonnes for 1978, rising to 1.385 million dry tonnes by 1996. These tonnages could contribute 8.4PJ and 25PJ of energy, respectively.

2. Strategy 2 involves placing an energy emphasis on the current management of even-aged single species plantations. Options range from growing trees for the full rotation and using all the biomass for conversion to fuel, to growing trees for the full rotation and using only the residues for fuel. The intermediate options would supply different quantities of thinnings to the energy market.

3. Strategy 3 involves growing a mixture of two species in a plantation, using conventional spacings but planting in alternate rows or strips. One species would be removed at Year 20 and used for fuel: the other would be grown to maturity for conventional use. Such a strategy would be difficult to manage in practice.

4. Strategy 4 involves growing trees on farmland using 12-20 year rotations. Estimates suggest that yields of 8-12 dry tonnes/ha/year could be achieved on fertile lowland sites and 5-7 tonnes/ha/year in the uplands. Production costs are estimated to be £0.40-£0.50/GJ.

5. Strategy 5 involves new management methods and a total commitment to energy forestry. Two options have been assessed:

    - trees grown on a very short (five-year) rotation - unlikely to be viable for single-stemmed trees
    - trees grown on a 12-20 year rotation - appears to be technically feasible.

Land availability

To maintain the current level of planting (15,000 ha/year) new land must be transferred to forestry from agriculture and other uses. Much of this is likely to be in the uplands where large areas have a poor agricultural potential. If two million hectares of the 3.8 million technically available were to be planted for fuel, using short rotations with improved species, the potential energy contribution could be 540 PJ/year.

Ecological implications

Whole tree harvesting and short rotations are likely to increase the loss of major soil nutrients. Although these can be replaced by applying fertilisers, the level of application will need to be greater than the level of loss to allow for the relatively small proportion of commercial fertilisers taken up by forest trees. Other options for rectifying or avoiding nutrient drain include leaving most of the nutrient-rich fine biomass on site, lengthening rotations on sensitive sites, selecting fast-growing trees with a low nutrient demand, and interplanting nitrogen-fixing species such as alder and lupins with the main crop.

Intelligent use of heavy harvesting machinery will minimise the chance of irreparable damage to soils.

Whole tree harvesting can be beneficial: reforestation is easier and cheaper, and the removal of stumps and roots can reduce the danger of infection from some fungi and insect pests.

Harvesting

Conventional forestry practice only harvests tree stems, and different techniques will be required for whole tree and residue harvesting. To minimise residue contamination with soil, whole tree harvesting should be the norm, with chipping of either whole trees or residues carried out in the forest to maximise transport efficiency. Machinery is also available for stump and root harvesting and processing.

Recommendations for Further Work

The main needs can be summarised as follows:

- More precise estimates of the location of forest residues, their harvestability and hence availability.
- Analysis of market forces in relation to traditional forest products and the energy market.
- Further examination of the potential for 12-20 year rotations on farmland, focusing on the economics of production, location and quantification of suitable areas, biomass production in relation to tree spacing.
- Mapping studies to identify suitable land and the institutional constraints likely to be associated with its use.
- Constant evaluation of nutrient loss and the economic viability of fertiliser additions.
- Experimental work on whole tree and residue harvesting under British conditions to ensure that the harvested product is compatible with the requirements of conversion plant.

Report No: ETSU B 3124 B Publication date: 1981

THE POTENTIAL OF FOREST BIOMASS AS A SOURCE OF ENERGY (WITH SPECIAL REFERENCE TO TREES WITH SINGLE-STEMMED HABIT OF GROWTH)

Department of Forestry, Aberdeen University

Background

The first year of this project (Report No: ETSU B 3124 A) identified four main biomass sources with an energy potential: forest and mill residues, early silvicultural thinnings and trees grown in energy plantations on rotations of up to 20 years.

Project Objectives (second year)

- To evaluate the use of forest and mill residues as a source of wood for fuel.
- To assess the likely yields of individual tree species.
- To examine the costs of producing woody biomass.
- To assess land availability for short-rotation forest energy plantations.
- To assess the validity of the Institute of Terrestrial Ecology (ITE) Land Classification Scheme as a means of predicting biomass yields.
- To establish the relationship between short rotation forestry and nutrients.

Findings

Forest residue availability

Forestry Commission Conservancies in Scotland, Wales and the north of England will generate the largest quantities of forest residues, and these will come primarily from the harvesting of conifers. Most broadleaved residues will come from Conservancies in the south of England and Wales - areas where there are already strong local markets for hardwood logs for wood-burning stoves. The figures in Table 1 below are for the technical potential only. A further study would be needed to establish harvesting constraints.

Table 1 Forestry residue forecasts (dry tonnes/year) by Forestry Commission Conservancy

	1977-1981		1982-1986		1987-1991		1992-1996	
Conservancy	**Conifers**	**B'leaved**	**Conifers**	**B'leaved**	**Conifers**	**B'leaved**	**Conifers**	**B'leaved**
N W England	36,679	394	46,279	533	60,848	713	64,899	874
N E England	49,477	334	74,561	532	99,667	794	150,974	917
E England	58,528	1237	79,602	1454	92,261	1784	97,351	1913
S E England	19,645	1696	27,066	2425	32,402	2985	41,604	3566
S W England	43,994	1671	45,934	2438	49,704	3085	56,144	3521
N Scotland	65,005	3	57,015	5	79,928	8	91,255	11
E Scotland	52,524	133	64,643	129	87,212	132	113,198	131
S Scotland	49,334	145	66,527	174	99,242	200	149,607	216
W Scotland	47,622	2	67,881	2	96,699	2	146,845	1
N Wales	53,355	217	75,192	416	91,083	689	113,613	802
S Wales	74,299	349	72,388	487	89,441	814	111,529	939

Wood processing residues

Residues from conifer sawmills are available mainly in the north, east and west of Scotland and in the southern parts of NE, NW and E England. Quantities are likely to treble in the period 1979-1994, giving a potential energy contribution of 6.5 PJ/year.

The energy contribution of residues from the sawmilling of hardwoods, most of which is located in southern England, is unlikely to increase from the present figure of 3 PJ/year.

Forest biomass yields and production costs

Likely biomass yields were estimated for a range of species, for two rotations, and for either whole trees (aerial portion of tree) or complete trees (including stumps).

Estimates of the likely yields and costs of growing trees on 20-year rotations were made for representative squares of five land classes, as shown in Table 2 below. Production costs varied widely within a given land class, and this variation was often as great as the variation in production costs between land classes. The most important factor affecting production cost was biomass yield.

Table 2 Yield estimates and costs

Land class	Location	Yield (dry tonnes/ha)	Cost (£/dry tonne)
3	East Anglia	193	15
7	Coastal England and Wales	75	23
15	Midlands of England	115	17
21	North-east Scotland	60	9
25	East Lowlands of Scotland	113	16

Land for forest biomass production

Of the estimated 1.5 million ha potentially available for farm forestry or other "opportunity crops", two thirds lies in the uplands and one third on lowland farms. A pilot study of the location and area potentially suitable for energy crops was carried out using the ITE Land Classification Scheme. The proportion of land technically suitable ranged from 3% in land classes under intensive agriculture to 37% where farming is more marginal. In the lowlands, the greatest potential appears to be on land currently comprising woodland, scrub and rough grazing. Moorland can be added to this in the north and uplands of Britain. Further work on the institutional problems associated with using this land is now required.

Mapping forestry yields

In order to test the suitability of the ITE Land Classification Scheme for predicting forest biomass yields, a study was made of Devon and Cornwall. Estimated dry matter yields from single stem trees was mapped for two rotations: a short (20-year) rotation and one based on the age of maximum mean annual increment. The total output per county derived from the maps is outlined in Table 3 below.

Table 3 Dry matter yield for Cornwall and Devon (two rotations)

County	Rotation	Yield (‘000 dry tonnes/year)	Energy contribution TJ/year
Cornwall	Short	13	260
	Maximum mean annual increment	31	620
Devon	Short	34	680
	Maximum mean annual increment	72	1440

Biological nitrogen fixation

The project has given further consideration to intermixing the main tree crop with nitrogen-fixing species such as lupins and alder, thereby seeking to minimise the effects of nutrient removal associated with whole-tree harvesting. For biomass plantations, the growth of nitrogen-fixing trees such as alder appears to be the most immediately attractive.

Report No: ETSU B 3117 (FR) Publication date: 1980

COPPICED TREES AS ENERGY CROPS

Forestry Commission

Background

There is currently great interest in America and Europe in the potential of close-spaced short rotation coppice systems as an alternative source of fuel. Coppicing exploits the natural ability of the growing root system of some tree species to produce successive crops of above-ground growth after the previous crop has been harvested. To date, in Britain, the practice of coppicing has been limited to a handful of species for a limited market - the production of firewood or of timber for hurdles and other rural industries. Its development could, potentially, contribute to national energy needs.

Project Objective

- To produce a balanced appraisal of the possible contribution that a close-spaced short rotation coppice system could make to the production of wood fuel in Britain.

Methodology

The study has examined and appraised literature on the subject emanating from research and commercial enterprise, mainly in the temperate climatic zones of the world, notably North America, Canada, Europe and Scandinavia. Some information is also available from Australia and New Zealand.

Findings

The coppice system

The coppice system involves establishing a plantation of trees from cuttings, rooted cuttings, seedlings or transplants, cutting back the initial stem after 1-3 years to encourage the rapid regeneration of multiple stems, and harvesting at recurring intervals. The number of rotations depends on the health and longevity of the stools. This in turn varies with species, site, harvesting method and, possibly, fertiliser applications.

Coppicing offers two fundamental advantages over other silvicultural systems: a succession of harvests can be obtained from a single financial input; and there is rapid early growth from established stools.

Growth factors

The productivity of any given site depends on the species planted. The criteria used to select coppice species are an ability to coppice naturally; rapid juvenile growth; site adaptability; easy establishment; and no obvious susceptibility to pests or diseases. The five most promising candidate species are discussed below.

Salix and *Populus* are highly productive, have few establishment problems and provide early growth. Intensive breeding has resulted in the production of clonal material of much enhanced vigour and an inbred resistance to certain common pathogens. They grow on a wide range of good forest or agricultural sites, but are unsuited to sites with a seasonal moisture deficit and to poor, limiting or upland sites.

Alnus is another possible species, exhibiting early vigour but requiring moist to wet sites for optimum productivity. *Nothofagus* has shown remarkable vigour, an ability to coppice freely and vigorously, and tolerance to a wide range of lowland site conditions. Their vigour and ability to coppice makes some *Eucalyptus* species obvious candidates, but they are susceptible to winter cold.

Soils with a high nutrient level are important to maintain high levels of production. Removal of all growth material apart from leaves limits the natural recycling of nutrients, and fertiliser addition is likely to be costly in financial and energy terms.

Soils must allow the trees to root to their optimum depth, both for stool stability and to maximise nutrient and water use. There should be optimum ground water conditions during growth and temperatures that provide an adequate growing season.

The sites most likely to meet these requirements will be located in the lowlands of the UK, in areas with high to moderate grade agricultural soils and the best forest soils.

Other factors

Other issues that may need to be considered include:

- the long-term balance of nutrients
- fencing against the risk of grazing or rubbing by wild or domestic animals
- the possible danger from fungal spores as a result of mechanical harvesting in particular.

The risk of damage from insect predation is perceived to be limited, and the risk of environmental damage - from frost, dessication, flood or fire - is also small.

Production

Several researchers in the Northern Hemisphere have predicted yields in excess of 20 dry tonnes/ha/year on the basis of limited experimental evidence. Large-scale trials will be needed to ascertain whether such high yields can be sustained over time.

Spacing is likely to be a critical factor to maximise the interception of solar radiation, and research into optimal spacing is required.

The estimated productivity of the five most promising species is shown in the following table.

Estimated productivity for five species

Species	Dry tonnes/ha/year
Poplar	20
Willow	≥ 15
Alder	≥ 6
Nothofagus	≥ 10
Eucalyptus	≥ 20

The energy yield is assumed to be 20 GJ/dry tonne, irrespective of species.

Harvesting

Traditional coppice harvesting was accomplished manually using edge tools such as axes and bill hooks. It was very labour-intensive. Energy coppice harvesting requires the mechanised severing of the shoots from the stool (avoiding stool damage) and their collection and immediate chipping before transport. Prototype machines (modified agricultural-type forage harvesters) have been tried on an experimental scale, and further developments are likely. It will be important to develop equipment with wide tyres or tracks to lessen the effect of soil compaction on heavy textured soils during the autumn and winter harvesting season.

Costs

Costs, ie all expenditure contributing to the production of the feedstock at the farm or forest gate, include:

- land costs (annual rents of £20-£60/ha/year)
- the costs of establishing and maintaining the crop - cultivation, fencing, planting, weeding (£10-£30/ha/year)
- harvesting costs (£4-£8/dry tonne).

The critical factor affecting costs is annual production. A best estimate of costs is £10/dry tonne (£0.50/GJ). This might be doubled by a failure to achieve the production predicted.

Evaluation

Further research will be needed to establish whether or not it is possible to sustain the target production of 20 tonnes/ha/year for more than 25 years. However, it would appear to be technically possible to achieve production levels in excess of those currently achieved.

Assuming a revenue of £10/dry tonne and a production of 20 tonnes/ha/year, analysis over a 20-year period shows a positive net discounted revenue for discount rates of 3-10%.

Yield values attributed to the 256 sample squares that make up the 32 Land Classes of the Institute of Terrestrial Ecology system highlight the unsuitability of the uplands and the variable suitability of the lowlands as potential coppice sites.

Certain categories of existing forest land could be upgraded productively if there were no conflicting interests. There are also perhaps 300,000ha of lowland agricultural land that are unproductive and suitable for coppice production.

The fact that production is likely to be fragmented indicates that the most promising scenario for development is one of on-site conversion of the feedstock to an energy product that can be directly used - for domestic use and/or crop drying on the farm.

Report Archive No: 000797 Publication date: 1984

WOOD UTILISATION SYSTEMS - COMBUSTION STRATEGIES

W S Atkins & Partners
International Forest Science Consultancy

Background

Fundamental changes in the prices of major sources of energy over the last decade have resulted in appraisals of the comparative costs of alternative sources of energy, including renewable resources such as wood. Most countries with large forest resources are interested in extending the recovery and use of residues both from forests and from other sectors of the timber industry.

Project Objective

- To establish the potential in the UK for the production of energy by the combustion of wood and wood residues.

This report is in three volumes. Volume 1 contains the main report, Volume 2 the Appendices and Volume 3 detailed maps showing both the ratio of woodland area to population density across the UK and the specific locations of woodland blocks and wood processing industries.

Methodology

A detailed picture of UK forest resources has been built up from published data and from sample field surveys. Saw, resaw, chipboard and pulp mills, and other wood-based industries have been identified, and details of residues and residue disposal have been determined from sample surveys. Harvesting methods and equipment have been investigated to determine the unit costs of harvesting wood fuel. Transport costs have also been determined, as have the overall costs for producing and delivering wood fuels from forest to user. Comparison of costs with those for coal, on an energy content basis, has allowed the development of appropriate strategies. Finally, the study has examined the development, performance and availability of wood-fuelled furnaces and boiler plants in the UK and elsewhere, and has estimated capital and operating costs for three different sizes of wood- and coal-burning plant.

Findings

Compared with total UK energy consumption, the energy available from wood represents only a few percent of total consumption. Nevertheless, there are considerable quantities of wood for which there is little other use.

The total growing stock amounts to 334 million m^3, of which about one-third is unsuitable for industrial manufacturing use and represents a potential wood fuel supply (111.5 million m^3 or about 52 million dry tonnes). If 90% of this were to be consumed over a 20-year period, it would be equivalent to 1.3 million tonnes of coal per year. An additional 0.6 million tonnes of coal equivalent per year (tce/year) arises from the timber processing industries.

Practical and economic factors limit the exploitation of wood for fuel, and only about 30% (385,000tce) of the annual potential is currently being used, of which almost two-thirds is obtained from primary arisings in commercial and non-commercial woodlands and the remainder from the wood processing industries.

The greatest single cost element in the strategies considered is harvesting cost. This cost currently ranges from £7.35/tonne for hardwood chips to £13.00/tonne for softwood chips, assuming a fuel wood processing plant with a capacity of 5000 tonnes/year. One important way of minimising harvesting costs is to combine the harvesting of timber and fuel wood.

Two other major cost elements are transportation and processing costs, and the most economically attractive strategies for wood fuel provision are those that draw their resources from concentrated woodland or wood-processing industries and that serve local boiler plants capable of burning wood fuel in its simplest form.

The study has shown that it is possible to increase the use of wood as fuel, mainly from primary commercial arisings. The short-term potential (up to the year 2000) is estimated at 627,000 tce/year, 33% from non-commercial woods, 37% from commercial plantations and 29% from industrial processing plants. Of the total, domestic consumption is likely to account for 310,000 tce/year, industrial consumption for 227,000 tce/year and agriculture for 90,000 tce/year.

Analysis of the longer-term potential suggests that, in general, development will tend to increase the amount of economically available fuel wood. However, the development that appears to have the greatest potential is the establishment of coppice energy crops on marginal land. This could produce 10 million tce/year, although the realisation of this potential would be severely restricted by practical and economic considerations.

The findings of this report are commented on in Report No: ETSU R 32 Potential for wood as fuel in the United Kingdom, published in 1985.

Report No: ETSU R 32 Publication date: 1985

POTENTIAL FOR WOOD AS FUEL IN THE UNITED KINGDOM

R Price (ETSU) and C P Mitchell (Aberdeen University)

Background

This report summarises and comments on the findings of two recent studies. Report No: ETSU B 1102, Growing wood for energy in Great Britain and Report Archive No: 000797. The following focuses only on the conclusions drawn from an analysis of both studies.

Analysis Findings

The supply of wood for energy is likely to be provided from two sources: thinnings and residues from modified conventional forest; and coppice wood, the latter becoming more important at higher energy prices. No single stem short rotation forestry would appear to be economic below a price of about £46/dry tonne (dt) for wood at the forest edge.

One major problem is that modified conventional forestry would be practised in regions that are relatively remote from potential markets, whereas coppice energy crops would be planted closer to those markets. A first approximation suggests that only about 40% of the produce of modified conventional forestry and 70% of the coppice would be close enough to a market to have access to it. Even so, it is unlikely that this supply could be realised, and the assumption made is that the realistic potential is about half of the accessible supply.

The value of wood as a fuel varies with customer and competition. For instance, wet wood sold to industrial/institutional energy consumers as an alternative to gas-firing in a 15 million Btu/hour industrial boiler would be worth £21/dt. Where the wood can be burned directly on a coal-fired boiler without any modification, it would be worth £27/dt, rising to £30/dt where it substitutes for firing with light fuel oil in a 5 million Btu/hour boiler. These prices allow for transport costs of around £8/dt for a 50-mile round trip.

A doubling of energy prices would increase these values to the £28-£48/dt range (£41-£48/dt if industry has by this stage largely moved out of gas and oil for large boilers and into coal).

At current energy prices, wood cannot compete with gas in the domestic market. However, in competition with coal and oil, it is worth £38-£49/dt, depending on the transport distance. The lower figure would correspond to a 100-mile round trip to a depot, plus local distribution: the higher figure would be for local supply only. A doubling of domestic fuel prices would boost wood values to £64-£98/dry tonne and would stimulate supply.

Wood supply also depends on discount rates and on the degree to which the land could not be used because of environmental pressures. The most easily realised supplies would come from land where forestry is a better bet at a 5% discount rate, and for which there are no environmental constraints.

Conclusion

Given current fuel supplies:

- the supply of wood for industrial and institutional markets could be about 1.6 million dt/year

- wood could not compete with gas in the domestic market but, at prices that allow wood to compete with oil or coal, supplies could be in the 3.0-6.7 million dt/year range, with 4.7 million dt/year as the central estimate.

If energy prices were approximately to double:

- the wood supply to industry could increase to around 5.7 million dt/year
- the wood supply to the domestic sector could reach 16 million dt/year.

Even a modest increase in the value of fuel wood at the forest edge could have a significant effect on the level of economic supply. An increase of about 25%, for instance, could double the level of economic supply. However, the successful marketing of this supply would depend on the development and demonstration of adequate fuel supply chains, and on combustion trials on a range of appropriate equipment.

Report No: ETSU B 1102 Publication date: 1987

GROWING WOOD FOR ENERGY IN GREAT BRITAIN

Compiled by Dartington Amenity Research Trust

Background

Early studies in the UK have indicated that the production of energy from wood is a feasible option. Because the wood would be chipped for transport and processing, it is possible to use small size material, including residues and other forest products, and to radically shorten the cycle of growth and felling (the rotation), thereby providing earlier cash returns than with conventional forestry. Furthermore the species of tree is less relevant than in conventional forestry.

Energy production also offers an opportunity for integration with farming. Small patches of land could be used for energy plantations, producing timber on a short rotation system.

Project Objectives

- To establish the extent to which energy forestry might compete with present land uses and to indicate those types of land use most likely to be affected by the exploitation of energy forestry.
- To estimate the potential contribution of energy forestry to national energy demand.
- To indicate what effect non-agricultural or social factors might have on this economic potential.

Methodology

The Institute of Terrestrial Ecology's Land Classification Scheme was used as a basis for the work, and a sample of 256 grid squares, each 1km square, was visited to supplement the map data with relevant ecological and land use data.

Models of financial performance were then developed for agriculture and for four different forestry systems - conventional forestry for timber production; modified conventional forestry for timber and energy production; coppice for energy production; and single stem forestry for energy production. These models were applied to the sample grid squares and, where one or other form of forestry provided a better return than agriculture, the land use was "altered" to reflect that fact.

Extrapolation of these results provided an estimate of the changes in forest area and the associated wood production for energy for Great Britain as a whole. Two sets of estimates were produced: one based solely on economic factors and the other taking into account the potential constraints on land use change.

These estimates were based on certain assumptions, and a land use model was developed during the study which allowed individual assumptions to be amended so that the results could be tested for their sensitivity to a range of conditions. One set of assumptions was selected to form the basis of an “exploratory case” against which the findings of the sensitivity analysis could be compared:

- a value of £20/dry tonne (1977 values) at the forest gate for wood produced for energy
- a timber price that remains constant in real terms
- agricultural costs and returns that remain constant in real terms
- a 5% discount rate
- grant aid available to both agriculture and forestry.

Findings

Assuming no social or environmental constraints on land use change, about 2.26 million hectares of land in Great Britain (9.4% of the total and 12.6% of all agricultural land) would give a better return if switched from agriculture to forestry. Full production on this land could generate 12.5 million dry tonnes/year of wood for energy and a further 25 million m^3 of timber for conventional markets.

Ninety percent of the newly afforested area would operate a modified conventional forestry system and would be planted mainly on upland rough grazing areas throughout the country. It would account for 77% of timber production for energy and all the timber for conventional use. The main tree species would be Sitka spruce and Douglas fir.

The remaining 10% of the predicted forestry area would involve coppice production. It would be located on some of the better rough grazing in central and south-west England and on scrub and derelict land throughout the country. The predominant tree species would be willow and poplar.

Social and institutional demands, for instance those reflected in designations such as National Parks, are likely to limit the exploitation of this economic potential. Assuming that no energy forestry would be permitted on any designated land, the total available area is reduced to 0.82 million ha (3.4% of the total) and production would comprise only 4.6 million tonnes/year of wood for energy and 8.8 million m^3 of conventional roundwood. Again, 90% of the production would be from modified conventional forestry, and this would produce 70% of the total wood for energy.

It is clear from the above that agricultural land giving the lowest financial returns is most affected by the potential for energy forestry. For example, 32% of the total rough grazing area shows an economic potential for forestry, compared with only 1% of high grade pasture. Furthermore, forestry is unlikely to be able to compete with dairying or well stocked beef and sheep enterprises except in the case of the highest yielding coppice.

The overall conclusion is that, even when constraints on changes in land use are taken into account, there is still a significant potential for energy forestry. However, considerable research into the technical and economic aspects of energy forestry is still required.

Future Investigations Required

- Market-oriented regional or sub-regional studies and supply chain demonstrations to establish the relationship between supply and demand and to increase confidence in the practicality of using wood for energy.

- A study of how farmers, institutional investors and the "nation" perceive the costs and benefits of energy forestry.

- Farm-level investigations into the opportunities for integrating energy forestry into agriculture.

- Further assessments of biomass yield (using new and existing trials) and integrated harvesting costs.

The findings of this report are commented on in Report No: ETSU R 32 Potential for wood as fuel in the United Kingdom, published in 1985.

Report No: ETSU B 1156 Publication date: 1987

AN EVALUATION OF THE METHODOLOGY FOR MANAGING EXISTING BROADLEAVED AND CONIFEROUS WOODLANDS FOR TIMBER AND ENERGY

Oxford Forestry Institute, University of Oxford

Background

The regional distribution of forests has a profound influence on the viability of using wood for fuel. Broadleaved woodlands, which consist of high forest, scrub, coppice and coppice with standards, are often located near regions of high population density in the UK. They therefore offer considerable potential as a source of wood for fuel, at least in the immediate future. Most of the country's coniferous plantations, on the other hand, are in more remote areas and are less accessible in this respect.

While there is already a great deal of published information about the coniferous forests, information about broadleaved woodland in terms of composition, rates of growth and fuel wood potential is incomplete. There is also a need for easy and reliable methods of estimating quantities of branchwood and coppice.

Project Objective

- To investigate the management of different types of woodland, both broadleaved woodland and coniferous plantations, in order to optimise the production of fuel wood and timber.

Methodology

The management of a range of woodland types was assessed for the production of fuel wood and timber. This involved a consideration of Land Expectation Values (ie net present values in perpetuity) and of the improvements to profitability that fuel wood can make. Specific studies examined:

- the forest resources of Britain (based mainly on existing censuses and surveys)
- the composition of existing woodlands (based on sampling using the Institute of Terrestrial Ecology's Land Classification System)
- the branchwood component of woodlands
- coppice yields and methods for estimating the volume content of each species
- harvesting and marketing of fuel wood
- the economics of woodland managed for fuel and timber production.

Findings

Forest resources in Britain

The country's 750,000ha of broadleaved woodlands comprise about 35% of the total forest area. More than half of this woodland is in the south-west, south-east and east of England, and this includes extensive areas of "worked" coppice, more than 75% of which occurs in south-east England. Broadleaved woodland is usually privately owned, with small individual plots and poor or non-existent management, although management in the north is usually far better than in the south.

The UK's coniferous plantations consist mainly of Sitka spruce and usually cover very large areas of land, particularly in the uplands of the north and west of the country. They are usually owned by the Forestry Commission, and levels of management are good.

Composition of existing broadleaved woodlands

The dominant species within broadleaved high forests is oak, followed by ash and beech in southern and lowland land class regions and chestnut and beech in northern land class regions. However, one of the main characteristics of the broadleaved woodlands in terms of species is the decline in the use of oak and the increase in sycamore, ash and birch. In the southern group of land classes, the high forest is more commonly of coppice origin.

The main species found in worked coppice are sweet chestnut, hornbeam and hazel.

Woodlands are classed as scrub if more than half of the trees are of poor form or consist of unmarketable species. The dominant scrub species are oak and birch, with sycamore being very important in northern land class groupings. Scrub woodlands tend to have a much higher stocking of coppice stools than high forest.

The average dry weight wood output of high forest is 205 tonnes/ha (232 tonnes/ha in the north and 191 tonnes/ha in the south). This compares with an output of 107 tonnes/ha for scrub woodland.

Branchwood component of woodlands

Where suitable markets exist, the harvesting and sale of branchwood for fuel and other purposes can be a valuable additional source of income. In conifers, branchwood, expressed as a percentage of stemwood, tends to decrease with increasing tree size. With broadleaved trees the opposite is true, with crownwood volumes for mature broadleaved trees being similar to those contained in the stems. There is, however, a difference between shade-tolerant and light-demanding species, the former having a higher proportion of branchwood than the latter.

The project has also established that it is possible to make a reliable estimate of total tree volume from the diameter at breast height of the tree. Crownwood can be estimated by subtracting the timber volume.

The content of coppice woodlands and coppice yields

Coppice woods in the south of England are ideally situated to cater for domestic fuel wood. However, regular coppicing has become rare, and renewed management faces problems, including difficulties of access and of estimating the content of such woodlands. The project has solved the latter problem by deriving functions and constructing volume and biomass tables that allow the estimation of volume or dry weight content of coppice, irrespective of species, from easy measurements of single shoots, coppice stools or stands.

Analysis of coppiced oak yields indicate that site quality has a very marked effect on yield, with mean annual increments at 30 years ranging from 1.8 to 7.4 m^3/ha/year to a top diameter of 7cm. Furthermore, the ages of maximum mean annual increment varied from 55 years for the poorest site class to only 25 years for the best.

Harvesting and marketing of fuel wood

Harvesting systems vary from the simple felling, delimbing and cross-cutting of trees motor-manually within the forest, with extraction by farm trailer or skidder, to fully mechanised, capital-intensive systems, with fuel wood recovered either as part of an integrated harvesting operation or separately via chipping or residue collection[1].

Fuel wood can be delivered to consumers as roundwood, sawn logs, chips or chunks. Because most of the large softwood forests occur in sparsely populated regions with low levels of industrial activity, there are marketing problems associated with transport costs and the size of demand. The broadleaved woodlands, although offering a considerable supply potential adjacent to the market, face the problem of their occurrence in small, dispersed units with individual ownership.

Economics of woodlands managed for fuel and timber production

Woodlands are managed for a whole range of reasons - to maximise timber production or returns on investment, for sporting purposes, or for conservation and amenity.

Profitability is influenced by site quality and size, tree species available, site accessibility and proximity to markets, and the availability of grants and fiscal incentives.

The study has drawn three main conclusions:

- Prices paid for fuel as roundwood for the domestic market are higher than those for chips in industrial markets, so it is always more profitable to try and sell small diameter roundwood to domestic consumers.

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[1] Further details on harvesting are given in Section 2.2 of this volume.

- The pure conifer crop is generally the most profitable and the pure broadleaf crop the least profitable.

- The advantageous sale of thinnings, and the improvement in land expectation value obtained by chipping branchwood for fuel will depend on the relative prices of fuel wood and timber. In the case of broadleaved crops, these improvements may be as great as 100% as a result of low initial land expectation values and can represent the difference between making a loss and making a profit at a 3% discount rate.

Woodland management and profitability

The most profitable options considered were pure conifer plantations, followed by conifer/broadleaved mixtures that result in a final broadleaved crop. New broadleaved plantings and new native coppice could be profitable at a 3% discount rate, but only with maximum tax incentives and planting grants.

Woodland profitability computer program

The development of a user friendly computer program allows the woodland owner to consider the profitabilities of selected management options under specific conditions relating to productivity, price level, financial support etc.

Report No: ETSU B 1165 Publication date: 1989

A STUDY TO EXAMINE THE FEASIBILITY OF INTEGRATING FORESTRY FOR ENERGY WITH AGRICULTURE ON FARMS IN GREAT BRITAIN

Centre for Agricultural Strategy, University of Reading

Background

Early studies have established that growing trees for fuel is technically promising and could be financially competitive with present land uses. These studies have not, however, identified or quantified the effects of social and psychological factors, nor have they considered how energy forestry might be integrated with other farm activities. This report seeks to address some of these issues.

Project Objectives

- To define the barriers and incentives to the adoption of energy forestry on farms in Great Britain, and to identify the circumstances, farm types and regions where adoption might occur.

- To make recommendations for encouraging and facilitating the implementation of energy forestry systems on farms and their integration with other agricultural activities.

Methodology

Phase 1 consisted of a literature review relating to the adoption and diffusion of innovation on farms.

Phase 2 used a postal questionnaire survey to determine the level of interest in energy forestry among British farmers, to identify the types of farm and farmer most favourably disposed to the technology, and to identify likely barriers and incentives to adoption.

Phase 3 investigated farmers' responses in more detail through 52 case study farmer interviews designed to validate and extend the postal survey findings.

Findings

Literature survey

The review of relevant literature and consultation with appropriate experts identified various incentives, from the farmer's point of view, for adopting energy forestry. These include increased income, farm value and credit-worthiness; taxation benefits; the more profitable use of fixed resources; scope for add-on enterprises such as woodland-based recreation; and an on-farm fuel source.

From the national viewpoint, energy forestry could help to solve problems associated with agricultural overproduction and Common Agricultural Policy budget costs. It could also provide additional employment in rural areas and offer certain environmental benefits.

Possible constraints to the adoption of energy forestry include:

- certain technical constraints relating to the stage of development of the relevant technologies and the present inadequacy of management recommendations and yield predictions for specific sites

- financial constraints, notably the income gap and high capital requirements

- organisational constraints relating to labour and machinery requirements, land tenure, poor access, marketing problems, lack of skills and expertise, and inadequate information and advice

- psychological constraints associated with the novel nature of energy forestry and the limited interest of farmers in forestry

- social constraints relating to land-use restrictions and environmental concerns.

A hypothetical farm/farmer profile was devised for testing during Phase 2 of the project:

"The farm most likely to adopt energy forestry, at least in the short term, is a large, owner-occupied, family farm with excess labour during the winter months and some areas of low-opportunity cost land, managed by a well educated farmer with some planning skills, financial resources, a high marginal rate of tax and, perhaps, significant off-farm income; the farm has on-farm uses for wood as fuel or identifiable local markets, and may have some existing woodlands."

Postal survey

The postal survey confirmed most of the findings of the literature review. There were three main conclusions:

- British farmers have a considerable interest in energy forestry. This no doubt reflects the current "crisis" situation in agriculture and the importance attached to the development of alternative enterprises.

- The farmers most likely to grow trees for energy are those with larger farms and high incomes. However, the areas planted, at least initially, are likely to be relatively small - less than 10ha.

- Farmers did not appear to be inhibited by shortage of advice and information or by the long-term nature of energy forestry. Many were deterred by the poor perceived financial returns, by labour shortages and, if tenants, by the terms of their tenancy agreements.

Farmer interviews

Three main conclusions were drawn from the farmer interviews:

- Most farmers currently see energy forestry as a small-scale enterprise primarily for unused or under-used land rather than as a major alternative agricultural enterprise. However, a minority is interested in larger plantings on prime agricultural land.

- Financial profitability is clearly a significant determinant of interest, and poor financial performance is a key barrier to adoption. However, there is a small but significant core of farmers whose interest is not solely financial.

- Farmers in general do not perceive the availability of resources and expertise as a barrier to adoption. They are more concerned about markets.

Conclusions

There is considerable interest in the technology among farmers across the country. Reducing the barriers and constraints - by reducing costs, raising revenues and providing grants and subsidies - would enhance this interest.

The availability of resources and expertise was not perceived to be a significant barrier.

Four types of measure are necessary to encourage the development of energy forestry:

- Research and development to improve yields and the reliability of yield estimates; to develop more reliable management packages; to improve associated technologies such as harvesting; and to reduce costs.

- Appropriate advice and promotion for farmers with a strong interest in growing trees for energy.

- Identification and development of markets - local markets in the short term and guaranteed markets in the longer term.

- Alleviation of financial concerns through mechanisms such as price support, low-interest loans, an "Energy Forestry Compensation Allowance", reverse mortgages, partnership schemes and annual support payments.

Report No: ETSU B 1322 Publication date: 1993

FARMERS' CURRENT ATTITUDES TO ENERGY FORESTRY IN GREAT BRITAIN

Centre for Agricultural Strategy, University of Reading

Background

In 1986/87, the Centre for Agricultural Strategy carried out a study examining the feasibility of integrating energy forestry with agriculture on farms in Great Britain. This study was the subject of Report No: ETSU B1165 and showed that there was appreciable interest among farmers but also a number of perceived barriers, notably inadequate financial returns, insufficient spare labour, tenancy restrictions and high initial costs.

Since then, there have been changes in agriculture and some advances in the state of the art of energy forestry, particularly energy coppicing. The report summarised below assesses the impact of these changes on the scope for energy forestry on farms and on farmers' perceptions of and interest in planting trees for energy.

Project Objectives

- To assess the current level of interest in energy coppice among farmers in GB and, hence, its present potential as a farm enterprise.
- To gauge the effects of any changes in the agricultural situation and in state-of-the-art energy coppicing since a similar study five years ago.

Methodology

The four main components of the study were:

- A literature review to assess UK agriculture, the changes that have taken place since 1985 and the implications for energy coppice.
- A consultative review of state-of-the-art energy coppicing and development of a brochure introducing the practice to farmers.
- A postal survey of the 1354 farmers responding to the 1986/87 survey.
- Interviews with 52 farmers all of whom expressed an interest in planting energy coppice.

Findings

Changes in UK agriculture since 1985

- Total land under agriculture declined by 1.7%. The number of holdings fell by 2.7%, and changes in enterprise included a reduction in barley and dairying and increases in oilseed rape, grass, beef cattle and sheep.

- Farm incomes have continued to fall, with farmers experiencing worsening terms of trade, larger debt burdens and poorer capital:income ratios.

- The labour force has continued to decline, with a 25% fall in regular full-time workers, a 10% reduction in seasonal and casual workers, and reductions of 11% and 6% in the number of full-time and part-time farmers.

- Social and environmental pressures on farming have intensified, but there are more opportunities for producing environmentally and animal welfare friendly products.

- Set-aside has had limited success in reducing overproduction, while Common Agricultural Policy budget expenditure, although less than in 1985, remains an issue.

Farmers have responded by improving the efficiency of existing operations rather than by extensification and diversification. Energy coppice could address current needs effectively, but depends on further technical development and demonstration, the addressing of cash flow and market issues, and ensuring the environmental acceptability of the crop.

Energy coppice

Changes in state-of-the-art coppicing include developments in planting and harvesting technology; a better understanding of weed, pest and disease control and fertilisation; and genetic improvements, particularly in relation to poplars. However, it is still new technology, and further research, development and demonstration is needed.

In cost terms, energy coppice could be viable with a subsidy equivalent to current set-aside payments. Forestry Commission planting grants are also available. However, its potential for widespread application depends particularly on market development.

Postal survey

Some 30% of respondents (compared with 44% in the earlier postal survey) said they might consider planting one or more areas of energy coppice, particularly on land currently identified as rough grazing, heavy land growing cereals and odd corners of the farm. Farmers in the eastern and south-eastern regions of England showed the greatest interest, particularly those in the younger age groups and those with farms of more than 120ha. These farmers currently operate a wide range of farming systems.

Profitability remains the ultimate determinant for both extent and speed of take-up, although the availability of farm labour to carry out the new level of tasks necessary with energy coppice is also an important constraint. Most farmers still regard energy coppice as a minor, almost marginal enterprise which is viable only if it can be accommodated within the existing pattern of resource allocation on the farm. As many farms are now family operated, only the larger farms are likely to have the necessary flexibility in terms of labour.

Despite the fall in the percentage of respondents interested in planting energy coppice, the level of interest of the interested 30% has increased, and estimates suggest that the total area that might be planted could be some 350,000ha, up 40% on the previous survey.

Farmer interviews

About 30% of the land that might be planted to energy coppice is currently being used for cereals, while more than 40% is unproductive.

The motive for change, for 64% of the proposed planting, was a desire to increase profitability. After reading the brochures about energy coppice, farmers revised the area that they might plant downwards from the average of 6.5 ha/farm associated with the postal survey to 3.6 ha/farm. However, every increase of £100/ha in gross margin seemed likely to increase planting area by 0.89 ha/farm. When given additional information on new grants available through the Forestry Commission’s Woodland Grant Scheme, farmers increased their proposed planting area to 7.41 ha/farm. Extrapolation to the national level suggests that some 405,000ha of energy coppice might be planted.

However, the case studies indicated the existence of a “core” of farmers interested in energy coppice for whom profitability is not an immediate concern. These are likely to be individuals who already have some on-farm use for the products of energy coppice, or for whom the amenity or environmental benefits of tree planting are of greater importance.

About half the case study farmers said they had spare labour during the winter months when most forestry operations have to be carried out. Others indicated a willingness to hire the necessary labour. Respondents were not interested in buying forestry equipment, preferring to hire equipment or contractors to do the work.

Most case study farmers considered that they either had or were developing a need for alternative enterprises because of the overproduction of existing farm products and the depressed prices associated with these. They were, however, aware of the lack of a market for energy coppice products at the present time. If such a market were to exist, it seems likely that many farmers in the UK would plant considerable areas of energy coppice, much of it on better land. This would help to reduce overproduction and falling prices, maintain farm income and increase employment in rural areas.

Recommendations

- Continued assessment of farmers' and public attitudes to energy coppice.
- Continued research to overcome technical constraints.
- Further economic evaluation of energy coppice at both farm and national level, and continued review of grant schemes.
- Assessment of the employment implications of energy coppice.
- Market development.

Report No: ETSU R 86 Publication date: 1994

THE USE OF INDUSTRIAL WOOD AS FUEL IN THE UK

Waste Resources Department, ETSU

Background

Almost all wood used in the UK is purchased from sustainably grown sources and is considered to be a renewable source of energy. Its use as a fuel offsets the use of traditional fossil fuels and helps to reduce atmospheric pollution, but this use is limited in the UK to the opportunistic combustion of wood processing by-products and logs or briquettes for on-site or domestic heating purposes.

There is good published statistical information on the quantities of wood grown in the UK or imported. There is much less information about the internal use of wood in UK industry and its potential as fuel.

Project Objective

- To identify and quantify the amount of wood currently used as a fuel within UK industry and to highlight the factors controlling this use.

Findings

Wood supply and consumption

Despite a substantial UK timber production industry, nearly 90% of UK annual timber consumption is imported. Most of this is softwood that has already undergone some degree of processing in its country of origin. The value of wood-based imports in 1991 was £6300 million. The equivalent figure for wood-based exports was £1800 million.

UK forestry activities account for about 10% of the total land area: nearly 40% is managed by Government through the Forest Enterprise and the remainder by the private sector. Two-thirds of coniferous species are grown by Forest Enterprise, and these forests are generally older and better established than the private forests. More than 90% of broad-leaved forests are in private ownership.

Softwoods account for more than 75% of wood-based imports, and 50% of this is in the form of pulp and paper. Coniferous sawnwood and pulp are imported mainly from Canada and Scandinavia, the latter countries also supplying large quantities of paper and paperboard. The largest supplier of sawn hardwood is Malaysia, with Indonesia being the main source of plywood.

In terms of overall UK consumption, paper and board applications account for more than 50% of the total used, and sawnwood for one third.

Wood processing and opportunities for use as fuel

The principal sources of wood residues are sawmills (primary processing); secondary processing industries such as furniture manufacturing, joinery, and panel and paperboard manufacture; and products recovered from the industrial waste stream.

Sawmill residues

Sawmilling produces sawn wood (50-60% of the total), saleable residues (25-30%) and other residues (15-20%). The saleable residues are purchased mainly by panel and board mills and by paper mills. The other residues consist mainly of bark and low-value wastes, and total more than 400,000 tonnes/year. These residues have a high moisture and grit content, but could be a useful fuel in a suitable boiler plant. Their low value means that they are best used on site or in very local markets, and estimates indicate that about 10% are already used in-house as fuel for kiln drying and/or space heating.

Secondary processing

The secondary industries probably generate around one million tonnes/year of residue. Production is very site-specific, with panel and paperboard mills, re-saw mills and the joinery sector producing about 300,000 tonnes apiece. It is estimated that about 100,000 tonnes/year of these wood residues are used in-house as fuel, two-thirds of them in dedicated boiler plant at the largest sites.

Industrial wood waste

Most domestic and general industrial waste is disposed of to landfill in the UK. Only 3% is incinerated, and only a small proportion of this will be wood. Although perhaps one million tonnes of industrial wood waste are produced each year, recovery for energy purposes from mixed industrial waste streams is generally considered to be too expensive. The main exception is in the case of pallet reclamation, where large quantities of wood become available when pallets cannot be repaired.

Domestic and industrial use of fuel wood

About 190,000 tonnes of wood are sold each year as a fuel for domestic, agricultural and industrial applications. Another source of waste timber are the Civic Amenity sites where the public can dump furniture, window frames and other items.

Estimated use of wood as fuel

Of total residues of nearly four million tonnes produced annually, perhaps 480,000 tonnes is used as fuel, the net energy content being nearly six million GJ/year. Transportation to markets is expensive, because of the low bulk density of the material, and this limits the potential for additional use as does the price at which residues are available.

Legislation

Pollutant gas and particulate matter emissions from the combustion of wood are controlled by legislation in the UK. Most processes with a thermal input of 0.4MW or more can achieve the limits by careful control of combustion conditions and by the use of efficient cyclone particulate arrestors. However, the combustion of treated wood has additional limits imposed, and afterburners and acid gas scrubbing may be required in such situations.

Small, manually fed wood burning heaters with a thermal input of less than 400kW face fewer restrictions, limited largely to the prevention of dark smoke.

Report No: ETSU B/M4/00487/08/REP Publication date: 1995

NON-ENERGY MARKETS FOR SMALL ROUNDWOOD, FOREST RESIDUES AND SHORT ROTATION COPPICE

John Clegg and Co

Background

The Third Order of the Non-Fossil Fuel Obligation (NFFO), which stimulates and supports energy production from renewable sources, was announced by the Government in July 1993. This generated considerable interest, and numerous proposals were submitted by the closing date for tenders in 1994.

Each proposal had to identify the source of its raw material supply for generating electricity, and it became clear that those interested in generating electricity from wood were unfamiliar with the nature and structure of the forestry industry, and lacked detailed information about existing and possible future markets for small roundwood, forestry residues and short rotation coppice (SRC) crops.

Project Objectives

- To review existing and potential sources of forest residues.
- To identify existing markets for forest residues, small roundwood and chips, describing and, where possible, quantifying their size and characteristics, and assessing their potential over the next 15 years.
- To examine the potential for willow and poplar coppice to compete in these markets.
- To identify possible future new markets for forest residues and SRC.

Methodology

Information was obtained from a wide range of sources, including the forestry industry, manufacturers and local authorities. Use was made of published sources, and additional information was obtained via personal and telephone interviews.

Findings

Trade

Britain imports about 87% of its wood and wood products and is the third largest importer of these items in the world. The estimated value of these imports in 1993 was £5.5 billion. However, the wood and wood products market is heavily influenced by what is happening in the world timber trade and, increasingly, since the introduction of the single European market, by events in Europe. This situation is likely to persist, with greater international attention being paid in future to issues such as conservation, wood recycling and added value prior to export.

The British forestry industry has invested heavily in new plant and equipment, particularly over the last ten years. It is now regarded as being internationally competitive and must remain so if it is to survive.

Main markets for roundwood

Competition for roundwood is intense at the present time. Just over half (54%) of the 6.9 million cubic metres produced in Britain is used as sawlogs, and a further 38% is used by the panel board and pulp and paper mills. Prices range from approximately £51/green tonne delivered at the mill for the best quality sawlogs to £20-£25/green tonne for firewood.

The main markets for UK roundwood can be summarised as follows:

- Four major pulp and paper mills take approximately 1.3 million green tonnes/year. Specifications are typically 1.8-3.0 metres in length and from 6cm underbark diameter (top) to 40cm underbark diameter (butt).

- Six existing panel board mills, plus one under construction, take approximately 1.8 million green tonnes/year. Specifications are typically 1.7-3.0 metres in length and from 6cm underbark diameter (top) to 60cm underbark diameter (butt).

- There is a highly fragmented and unquantifiable fence post market, for which peak demand occurs in the spring.

- An unregulated and fragmented firewood market accounts for between 120,000 and 230,000m^3. Supplies are normally provided in summer so that logs can dry out prior to burning.

- Other uses could amount to about 315,000 m^3/year.

Main sources of residue

There are several sources of residue:

- The sawmilling industry produces nearly two million tonnes of residue each year, about 85% of which is used by panel board and paperboard mills. The remainder, consisting mainly of bark and some unpeeled chips, is used as material for mulching, landscaping and horticultural use, play areas, paths and horse gallops, soil composting and soil conditioning.

- Wood shavings and sawdust produced by joinery and milling firms from imported sawn timber amounts to about 300,000 tonnes/year. About 70% of this is used for higher-priced markets - bedding for horses, chickens, turkeys, cattle etc. The remainder is used in the wood processing industry.

- Solid wood waste that was previously disposed of to landfill is now being recycled and used by the wood processing industries. In 1993, about 32,000m^3 of such waste was recycled, and this trend is expected to continue.

- About 1.38 million green tonnes of forest residues are produced each year. Of this, only about 100,000 tonnes are used, mainly as a horticultural/landscape mulch.

- Arboricultural work in urban and peri-urban areas generates significant quantities of residues each year, a proportion of which is left to dry and then used as a mulch.

- There are no end-use markets for offcuts and waste material made from chipboard, orientated standard board and medium density fibreboard because the material contains glues. Most such material is disposed of to landfill. Similarly, there are no markets for animal bedding that contains wood chips.

Other sources of timber

Traditional coppice harvested on a 15-year rotation could generate large quantities of timber. In the case of sweet chestnut, there is a potential output of 92,000 tonnes/year. However, in practice, the market for chestnut coppice is limited to 23,000-27,000 tonnes/year, although work is under way to develop new markets that would increase consumption by 7,000-10,000 green tonnes/year.

Although there are no established markets for recently planted non-traditional willow and poplar coppice with a potential for energy production, trials indicate that the material would be suitable for chipboard production provided the bark percentage is not too high.

Future supply and demand

Annual roundwood production from conifers is expected to increase by about 70% between 1992/96 and 2007/11. Annual production of broadleaved roundwood, however, will remain constant or fall.

The net increase in production is likely to have two effects:

- expansion in the sawmill industry, which will increase the volume of residues - chips, bark and slabwood - available

- an increase in existing panel board, paper and paperboard manufacturing capabilities to absorb the increase in both sawmill residues and roundwood.

Competition for roundwood and sawmilling residues is therefore likely to remain strong, unless economic recession causes a short-term drop in demand.

Report No: ETSU B/M4/00487/30/REP Publication date: 1995

FUEL-WOOD FROM UNDERMANAGED WOODLAND

LRZ Ltd

Background

Much UK broadleaf woodland, for example traditional coppice, is undermanaged because of the lack of viable markets for its products. Initiatives are now being taken in many areas to redress this situation, both to revitalise the associated rural industries and to stimulate employment.

Historically, the production of wood fuel was an important component of woodland management, and the harvesting and sale of firewood is still widespread, although unit energy prices are high. Wood fuel can, however, represent a very significant market for the lower-grade products resulting from the management of neglected woodland areas, provided lower-price harvesting strategies can be implemented.

Project Objectives

- To identify the wood fuel markets and resources associated with undermanaged broadleaf woodlands.
- To identify management opportunities and constraints.
- To examine the availability of suitable equipment.
- To identify and cost appropriate systems of work.

Findings

Market potential

There is a huge potential market for wood fuel, particularly for heating domestic premises and municipal/commercial properties such as schools, colleges, hospitals and prisons in rural areas. Although logs are the obvious form of fuel, it is possible to reduce labour requirements by using a more automated wood chip burning system.

The quantity of fuel required will vary between establishments, with guidelines from around 20 green tonnes (gt)/year for a farmhouse to 150 gt/year for a school and 400-1000 tonnes for a college based in/around a stately home. The fuel should have a moisture content of no more than 50% - often less. If the felling moisture content is higher, some degree of drying is necessary.

Potential fuel sources

There are three main potential fuel sources: neglected broadleaf woodland, traditional coppice that has partially reverted to high forest or scrub, and coppice with standards. Poor management has been associated with poor returns, eg from pulp and other small roundwood outlets, and the decline of traditional coppice-based industries. As a result, effective thinning and/or coppicing has rarely been carried out. Returning these woodlands to proper management will provide a vast immediate source of wood fuel from thinning or clear felling. In the case of renovated coppice, it will provide fuel wood on a sustainable basis.

Management benefits and constraints

From the point of view of shooting, wildlife conservation and amenity value, there are accepted benefits to be gained from managing neglected woodlands. The management of otherwise untouched woodland is, for instance, likely to increase its potential as a shoot. However, the optimum management system for shooting may not coincide with the optimum management system for fuel. Where woodland is managed for fuel, the benefits to shooting should be capitalised on and credited against the harvesting cost.

There are also specific practical constraints:

- It is important to avoid severe damage to remaining woodland during wood fuel harvesting.

- Felling should not take place in the nesting season, nor should extraction take place under very wet ground conditions.

- The programme of work must fit in well with other estate enterprises and sporting activities.

- Deer - and often sheep - control is essential, especially on coppice sites.

Tight constraints on operations will raise costs and inhibit woodland management. While some payments may be available at certain sites to compensate for this, some element of compromise is usually necessary. An example of such compromise is the working of relatively small non-adjacent coupes in coppice, thereby allowing adjoining zones to buffer the work in progress. This option may also be desirable for shooting.

Systems of work

Three general systems of work have been identified:

1. Fell → chip → cart → store → burn systems are best suited to clearfell sites such as coppice coupes in a regular rotation or to high forest sites where clearfell or thinning has generated residues. Such systems are not well suited to situations involving large-diameter material such as that encountered in coppice restoration.

2. Fell → Extract → Stack → Unstack → Chip → (Store) → Burn systems involving storage in the round before chipping. If this component is omitted, then the extract work rate will need to match the chipper workrate for capacity operation. The latter system is potentially suited to tree-length or shortwood extraction, provided the chipper can be operated to capacity and justify its hire costs.

3. Fell → Extract → Stack → Unstack → Cart → Chip → Burn systems are appropriate for shortwood extraction and involve the use of a dedicated chipper at the combustion plant end of the process.

Of these, System 1 is appropriate to in-cycle coppicing, small-diameter broadleaf thinnings and clearfell residues. Systems 2 or 3 can be used for coppice restoration, broadleaf clearfell, or large diameter broadleaf thinnings. The modified version of System 2 is also appropriate to in-cycle coppicing and small-diameter broadleaf thinnings.

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.

The application of any system will depend on the practical availability of equipment and contractors within a sensible distance. The chipping stage is the most specialist, and heavy duty machines are needed for large tonnage throughputs. Hired machines must be carefully selected and fully used to be cost-effective.

Delivered fuel costs

The procedures and delivered fuel costs for two case studies can be summarised as follows:

At West Dean Estate motor-manual felling was followed by snedding and cross-cutting before immediate extraction by forwarder to a hard rideside for stacking. After storage in the round, the timber was loaded and carted to the boiler plant where it was chipped directly into the boiler bunker using a static chipper. The delivered fuel cost was £41/gt.

At Gamlingay Wood in Cambridgeshire, the system suggested is for felling to be followed by extraction to rideside in late summer, chipping using a hired-in chipper in the autumn, and finally carting to and clamping at the boiler plant. The delivered fuel cost is estimated to be £36/gt.

In both cases the cost of the fuel exceeds the cost of equivalent heating using oil. The in-rotation coppice system described above can deliver wood chips into store for a cost of less than £25/gt.

Report No: ETSU B/M3/00388/31/REP Publication date: 1996

BIOMASS RESOURCES FOR GASIFICATION POWER PLANT

Energy for Sustainable Development Ltd
Kings College, University of London

Background

The term biomass covers all plant-derived matter except that which is fossilised. It includes dedicated agricultural and forest products such as sugarcane, rape seed and fuelwood; agricultural and forestry residues; and the products of energy plantations.

Heating values range from 17.5 GJ/tonne of dry matter (tdm) for herbaceous feedstocks to 20 GJ/tonne for woody feedstocks. Biomass resources produce 0.4-2.0% by weight of ash that is generally free of toxic and other waste contaminants. Sulphur contents are 0.01-0.1% by weight.

The lower useful energy content (1-8 GJ/m^3), when compared with coal (about 25 GJ/m^3), has important implications for plant size. High transport costs and the dispersed production of biomass means that the maximum size of generating plant is likely to be 50-100MW_e, far smaller than for a typical fossil-fuel-fired plant. Storage and handling equipment, on the other hand, is typically larger and more expensive.

Project Objectives

- To estimate the current global biomass resource and its potential for electricity production.
- To provide preliminary estimates of the long-term markets for electricity from biomass.

Findings

Global biomass resource

The global production of biomass is estimated at 220 billion dry tonnes/year, nearly all in the form of natural growth wood and agricultural and forestry residues. Biomass accounts for about 15% of global energy consumption - averaging 3% in industrialised countries and about 38% in developing countries.

Agricultural and forestry residues

Agricultural and forestry residues consist of:

- Straw and other agricultural residues left in the field after harvest. These often have local uses and major non-energy markets which reduce their availability as a fuel. They remain a potential fuel where they are in surplus, and straw is already used to fire several district heating schemes in Denmark,

- Residues from mill processing, including rice husks, sawdust and wood off-cuts, bagasse, groundnut shells, coffee husks. They are often already used to provide heat and, sometimes, power to the mill.

- Forestry residues from clear felling, thinning etc.

The trend towards centralised processing in both developing and industrialised countries will increase the proportion of residues available for fuel. However, the economically realistic and environmentally sustainable supply of residues for electricity generation is much lower than the overall potential. Crop residues have an important role in maintaining soil fertility and limiting erosion, and there are technological limitations to the degree of recovery and storage.

Biomass plantations for energy

Only about 6 million ha of the world's 100 million ha of industrial tree plantations are the fast-growing, non-coniferous trees most suited to biomass energy production. Brazil's eucalyptus plantations are particularly successful. Experience in temperate climates is more limited: Spain and Portugal have more than 0.8 million ha of pulpwood eucalypts; Northern Europe has about 15,000 ha of experimental short rotation crops (mainly willow); and the US has about 24,000ha of hardwood plantations in the Pacific Northwest. Future energy from biomass plantations will comprise species with a very high dry matter production, which will ideally be grown on good quality agricultural land, and species capable of reasonably high dry matter production on marginal and degraded land.

Although much more R&D is still needed, governments and international organisations have carried out work in this area, and there is a rapid growth in the literature on all aspects of energy crops and their conversion to electricity.

Considerable efforts are being made to improve crop yields generally and, although these improvements are not yet apparent in plantation-based biomass energy systems, hybrid poplar yields of 43 tdm/ha/year have been achieved in experiments in the US Pacific Northwest, and eucalyptus yields of 39 tdm/ha/year from trials in Brazil. These compare with existing yields of 10-15 tdm/ha/year in temperature zones for poplar and willow, 12-30tdm for miscanthus, 8 for switchgrass, 2-20 for cordgrasses and 13-25 for sweet sorghum. It is generally assumed that long-term yield increases will parallel those achieved in grain crops in industrialised countries.

Both surplus agricultural land and marginal and degraded land should be available for energy plantations. The former will be available mainly in the developed countries where slow population growth combined with rising agricultural productivity is rapidly reducing the amount of land needed for food production. The use of degraded land could have a two-fold benefit: the production of energy crops and the mitigation of many of the problems that have caused the degradation. Short rotation coppice could be particularly beneficial in this respect.

The total global biomass resource

Assuming residue recovery levels of 100% for bagasse, 25% for sugar cane leaves and tops, 25% for logging residues; 75% for mill and manufacturing residues, and 25% for other crop residues, the potential, sustainable global total for residues is equivalent to 26.2 exajoules/year. To this must be added the biomass energy available from plantations, which is estimated at 266.9 exajoules/year. The global total of about 293 exajoules/year is equivalent to more than 90% of present commercial energy use.

Future projections

Electricity demand is expected to more than triple between 1985 and 2050, irrespective of policy scenarios relating to emissions. Most of this growth will take place in the newly industrialising and developing countries.

Whether economically available biomass supplies exist to meet this growing demand will depend on whether governments actively pursue a renewables-intensive global energy policy or maintain the present status quo:

- The potential market for power from biomass, assuming a renewables-intensive policy, is 355GW in 2025 (equivalent to 9200 50MW_e plants) and 687GW in 2050 (13,700 50MW_e plants).

- The potential market for power from biomass under the existing policies scenario is 207GW.

Biomass power would meet about 18% of the electricity requirement under an emissions reduction scenario. Furthermore, there is an enormous potential market for plant of all sizes.

Report No: ETSU B/W2/00548/15/REP Publication date: 1997

UK INDUSTRY WOOD FUEL RESOURCE STUDY: ENGLAND, WALES AND SCOTLAND

Forestry Contracting Association Ltd

Background

It is predicted that there will be a major demand for wood fuel from forestry sources in the UK. This will be necessary to meet both proposed developments under current and proposed Non-Fossil Fuel Obligation (NFFO) licensing rounds, and the expanding market for small-scale heating plants in rural areas. Earlier studies have investigated the potential wood fuel resource in the UK, estimating that it is likely to be around 1.03 million oven dry tonnes (odt)/year by 2000.

Project Objective

- To develop models for four potential wood fuel sources:
  - forestry residues and residuals from clear-fell conifer forestry;
  - dedicated wood fuel production plants;
  - broadleaved woodland;
  - arboricultural residues;

taking into account the exacting environmental and commercial constraints likely to be placed on wood fuel harvesting by the Forest Enterprise.

Findings

Forest residues and residuals

Forest residues consist of all above-ground material removed from merchantable trees, plus unmerchantable stem pieces from in-forest conifer harvesting operations. The material available for fuel depends on the demand from the pulp and board industries for upper stem wood, and also on the species, age and spacing of the trees, site quality and location, and harvesting system adopted. Residue yields for clearfell, calculated using regression analysis, are shown in Table 1 below.

Table 1 Clearfell residue yields

Species	Yield
Spruces	25.72%
Pines	20.18%
Other conifers	23.42%

Residuals consist of small trees with a diameter at breast height of less than 7cm, dead trees and fallen trees that are unmerchantable because of rot or decay. The percentage of residuals varies with species and silvicultural practice, but may amount to 5.5% of merchantable stem weight in a clearfell of previously unthinned Sitka spruce.

There are two operational constraints to the harvesting of wood fuel: harvesting systems and environmental impacts.

Those whole tree harvesting systems that are currently in operation in the UK are cost-effective. They could be converted into integral harvesting operations if residue collection could be added as a profitable element. The demand for wood fuel could also justify the conversion of existing pole-length harvesting systems to whole tree operation, and the reintroduction of feller clam bunk systems. A more likely option is the addition of residue harvesting to conventional shortwood and tree length harvesting systems as a second-pass operation.

The loss of nutrients as a result of residue removal is a major environmental consideration. This can, to some extent be alleviated by leaving the residues for a period of drying prior to harvesting to encourage needle fall and ensure that a higher proportion of the nutrients remains on site. Another area of concern is that the lack of a residue mat might result in drought stress and the death of fine roots, together with compaction and erosion on some of the wetter and more poorly drained organic upland soils. On the other hand, removing residues can facilitate restocking operations.

Potential wood fuel availability for 1998 is estimated at 308,639 oven dry tonnes (odt), the majority from Scotland and Wales. This figure is expected to rise to 660,548odt by 2013.

Dedicated wood fuel plants

The introduction of markets for large volumes of wood fuel is likely to encourage the development of specialist wood fuel production plants.

In-forest plants might comprise specialist chain flail delimbing/debarking units plus associated in-woods chippers. Growth in this area is more likely to come from the private sector as it responds to changing market conditions. A typical scenario might be the conversion of existing pole-length extraction systems to whole tree extraction and landing processing for residue collection. There are three possible sources of timber: premature clearfell; timber released by the proposed increase in top diameter required for small roundwood processing; and increasing levels of clearfell in the private sector. The total wood fuel potential from these sources is estimated at 54,405odt for 1998 and 85,063odt for 2013.

The establishment of out-forest plants for the primary processing of roundwood would optimise timber quality to the mills, and generate large quantities of bark, butt reducer chips and other arisings.

Arisings from broadleaf woodland

Fuel arisings from broadleaf woodland could come from either productive or unproductive woodland or from non-woodland trees. Assuming that the operational constraints are half as great again as for conifers, then arisings in excess of 117,000 odt/year, and possibly more than 200,000 odt/year, are likely.

Arboricultural residues

Arboricultural residues - the residues from single tree harvesting and other pruning operations carried out in urban and semi-rural areas, and alongside railways and roads - are likely to form a significant component of UK wood fuel resources. Surveys of three local authorities who have undertaken waste stream auditing indicate that arboricultural residues account for about 4% of all waste arisings. Applying this figure to all UK waste arisings gives a figure of 380,000 odt/year from local authorities plus a further 88,000 odt/year from commercial waste management companies. The lack of detailed waste stream data means that these figures are likely to be conservative.

Conclusions

The total wood fuel resource for England, Scotland and Wales is summarised in Table 2.

Table 2 Total wood fuel resource for England, Scotland and Wales

Wood fuel source	**Arisings (odt/year)**	
	1998	**2013**
Residues and residuals	308,639	660,548
Dedicated wood fuel plants		
In-forest	54,405	85,063
Out-forest	93,834	294,804
Broadleaf woodland	203,275	203,275
Arboricultural arisings	484,000	484,000
Total	**1,144,153**	**1,727,690**

Practical considerations will reduce these figures to the 80-90% that is readily available, ie not in isolated woods or on the wrong side of a stream. More likely figures are therefore 915,322-1,029,738 odt/year for 1998 rising to 1,382,152-1,554,921 odt/year by 2013.

Overall, the introduction of wood fuel harvesting on the scale envisaged in this report is likely to be environmentally positive and beneficial to the current and future status of UK forests.

1.2 The Environmental Implications

Report No: ETSU B 1166 Publication date: 1988

ENERGY FORESTRY IN BRITAIN: ENVIRONMENTAL ISSUES

Environmental Resources Ltd

Background

Other studies have shown that there is land in Britain that, from an economic viewpoint, offers potential for growing trees for energy. However, it is recognised that energy forestry could have an effect on the environment, and that some of its effects may be adverse, constraining the development potential. This report addresses the issues involved. Volume 1 summarises the background, methodology and project findings. Volume 2 comprises the associated Technical Annexes.

Project Objectives

- To identify and assess the environmental effects of energy forestry and their impacts and benefits.
- To identify ways in which these impacts may constrain energy forestry development.
- To recommend areas for further research and possible mitigation measures.
- To make information on the environmental effects of energy forestry available to decision makers, land users and others, and to obtain their views on the possible environmental impacts.

Methodology

Hypothetical forestry sites were used as a framework for identifying and assessing the environmental effects. Environmental studies examined the impact of energy forestry on soil resources, water yield and quality, ecology, and landscape and amenity. In addition, a consultation document was prepared and circulated to 53 organisations likely to have an interest in energy forestry and its impact. Organisations were invited to comment on the project findings.

Findings

Impact of energy forestry on the countryside

Coppice and single stem plantings would have an adverse effect on the landscape if they were located so as to obscure a notable landscape feature or if they were established in landscapes that are not characterised by mixed agriculture. It would be inappropriate for coppice planting to replace scrub woodland that is an existing landscape feature. Single stem planting would need to fit into the existing pattern of field boundaries.

The potential benefits of coppice planting are limited, but might include twig colour, variation in texture and, depending on the species planted, foliage colour. Single stem planting is more akin to traditional broadleaved woodlands: it would contribute textural and height diversity, and plantations could be designed to highlight landscape features.

Harvesting would generate some noise disturbance and might constitute a hazard to the public.

Modified conventional forestry is broadly similar to conventional conifer forestry practice. However, additional plantations would further reduce existing natural landscapes, notably the remaining moorlands and blanket bogs noted for their colours and landforms. It could also generate access problems in hill walking areas, while the movement of thinning and harvesting machinery would make a significant impact on road facilities in remote areas. Quality forestry design can be applied to create an attractive forest landscape resource, but usually only in areas of more diverse and complex topography.

Impact of energy forestry on soil and water resources

Good coppice management on disadvantaged or previously cultivated land is likely to improve soil nutrient capital and structure. Low-lying areas would be vulnerable to compaction and structural damage as a result of machinery use. Water catchment yields could fall, and this could be a significant problem where catchments are small, extensively planted or used for irrigation, effluent return or groundwater recharge.

Single stem plantings in the uplands are likely to give rise to soil erosion and sedimentation of adjacent watercourses after harvest. There may also be some soil acidification, similar to that encountered in conventional forestry. In the lowlands harvesting may cause some structural damage, and water catchment yields could fall. However, land previously used for agriculture could benefit from the less frequent application of fertilisers.

Modified conventional forestry is likely to cause acidification and, in sensitive areas, could have an adverse effect on fisheries, ecology and water treatment costs. Conventional forestry has also caused sedimentation and eutrophication of adjacent waters, and the same is likely to be true for modified conventional forestry. Water yield is also likely to be reduced.

Impact of energy forestry on ecology

Coppice planting on neutral grasslands that are botanically rich or support bird species of particular interest would have adverse ecological effects, as would planting in scrub woodland where the ground flora is of a type associated with remnant ancient woodland. Even disadvantaged land can include sites with nature conservation interest. There is also the danger of pest problems increasing with the introduction of hybrid, clonally propagated material or the greater use of species not normally found in Britain.

On the other hand, former agricultural land would benefit ecologically, and coppice has some potential for improving bird and other habitats, particularly if some ground flora development or a variety of stand ages can be permitted.

As with coppice planting, the ecological impact of introducing single stem planting would depend on the location. Single stem plantations of broadleaved species would be particularly beneficial in terms of habitat in areas of ecologically uninteresting lowland grassland, in arable regions and also in some upland areas, although the incremental loss of upland grazing could be cause for concern.

Modified conventional forestry plantings on moorland and blanket bogs would give a significant ecological loss. There is also some concern over pest outbreaks and the implications of pest control.

Main Recommendations

- Advice on coppice design, siting and mitigation measures should be prepared and disseminated to those involved in its development.

- Particular consideration needs to be given to the relative benefits of establishment on former arable and disadvantaged land.

- If single stem forestry were to become a realistic option, further attention should be given to assessing the relative importance of the different impacts and benefits that could occur.

- Any constraints on modified conventional forestry must be seen in the context of constraints on conifer afforestation as a whole.

- The mitigation measures and measures for maximising benefits that are adopted by conventional forestry must also be applied to modified conventional forestry.

Report No: ETSU B/W5/00216/REP Publication date: 1993

SHORT ROTATION COPPICE: A LITERATURE REVIEW

Environmental Resources Ltd

Background

This report updates an earlier literature review undertaken in 1992 as part of the Farm Wood Fuel and Energy Project (see Section 3 of this volume) It focuses on the influence of coppice management on wildlife and gives particular attention to short rotation coppice (SRC) where information is available.

Project Objective

- To summarise existing scientific literature relating to the influence of coppice management on wildlife.

Findings

General conclusions

The practice of growing SRC as an energy crop is relatively recent in the UK, and little information is readily available regarding either its ecological status or its nature conservation interest. Traditional coppice woodland, on the other hand, with its variety of tree species and longer cutting cycles, has been widely studied throughout the UK. These traditional woodlands are recognised to be important for their variety of flora and fauna. Some species rely on specific conditions provided only within coppice woodlands - the changes in microclimate through the coppice cycle, the availability of food and the provision of shelter.

There are few similarities between traditional coppice and SRC grown as an energy crop. The information from traditional coppice studies can therefore only be applied to commercial crops with caution. They should be used to outline physical changes that are likely to occur. They should not be used to predict likely species composition.

Unlike traditional coppice, SRC is managed intensively to maximise biomass production. Nature conservation objectives can only be applied where crop productivity will not be affected. Although SRC is unlikely to support the diversity of species associated with traditional coppice woodlands, it should support a wider range and a greater number of species than when the sites were managed as agricultural land.

The main opportunities for ecological enhancement lie in the management of the coppice edges and rides. This might include:

- developing as large an edge as possible around the plantation and developing this boundary to enhance or integrate the coppice with sites of nature conservation interest in the vicinity
- establishing flora, including food plants, in appropriate locations
- protecting the site from intensive grazing by animals
- creating wide, vegetated rides
- planting additional tree species around the coppice edge, allowing some to grow as standards.

Specific conclusions

Flora

Much SRC has been planted on former agricultural land that has been managed intensively and supports only a poor ground flora. As a result, the early stages of the coppice cycle are likely to be characterised by plants associated with disturbed or agricultural land.

Subsequent development of the flora will depend on the degree of management imposed. Studies in Sweden have shown that SRC grown as an energy crop has the potential to develop a species-rich flora if managed sensitively. Options include the development of rides, glades and boundaries, and the introduction of seeds or young plants where appropriate. Large, commercial and intensively managed stands, on the other hand, are likely to support only an impoverished flora.

Invertebrates

Short rotation coppice generally involves monoculture and would therefore be expected to support a less diverse range of invertebrates than more varied and complex systems. Willows, however, have been found to contain one of the most diverse invertebrate assemblages.

While the species and populations present will depend on the management systems imposed, careful management and design of both willow and poplar plantations could encourage the development of invertebrate populations. Options include maintaining deadwood on boundaries, planting in the vicinity of established woodlands and hedgerows, and planting appropriate food plants.

Birds

Changes from intensive arable to coppice woodland are likely to increase the ornithological value of the site, particularly if managed sensitively. The presence of insects will encourage birds into the coppice, and the dense canopy that is produced by both poplars and willows after at least two years' growth has the potential to attract dunnocks, garden warblers, linnets, yellowhammers and whitethroats within a three-year rotation.

Woodlands provide important overwintering sites for pheasants, and their edges are an important territorial component for the male pheasant. It may be possible to incorporate management for game within general SRC management.

Mammals

Traditionally managed coppice woodlands are able to support a variety of mammals. Short rotation coppice experiences much greater levels of disturbance and this is likely to deter many species. However, the SRC system is likely to provide habitats for certain small mammals, with species density declining after three years but improving again both after cutting and as the stools mature and provide more crevices for small mammals to inhabit.

The existence of large mammals, especially deer, can have an adverse effect on the crop as a result of grazing. Fencing is used to discourage these species.

Report No: ETSU B/W5/00340/REP Publication date: 1993

PUBLIC PERCEPTIONS OF SHORT ROTATION COPPICE

St Ronans Research

Background

The Department of Trade and Industry's Wood as a Fuel programme is well established, with ten trial coppice sites in operation, plus some 40 others. Several successful willow and poplar clones are available, machinery for planting and harvesting has been developed, and local consortia of farmers and users are being established to provide long-term markets for the wood fuel produced. Because of the extensive areas of arable land set aside from food crop production, farmers are seeking alternative non-food crops. Short rotation coppice (SRC) is eligible for European Community set-aside subsidies and for Forestry Commission grants to support planting. However, there is concern that the public's perception of coppicing could affect farmers' willingness to try this crop for themselves.

Project Objectives

- To explore the perceptions and attitudes of four groups who might be most affected by coppice developments - country residents near existing coppice trial sites, other country residents, visitors to the countryside from conurbations and members of special interest groups from conurbations.
- To assess how the views of these key groups are affected by personal circumstances and expectations about the countryside.
- To identify what sorts of information each group needs to help it understand and accept the need for extending coppice use for wood fuel.

Methodology

Fourteen group discussions were held in ten different locations in England, Scotland and Wales. Each lasted for 1.5-2 hours and each was made up of 6-10 members of the public who make regular recreational use of the countryside. A structured recruitment questionnaire was used, and discussions were taped and transcribed (with participants' knowledge) for subsequent analysis.

Findings

Proposals to encourage the widespread establishment of willow and poplar coppice for wood fuel is potentially acceptable to most countryside users. Its actual introduction is more likely to be accepted if all the questions raised are answered satisfactorily in advance.

Potential objections relate to:

- the considerable loss of amenity value associated with “industrial”-scale coppice plantings - with disruption from harvesting, noise, increased traffic, and limited habitat for wildlife

- the feeling that unrestricted coppicing could damage the countryside - blocking favourite views, regimented planting of single species, buildings for storage or processing

- the fear that farmers are hard-headed businessmen who might rush into coppicing on a grand scale if it proves profitable.

Few people are aware of the proposals to use set-aside land for willow and poplar coppices for wood fuel. When they do become aware, they regard it as a more acceptable use than alternatives such as golf courses, oil seed rape, caravan sites or leaving the land fallow.

Because people often equate coppice with copse and want to see more mature trees in the countryside, the type of coppicing proposed can be a slight disappointment.

However, increasing awareness does engender interest and cautious optimism, provided certain questions can be satisfactorily answered. These relate to:

- Environmental impact - people are concerned about the scale of the proposal, the implications for the look of the countryside, and the habitat issue. They are reassured by suggestions that coppices will not exceed 10ha in size, that they are likely to be in the less accessible and productive corners of farms, and that coppice is a good habitat for wildlife after the first two years.

- Economic viability - particularly the merits of wood as a fuel, its price, and any Government support required. Some people regard wood fuel as a low-tech, retrograde step.

- How wood as a fuel fits into the national energy policy - people are reassured to find it is a Government-backed programme rather than one initiated by “big business”. They would prefer to see coppicing as one strand in an energy policy that embraces several renewable energy sources and that also encourages energy efficiency and conservation.

- The possible conflict of interest between local and national interests, although some people did accept that coppicing could provide local opportunities for growers and users.

Overall, most people support the greater use of renewable energy sources to reduce global warming, and the fact that sustainably grown wood fuel is a renewable resource is its greatest asset.

Recommendations

1. The public must be kept informed of any planning guidelines or regulations that are introduced to control the siting and size of coppice plots, or to limit the extent of coppicing on any farm or area. Suggestions were made that a maximum of 10-15% of arable land, or of one field in five, might be acceptable.

2. Communications about the coppicing programme should come from Government and should be backed, where possible, by environmental groups.

3. Any Government communications programme needs to communicate the benefits, the scale envisaged, and the national energy policy context within which coppicing is set.

4. Particular emphasis should be placed on communicating the following facts:

   - Coppices are a source of renewable energy.
   - Grown sustainably, there is no net CO_2 output.
   - Switching to wood fuel helps to combat global warming.
   - Coppicing provides new local opportunities and jobs.
   - Coppicing provides new habitats where wildlife can flourish.
   - Coppicing is one way of bringing more trees back into the countryside.

1. Literature should provide reassurance.

2. Full use should be made of both television and print media to tell the story and generate support for coppicing.

Report No: ETSU B/W5/00277/REP Publication date: 1994

ENHANCING THE CONSERVATION VALUE OF SHORT ROTATION BIOMASS COPPICE - PHASE 1: THE IDENTIFICATION OF WILDLIFE CONSERVATION POTENTIAL

The Game Conservancy Trust

Background

Short rotation coppice (SRC) for wood chip fuel has the potential to become a widespread crop on farmland taken out of food production. It is therefore necessary to consider some of the wider effects of its introduction, particularly its suitability as a new habitat for wildlife species and its value to conservation generally. At present, there is only limited information on the plant and animal species associated with the crop and on the ways in which its management could be adapted to increase its value to these species (or reduce their impact on the crop). A better understanding of these issues would be advantageous to growers and to the developing industry.

Project Objectives

- To visit all SRC sites in Britain and Ireland during the winter of 1992/93.

- To record songbird, butterfly, floral and pheasant populations at a selected sample of sites during 1993, and to relate these populations to the size, structure, site characteristics and management of the plots.

- To identify those features associated with increased conservation interest, and to put forward management recommendations likely to increase the game and wildlife value of commercial crops.

Methodology

Songbird surveys were undertaken at 29 of the 51 willow or poplar SRC sites identified during the winter of 1992/93. This involved taking between one and seven bird point counts in each of 66 sample plots between 0600 and 0800 one morning during the Spring of 1993.

The presence or absence of pheasants and red-legged or grey partridge was recorded on each of three visits to the 19 SRC sites in England. The spring visits were also used for pheasant counts, to establish the number of males with territories associated with the crop. One count was made at each site during the early morning or evening, usually from a car.

Butterfly counts were made along standard 50m transects through different sections of SRC crops or integral unplanted areas adjacent to the crop, such as headlands or rides. Counts were conducted between 1000 and 1600 hours on sunny days with light winds during late June, July and early August.

A survey of ground vegetation within the crop at 29 sites was undertaken using 10 x 1 metre quadrats in both the spring and the summer of 1993. The presence of herb species in the rides and headlands was also noted.

Multivariate analysis was used to identify the sites that were particularly attractive and to ascertain the site, structural or management characteristics that were associated with an increased game or wildlife value.

Findings

The songbird counts showed that SRC attracted high densities of typically woodland species, with willow attracting higher densities and a greater species diversity than poplar. Both willow and poplar appeared to be at their most attractive two years after cutting, two-year-old willow being particularly attractive to migrant warbler species of recognised conservation interest. The conclusion to be drawn is that the introduction of SRC, particularly willow coppice, on farmland should increase the abundance and diversity of songbirds.

Short rotation coppice, particularly willow, can provide attractive winter cover for pheasants. It also provides suitable sites for male territories in the spring, enhancing local breeding populations: breeding densities along the edges of SRC were comparable to those found along the edges of more traditional woodland. However, although it seems likely that its pheasant potential may increase the attractiveness of SRC in management terms, special consideration needs to be given to the size and shape of plots, to management of the edges to make them windproof, and to the inclusion of mixed age classes.

The survey identified 14 butterfly species, mostly common species such as the Browns, which form local colonies feeding on stress tolerant grasses, and the Whites and Aristocrats which form mobile populations exploiting weeds found on fertile and disturbed ground. Headlands contained the highest butterfly numbers: uncut areas of crop contained the lowest. There was also a significant geographical variation, with plots in the south of England containing the maximum number of individuals and species.

As well as identifying 182 ground flora species, the survey found that existing SRC sites are still heavily influenced by the previous land use and their relative youth. Few, if any, plots appear to have achieved stable ground flora communities. The more recently established plots are dominated by annuals germinating from the seed bank. These are quickly replaced first by short-lived perennial species (including many weeds) and then by a wide range of long-lived perennials, often of higher conservation value. These long-lived perennials have the potential to control many weeds in the longer term.

Guidelines

The survey has generated clear guidelines for improving the game and conservation value of future SRC plots. These should be disseminated to potential growers and can be summarised as follows:

- Planting to extend the crop edges that are particularly attractive to pheasants and other species is an important consideration. However, there has to be a balance between wildlife and economic production, the latter benefiting more from bigger plantings with less edge per unit area.

- Willow, particularly the low-growing, multi-stemmed clones, offers clear advantages over poplar for both pheasants and songbirds.

- Ensuring that each SRC plot contains a mixture of age classes will help to provide habitat continuity for certain species, eg butterflies. It will also increase the length of edge habitat within the plot.

- The inclusion of a grassy headland helps to create attractive conditions for flowers and butterflies.

- The crop edge should provide low, dense windproof cover. This can be achieved by siting next to existing hedgerows, planting new hedgerows or managing a specially designed strip of dense SRC around the periphery of the plot that is cut annually.

- Internal rides are attractive to butterflies and flowers and provide suitable areas for pheasant feeding.

Further research on experimental or demonstration plots is required to assess the effectiveness and financial implications of these recommendations. There is also a need for research to examine how plant and insect species can be managed to reduce the incidence and severity of pest outbreaks while at the same time improving the conservation value of the crop.

Report No: ETSU B/W5/00337/REP Publication date: 1994

MODELLING OF CARBON AND ENERGY BUDGETS OF WOOD FUEL COPPICE SYSTEMS

Forestry Authority Research Division, Forestry Commission

Background

For any bioenergy system to be worthwhile, the energy produced must be greater than the inputs of non-renewable energy required to establish and operate the scheme. Moreover, to be truly sustainable, the establishment and operation of the bioenergy generation system must cause negligible net emissions to the atmosphere of greenhouse gases, principally the carbon-based compounds such as carbon dioxide. To confirm that a bioenergy generation scheme meets these criteria, it is necessary to evaluate the energy and carbon budgets of the proposed system.

Project Objectives

- To develop a methodology for assessing the energy and carbon budgets of biofuel systems, using wood fuel coppice as an example.

- To monitor the energy and carbon budgets of wood fuel coppice systems.

- To identify the main fossil fuel inputs that limit the efficiency of wood fuel coppice systems.

Methodology

Defining the system

The system is taken to consist of the biomass-producing site, typically a farm, and all the operations that are necessary to turn the harvested biomass into a usable biofuel (ie into manageable chips). Subsequent processing into, for example, bioethanol, is regarded as an entirely separate system. Furthermore, the system using the biofuel is not included in the analysis.

Evaluating the energy benefits and costs

There are two principal energy flows out of the system:

- energy stored in the woody biomass produced by the system
- energy dissipated during the production process.

The first of these represents the energy benefit attributable to the system. The energy benefit of the harvested wood component can be calculated using an appropriate calorific value for the wood that takes into account its moisture content. Oven dry wood has an estimated calorific value of 18.7 MJ/kg after allowing for hydrogen and ash content.

Five main energy flows into the system have been identified:

- solar energy
- fossil fuel energy
- energy embedded in materials consumed
- energy embodied in machinery used
- human labour.

The most widely accepted conventions for energy analysis usually exclude solar energy and human labour, and focus on non-renewable energy sources. Determining the energy costs involves quantifying the energy inputs in terms of fossil fuel, materials and machinery. This, in turn, requires accurate identification of all the activities involved in plantation management and biofuel production.

The activities inventory for the production of wood from short rotation coppice (SRC) includes ground preparation, planting, fertilising, weed control, cut-back, beat up, harvesting, chipping, storage, drying and transportation. It also includes the grubbing up that takes place at the end of the plantation's useful life. Each activity involves the use of materials, machinery or fuel - often all three. Energy and carbon costs have been determined in each case.

The computer model that has been developed calculates the total energy benefits and costs of a biofuel system based on the biomass productivity of the crop, the activities inventory for production, and information on the energy costs of the fossil fuels, materials and machinery used.

The energy budget for the system can be summarised using statistics such as the energy ratio. This can be defined as follows:

$$\text{Energy ratio} = \frac{\text{Total energy benefit}}{\text{Total energy cost}}$$

This gives the number of units of usable energy produced for every unit of non-renewable energy expended in operating the system. For a biofuel system to be worth operating, the energy ratio needs to be significantly greater than 1.

Evaluating the carbon sequestered and emitted

The biofuel system has three main carbon pools each of which store carbon and each of which can return carbon to the environment. The biomass that is used for fuel releases its stored carbon back to the atmosphere when the fuel is burnt. However, carbon is also stored in the unused biomass (roots, stumps, foliage and detritus) and in soil organic matter.

In addition to this exchange of carbon between the three carbon pools and the atmosphere, there are three irreversible emissions of carbon, mainly in the form of carbon dioxide. These are associated with fossil fuel combustion, manufacture of the materials consumed, and machinery manufacture.

The carbon budget for the biofuel system can be summarised using statistics such as the carbon requirement. This can be defined as follows:

$$\text{Carbon requirement} = \frac{\text{Total carbon emitted}}{\text{Total energy benefit}}$$

This indicates the quantity of carbon irreversibly emitted to the atmosphere per unit of biofuel energy produced. For a biofuel production system to be renewable, the carbon requirement should be zero. In any event it should be as low as possible.

Findings

It is impossible to make precise statements about the energy and carbon budgets of SRC crops for the production of wood fuel because of uncertainties in the estimation of certain energy and carbon costs, and the wide variation in crop management, wood harvesting and fuel processing techniques. However, for most cases, the energy ratio is estimated to be significantly greater than 1, with typical values close to 30. In other words, the total consumption of non-renewable energy associated with the consumption of 1MJ of energy in the form of wood fuel is estimated at 0.035MJ.

The estimated energy ratios are consistent with those reported in earlier studies for both short rotation and traditional long rotation methods of wood fuel production. They are 30-32 times lower than equivalent values for fossil fuels.

Indirect energy inputs associated with the consumption of materials account for nearly 60% of total energy costs.

The carbon requirement, ie the carbon emitted to produce 1MJ of energy in the form of wood from SRC, is typically 0.0013kgC. Because wood fuel itself is "carbon neutral", this figure represents total emissions of carbon to the atmosphere using wood fuel and is 13-24 times lower than equivalent values for fossil fuels. These carbon requirement figures make no allowance for carbon sequestered in unused coppice components (stumps, coarse roots etc), although the level of the latter is estimated to rise to between five and 12 tonnes of carbon per ha over 25 years.

There is insufficient information to predict the impact of coppice crop establishment on soil carbon content.

Crop management and fuel handling methods can influence the energy and carbon budgets:

- The maximum energy ratio is achieved with planting spacings of about 1 metre.

- Fertiliser treatments are only cost effective if they at least double biomass productivity.

- The energy ratio rises with increased biomass productivity, longer cutting cycles and longer rotations.

- Significant reductions in energy ratio are observed for management units less than 3ha in area.

- Traditional harvesting systems are associated with lower energy ratios. However, the most modern harvesting systems cannot handle crops of more than 65 oven dried tonnes/ha.

- The combination of harvesting and chipping as a single operation achieves lower energy costs and higher energy ratios than methods with a separate chipping exercise.

- Around 40% of total energy costs are attributable to the construction of barns for fuel storage.

- Active drying of harvested wood fuel significantly reduces the energy ratio.

Report No: ETSU B/W5/00275/REP Publication date: 1996

HYDROLOGICAL EFFECTS OF SHORT ROTATION COPPICE

Natural Environmental Research Council (NERC)
(Institute of Hydrology and British Geological Survey)

Background

The possibility of planting short rotation coppice (SRC) on a large scale in the UK over the next few years has highlighted the need for careful consideration of its likely environmental impact. In relation to water, work carried out in other countries suggests that SRC could be detrimental to water resources because of increased evaporative loss, but there are no direct measurements for UK conditions to substantiate this. Evaporative losses occur as a result of interception and transpiration.

Trees generally use more water than grassland or crops, causing a reduction in stream flow and reduced aquifer recharge. This could be particularly problematic in areas such as south-east England, where the difference between precipitation and evaporation is small, where groundwater recharge is already low, or where groundwater is the major water supply source.

Large-scale SRC plantations could also have an impact on water quality. Nitrate and pesticide leachings are likely to be limited in a low input production system, and SRC could be a very attractive crop in nitrate-sensitive areas or in buffer strips close to rivers. There is also interest in applying sewage sludge to SRC and, again, the extent of possible nitrate leaching needs to be established.

Project Objective

- To determine the impact of SRC in the UK on water resources by:
  - acquiring a fuller understanding of the mechanisms controlling SRC water use
  - quantifying the effect of SRC on groundwater quality.

Methodology

Water quantity was measured at two sites:

- the yield-trial plot on former permanent pasture at Swanbourne, Bucks (1993/94)
- the plot on former arable land at Knowle Farm, Hunstrete, Avon (1995).

The measurements at each site were designed to provide direct estimates of transpiration and interception loss, and also to provide the weather and biometrical data necessary for understanding the processes and for modelling.

At Swanbourne, the 1993 measurements were made on three-year-old shoots on seven-year-old stools: the 1994 measurements were on two-year-old shoots on eight-year-old stools. In both cases the clones involved were *Populus trichocarpa x deltoides* (Beaupre) and *P. deltoides x nigra* (Dorschkamp).

At Hunstrete, measurements were made on three-year-old shoots on four-year-old stools of Beaupre and (a more restricted set of measurements) on *P x trichocarpa* (Trichobel) and *Salix burjatica* (Germany).

Six existing SRC trial plantations (poplar and willow) were sampled for water quality. Sewage sludge had been applied at Medmenham, Markington and the North Norfolk site. Fertiliser had been applied at Swanbourne. The other two sites were Long Ashton and Downham Market. The work involved extracting mineral nitrogen from the soils using a neutral salt and estimating the nitrate concentration in the drainage water. Where possible, soils were sampled to a depth of 2 metres. Effective evaporation was estimated from meteorological data.

Findings

The water use of SRC

Annual transpiration from three-year-old SRC poplar shoots is higher than for all other vegetation covers, and significant soil water deficits arise before there is any reduction in transpiration rates. The high transpiration rates (typically 500 mm/year) were found to be the result of high stomatal conductances rather than leaf area. Transpiration rates from two-year-old shoots are lower, but still high: rates from one-year-old shoots are likely to be about 50% of those from three-year-old shoots.

The interception loss measured at Hunstrete during the foliated period was 21% of the rainfall and within the range of interception losses reported for mature foliated broadleaf forest in the UK (8-36%). Modelling showed that the annual interception loss, including the unleafed period, is about 14% of the annual rainfall.

There were no significant differences between poplar and willow.

Modelling to compare SRC water use with that for other crops over time showed that SRC water use would only be exceeded by that for coniferous forest.

The poplar root system was shown to be efficient and adaptable. In the well drained Hunstrete soil, the crop was able to extract water from depths of up to 3m. At the poorly drained Swanbourne site, it extracted water from the surface soil when adequate moisture was available and from the water table during dry periods.

The hydrological implications of these findings can be summarised as follows:

- Extensive SRC plantations will normally reduce stream and peak flows. The reduction will depend on rainfall and former land use, and will normally be greater where SRC replaces agricultural crops than when it replaces pasture.

- The total conversion to SRC of grassland catchments in the driest parts of the country will reduce annual net recharge to aquifers and drainage to rivers and streams by up to 80mm.

- During the summer, SRC may cause springs and ephemeral streams to dry up sooner and for longer.

- In dry summers with a significant initial soil water deficit, poplar SRC will use a similar amount of water to grassland - and much less than coniferous forest.

Water quality

Although atmospheric nitrogen fluxes to SRC are likely to be smaller than to a mature deciduous woodland, nitrogen inputs are likely to be substantial, and the application of nitrogen fertilisers to SRC may not be required.

The average nitrate concentration in the drainage water from Swanbourne, Long Ashton and Markington (no or minimal fertiliser inputs) was less than 1 mg/litre NO_3-N at Long Ashton and 2-6 mg/litre NO_3-N at Swanbourne. The relatively high figure for Swanbourne may have reflected the high water table and a downslope contribution from an adjacent pasture. These results suggest that nitrate leaching under established SRC will be low and comparable with unfertilised grassland.

Average nitrate concentrations at the Medmenham, Downham Market and North Norfolk sites were higher (10-16 mg/litre NO_3-N below 1 metre). These values probably reflect past arable cropping, the short period since SRC establishment and the low effective rainfall.

These findings suggest that, in the wetter parts of Britain, nitrate concentrations below SRC are likely to be less than 3 mg/litre NO_3-N and possibly less than 1 mg/litre NO_3-N. In the drier south-eastern areas, where effective rainfall is likely to be less than 150 mm/year, even low rates of nitrate leaching could give rise to nitrogen concentrations close to or exceeding the 11.3 mg/litre NO_3-N limit for drinking water.

Where sewage sludge had been applied, average nitrate concentrations were significantly higher in the topsoils (13-90 mg/litre NO_3-N). Some of this increase was also apparent below 1 metre, indicating an increase in nitrate leaching to surface and groundwaters.

Recommendations

- Large SRC plantations should be in the wetter parts of the country.

- Run-off can be increased by using a shorter rotation period and staggering harvest times.

- A small number of large blocks rather than many small blocks will reduce evaporation.

- Growers should avoid using nitrogen fertilisers - or use them sparingly.

- More water-use research and monitoring is needed in the driest parts of the country and where sewage sludge applications are to be widely used.

1.3 The Production Potential of Derelict Land

Report No: ETSU B 3116 Publication date: 1979

AN ASSESSMENT OF THE POTENTIAL OF DERELICT AND INDUSTRIAL WASTE LAND FOR THE GROWTH OF ENERGY CROPS

Derelict Land Reclamation Research Unit, University of York

Background

Biologically converted solar energy has a number of attractions as an alternative energy source. It is renewable, the technology for biomass production is already well developed, biomass represents a readily stored source of energy, and its production is generally held to be environmentally acceptable. However, a large area of land would be required to accommodate crops grown specifically for energy purposes, and in the UK there is already increasing competition for land from agriculture, industry, housing and amenity.

Government sources suggest that there are more than 71,000ha of derelict land in Great Britain, plus a considerable area of neglected and waste land. This represents a substantial and unused land resource.

This report is in five volumes, of which Volume A is the Management Report and Volume B the Final Report. Volumes C, D and E provide details of derelict and degraded land for each county district in England, Scotland and Wales.

Project Objective

- To assess the potential of derelict, neglected and waste land for energy crop production.

Methodology

There are three main sources of data on derelict and waste land in Great Britain:

- Government surveys for England (1974), Wales (1971/72) and Scotland (1973) cover derelict land associated with mineral working, railway dereliction, military dereliction and other forms of dereliction. Disadvantages of these surveys include the fact that they are out of date, contain inconsistencies in the data, ignore waste land, and aggregate data by district, thereby failing to provide information on the location and size of individual sites.

- The 1960s Second Land Utilisation Survey mapped more than 70 land-use categories, including derelict land, heath and rough land and land in use for tipping and extractive industries. Some areas have been resurveyed, and the resurveys are perceived to be a reliable source of data.

- Some local authorities have carried out independent surveys which have included both derelict and waste land.

Findings

The areas of derelict and waste land and their geographical distribution

The total areas of derelict and derelict + waste land in England, Wales and Scotland are shown in the Table below.

Areas of derelict and derelict + waste land in England, Wales and Scotland (ha)

	Derelict land	Derelict + waste land
England	43,273	200,000
Wales	14,478	59,000
Scotland	13,404	80,000
Total	**71,155**	**339,000**

The areas of greatest dereliction correspond to the counties containing the major coalfields of North and North-east England, the Midlands, South Wales and Central Scotland.

Future years are likely to see an increase in the area of derelict land as a result of mineral working, waste tipping, industrial closure and urban decay. Between 1964 and 1974, the rate of increase averaged about 900 ha/year. Although local authorities are able to impose conditions for the restoration of land used for mineral working and waste tipping, a recent survey has shown that sites are not always satisfactorily restored.

Restoration of derelict land

Substantial areas of derelict land have been restored in England, Scotland and Wales, usually with the aid of Government grants. In England, 25% of this land is planted with trees and 46% is used for agriculture. In Scotland, the emphasis is on amenity use, with 34% being used for agriculture. In Wales, most restored land is used for industrial development, housing and public amenity.

Most restoration schemes involve reshaping and regrading the land. Where it is to be used for planting, the site is deep ripped, disced, harrowed, limed and fertilised. Liming is particularly important on colliery spoil sites which may be very acid, while fertilisers are essential on sites that have lost their top soil and have a poor nutrient status. Grass or grass-legume mixtures are usually planted first to reduce run-off and erosion. If grass is to be followed by trees, the grasses used are low maintenance mixtures. Trees are usually bare rooted forest stock and may be notch or pit planted, 1.5-2.0 metres apart. Among the more successful species for this environment are common and grey alder, silver birch, Corsican pine, lodgepole pine, false acacia, poplar and willow.

Plant yields on derelict land

Because the main aim of restoration is often the visual improvement of sites, data on plant yield are limited. Figures that are available indicate that yields on derelict sites are low (of the order of 3 tonnes/ha/year). However, these data are from the more difficult sites, and sites such as general waste land or restored railway land is likely to be more productive.

Choice of energy crop

Trees offer certain advantages as energy crops on derelict sites. They require minimum initial cultivation, and low fertiliser and lime inputs by comparison with herbaceous crops. Both broadleaved and coniferous species can be grown and some species (alder, birch, willow and poplar) can be coppiced, giving several crops from one planting. The lower moisture content of trees compared with herbaceous crops reduces transport and drying costs.

Cultivation and management of crop

Restoration schemes commonly use plants that have spent one year in a seed bed and one year in a nursery. Some species (willow and poplar) can be propagated by cuttings. Thereafter, maintenance and management is likely to be more demanding than for trees on more conventional forest sites. Reasons include high levels of vandalism, adverse physical and chemical conditions, and the poor nutrient status which necessitates fertilisation. Because initial growth tends to be slow, the first coppice rotation would probably be longer (6-10 years) than on ordinary forestry sites. Thereafter, harvesting would take place, at intervals, over an assumed period of 30 years.

Provisional costings for an energy plantation on restored derelict land

Provisional costs are estimated to be more than £18,000 over the 30-year period. This is based on an assumed yield of 4 dry tonnes/ha/year and an energy content of 20 GJ/tonne. The cost per dry tonne is £153.00 and the cost per unit of energy is £7.70/GJ. These costs are perceived to be high.

Provisional energy budget for coppice on derelict land

The total energy input for land preparation, crop establishment, maintenance and harvesting is estimated at 650 GJ/ha.

Conclusions

- Energy derived from tree crops on restored derelict land may be extremely costly, both financially and in energy terms.

- Restoration work is normally heavily subsidised by Government but rarely yields a direct economic return. Growing energy crops might offset some of the restoration cost while providing an aesthetically pleasing landscape.

- Sites with coppiced tree crops would be less costly in maintenance terms than many other restored sites.

- Restored landfill sites, which are liable to subsidence, may be ideal for growing trees.

- If land still being used for mineral working and waste tipping is excluded, along with sites that are unsuitable for plant growth or too small for an economic energy crop, the total area of derelict and waste land that might be used for this purpose is about 250,000ha. It could yield about one million tonnes of dry matter per year.

Report No: ETSU B 1054 Publication date: 1982

AN ASSESSMENT OF THE POTENTIAL OF DERELICT AND INDUSTRIAL WASTE LAND FOR THE GROWTH OF ENERGY CROPS: YIELD ASSESSMENTS AND MANAGEMENT STRATEGIES

Derelict Land Reclamation Research Unit, University of York

Background

During the past 20 years, local authorities throughout Britain have been involved in the restoration of derelict land. The aim of restoration has usually been the improvement of public amenity and, even where trees have been planted, these are rarely for commercial timber production. As a result, there is little information on the productivity of tree species on derelict land, and this is essential if a realistic assessment of the potential of such sites for energy cropping is to be made.

Project Objectives

- To determine the productivity of broadleaved and coniferous species grown on a range of restored derelict and waste land sites.
- To assess the effects of harvesting on site nutrient levels.
- To determine the costs of restoration and determine an appropriate management strategy.

Methodology

Twelve derelict and waste land sites supporting tree growth were selected for the study. These cover a range of substrates - colliery spoil, pulverised fuel ash, railway land, sand/gravel workings, land contaminated by heavy metals and land degraded by atmospheric pollution - and are located in different parts of the country, from North-east England to South Wales. The sites contained softwood and hardwood tree species including common alder, birch, goat willow, poplar, lodgepole pine, Scots pine and Japanese larch.

Tree density was recorded in a series of plots on each site, and the diameter of each tree within a plot was measured at breast height using diameter calipers and diameter tape. Between ten and 20 sample trees were selected to cover the range of diameters encountered in the density sampling process. The diameter of each sample tree was recorded and it was cut down at ground level. The weights of trunks, branches with leaves and branches without leaves was determined using appropriate techniques, and sub-samples of the fresh material were returned to the laboratory in sealed polythene bags so that their dry weight could be determined. Chemical analyses were then carried out on acid digests of the plant material.

Findings

Yields

Yields ranged from 0.39 dry tonnes/ha/year for two species of alder on colliery waste to 11.22 dry tonnes/ha/year for common alder on pulverised fuel ash. Birch, lodgepole pine and poplar yielded more than 4 dry tonnes/ha/year on a number of sites.

Site productivity is very variable and, for most sites, there are two major substrate factors that affect plant growth: nutrient status and toxicity. The study showed that pulverised fuel ash sites, with no acidity or toxicity problems, can give excellent yields when nutrient status is improved, as can some metal contaminated and railway sites. Acid colliery spoil sites and eroded, impoverished soils, however, gave much lower yields, although some of the problems can be overcome using lime and/or fertiliser. Productivity is also affected by water availability, by geographical location/climate and by tree density - although the greatest densities do not necessarily give the highest yields. Densities of the order of 10,000/ha appear to be appropriate.

It is clearly important to select appropriate species for each site. Alder, for instance, gives better yields on wet sites.

Nutrient analysis

Nutrient analyses show that harvesting a crop of 4 dry tonnes/ha can remove up to 36 tonnes/ha of nitrogen, 2 tonnes/ha of phosphorus and 17 tonnes/ha of potassium. However, 51-85% of the nitrogen, 50-75% of the potassium and 88-96% of the phosphorus in the standing crop are to be found in the foliage, and considerable conservation of nutrients can be achieved by harvesting deciduous species after leaf fall, reducing the total yield by about 19%. Nevertheless, repeated harvesting of coppice crops will, in the absence of regular fertiliser additions, severely deplete the soil nutrient pool on many derelict sites.

Restoration costs

The cost of restoring derelict sites is very variable and highly site-specific. It ranges from about £14,000/ha for sites restored to agriculture to £95,000/ha for sites restored to industry and commerce. The major part of the cost, particularly in the latter case, is associated with demolition, site clearance, earth-moving and drainage. Restoration costs are highest in urban areas, where sites have the least potential for energy cropping.

In rural areas, where sites are less costly to restore than in urban areas, the lowest costs are incurred on railway sites. Such sites are often well drained, relatively fertile and have no toxicity problems. They therefore offer considerable potential for tree growth, although they are often linear in nature and fencing costs are high.

Spoil heaps and other tipped sites, which usually arise on the urban fringe, are also appropriate for energy cropping. They often cover a large area and are generally restored to public open space, an end use compatible with growing trees for energy.

Management issues

Derelict substrates will require special management for energy cropping since sites present a number of problems not encountered in conventional forestry. The main management issues are:

- identification and selection of an appropriately located site of a suitable size (probably 5ha or more)

- assessment of the site's potential for tree growth, particularly in relation to environmental factors - climate, exposure, aspect - and substrate characteristics - nutrient status, toxicity

- site acquisition and, if necessary, restoration or adaptation for energy crops

- establishment and maintenance of energy crops, with planting densities of no more than 10,000 trees/ha for short rotation coppicing

- harvesting, chipping and transportation.

Conclusions

About 50% of the 339ha of derelict and waste land identified in Report No: ETSU B 3116 occurs on sites that are too small for the production of energy crops. A further 10% occurs in urban areas. Of the remainder, almost 116,000ha are estimated to be neither too steep nor too unsuitable in terms of substrate for energy cropping. Assuming yields of 4.5 dry tonnes/ha/year, this land could yield 520,000 dry tonnes/year, an energy yield equivalent to about 0.1% of the UK's expected energy requirement in 2000.

2. THE SUPPLY CHAIN

2.1 Overview

Report No: ETSU B 1176 Publication date: 1990

WOOD FUEL SUPPLY STRATEGIES

Harvesting Unit, Department of Forestry, University of Aberdeen

Background

Studies already completed have established that there is a potential supply of forest biomass from existing conventional forestry which could be used for combustion in industrial and commercial markets in the UK. However, the successful take-up of wood fuel will depend on the creation of a wood fuel supply chain.

Project Objectives

- To ascertain the main sources of wood fuel supply.
- To undertake wood fuel harvesting/processing and storage/transportation trials.
- To analyse the trial findings and develop appropriate wood fuel supply strategies to service industrial markets.

Methodology

Twenty-nine harvesting trials were carried out in a range of locations throughout Scotland, England and Wales. The trials covered various combinations of wood fuel source and harvesting system for a range of tree species (hardwood and conifer), tree sizes and terrains. The harvesting trials were complemented by four storage studies designed to determine changes in moisture content and dry matter in wood fuel stored both covered and uncovered. Transport of the comminuted wood was monitored to establish productivities and costs.

A computer program, the Harvesting Decision Support System (HDSS) was developed for data analysis and, subsequently, for constructing harvesting models. These models, when linked with the storage and transport options, provided 24 supply options as a basis for the development of wood fuel supply strategies.

The study findings are presented in two parts. Part 1 is an overview. Part 2 summarises the harvesting trials.

Findings

Sources of wood fuel

Conventional forestry provides three potential sources of wood fuel:

- whole conifer trees from early thinnings and premature clearfell
- whole hardwood trees from thinnings
- tops and branches (forest residues) arising from conifer thinnings and clearfell.

The main conifer resource is in Scotland and Northern England, and the main hardwood resource in the south of England.

Total annual wood fuel availability is currently estimated at 3.26 million tonnes. It is expected to rise to four million tonnes by 2010.

Harvesting systems

The project identified three wood fuel harvesting systems that are compatible with existing harvesting methods:

- whole tree comminution (conifers and hardwoods)

- residue harvesting in conifer stands where stemwood has been harvested using conventional forestry methods

- integrated harvesting of conifer stands, which combines stemwood and wood fuel harvesting into a single operation.

Supply strategies and costs

Supply strategies were developed for wood fuel provision to three sizes of combustion plant: 1.5MW, 6.0MW and 30.0MW. Combustion plant size determines the area from which wood fuel supplies need to be drawn and the associated transport distance. Average primary transport distances (from forest to store) assumed for the three plant sizes are 28km, 44km and 70km, respectively. Secondary transport from the store to the combustion plant is assumed to be either 16km or 64km in every case. Delivered fuel prices include the cost of storage for three months and both primary and secondary transport costs.

The integrated harvesting of conifer clearfell gave the lowest delivered fuel costs: £1.17/GJ, £1.31/GJ and £1.54/GJ, respectively, for the three plant sizes, assuming minimum primary and secondary transport distances in each case. Integrated harvesting systems offer the greatest potential for the cost-effective harvesting of wood fuel in conjunction with conventional forest products from stemwood. However, the high levels of mechanisation involved require a minimum capital investment in harvesting equipment of more than £275,000. The adoption of such systems in the UK would depend on market security and on contractors having access to detailed information on the costs and productivities of harvesting systems over a range of terrain and crop conditions.

Residue harvesting systems offer the greatest short-term potential for harvesting wood fuel from conifer clearfell. The delivered fuel costs range from £2.18 to £2.33/GJ, and residue harvesting can be incorporated into existing shortwood systems. Capital costs are lower than for integrated harvesting as conversion requires only the addition of a chipper to existing equipment. Residue removal has major benefits for restocking, and this is likely to be a major factor in its adoption. However, widespread take-up will depend on cost reductions associated with the improvement of comminution technology.

Whole tree comminution systems have the potential for reducing the harvesting costs of early thinnings. The multiple-tree handling systems investigated in several of the harvesting trials is one likely element of this reduced cost. Another is the screening and sorting of whole tree chips to provide both an energy and an industrial chip component.

Delivered fuel costs based on hardwood thinnings begin at £1.79/GJ, and current felling and extraction rates are considered appropriate to small-scale operation in the scattered woodland blocks that make up most of the hardwood resource. Two of the harvesting models provided for the whole tree comminution of early conifer thinnings and, although delivered fuel costs were £2.32/GJ-£2.40/GJ, this option does have a role to play because of the silvicultural advantages to be gained from early thinning. Delivered costs arising from the whole tree comminution of premature conifer clearfell ranged from £2.11/GJ to £2.38/GJ.

Storage and transport are important cost elements in the supply chain. Although the effects of time on energy losses in storage are difficult to quantify for comminuted wood fuel, the storage studies did show that the cost of providing covered storage is offset by the reduction in energy losses associated with a reduction in moisture content and dry matter loss.

Transport costs for comminuted wood fuel are high, and cost-effectiveness improves as distances shorten. However, as combustion plant capacity rises, so do the transport distances involved in obtaining sufficient wood fuel supplies, and this reduces the options available.

The diagram below illustrates the main components of the supply chain.

Main components of the wood fuel supply chain

Report No: ETSU B/W1/00420/REP Publication date: 1996

FOREST INDUSTRY WOOD FUEL SUPPLY

Border Biofuels Ltd

Background

The potential for wood-fuel-fired energy production in the UK is significant, and large-scale developments are currently under way that could use more than 100,000 green tonnes (gt) of forest residues. However, the wood fuel supply chain is potentially more complicated than many other fuel supply chains: it is scattered, the fuel has a highly variable calorific value, there is no experience in gathering and processing the product commercially, and the number of independent contractors and companies likely to be involved is large. For these reasons, wood fuel carries a high perceived risk status. This study addresses some of the risks involved and suggests suitable measures for reducing them.

Project Objectives

- To examine six areas of the fuel supply chain - extraction, comminution, transportation of uncomminuted residues, assessment of and payment for wood fuel, environmental impact and nutrient recycling.

- To reduce the costs and risks associated with these areas by undertaking, as far as possible, commercial trials and assessments.

Methodology

The project has drawn on the expertise of a consortium of organisations most likely to be involved in the harvesting, transportation and use of wood fuel. Modelling techniques have been used to analyse the impact of each area on the overall cost of fuel supply.

Findings

Extraction

There is very limited use of whole tree harvesting in the UK, and little information is available, although trials in Wales and Kielder (Northumberland) indicate this technique, with feller clambunk extraction and roadside conversion, is practical. However, current methods leave residues between two and five metres from the roadside, which makes loading difficult. No practical method of processing to leave residues at the road edge has yet been suggested, although it may be possible to use an independent loader mounted on an excavator base to lift residues from existing systems.

A high standard of planning, organisation and liaison is required if whole tree systems involving several machines are to be successful.

Comminution

Comminution (chipping, shredding or crushing) is central to the economic production of wood as a fuel. The machines used must produce a consistent product, and that product must be appropriate for the conversion technology (combustion or gasification system) and handling equipment for which it is intended. In other words, fuel specification is likely to be the most important consideration in choosing a comminution device. Furthermore, oversized particles and fines must be avoided on the grounds of increased cost.

Four main types of machine are available: hammer mills, drum chippers, slow speed crushers and a hybrid machine that is effectively a sharpened toothed hammer mill. However, only one, the slow speed crusher, appears to meet most of the required specifications for a centralised comminution facility (the most cost-effective option). The product quality from hammer mills and hybrid machines is poor, while drum chippers are not easily available in sizes that are large enough to meet the requirements of a power station.

Transportation of uncomminuted residues

Comminution on forest roads or in-field in the UK gives rise to organisational problems and unacceptable costs. Chipping at a central plant is therefore likely to be more practical and cost-effective. This in turn requires transportation of the uncomminuted residues.

Trials achieved an average load weight of 11.8 green tonnes, with a load bulk size of 66m^3 and a bulk density of 180 kg/m^3. If bulk trailers were to be built to the maximum dimensions allowed on UK roads, they would have an approximate bulk volume of 118m^3 and a maximum load weight of 20 tonnes. A required bulk density of 170 kg/m^3 is theoretically possible with such a trailer, although a fully loaded trailer of this type would be unstable on forest roads. A more suitable trailer would be one 4.3m high, with a 100m^3 load size and a tare weight of 16.5 tonnes. The maximum load weight would be 21.5 tonnes, equivalent to a bulk density of 215 kg/m^3.

Because of the nature of uncomminuted residues, load compression is an important consideration. This could be carried out by the independent loader, with the addition of a load restraining device that would be activated and locked when the load was under compression. However, the weight of this device would reduce the weight of residue transported.

Assessment of and payment for wood fuel

Cost and quality control are of prime importance to the commercial viability of wood fuel. The parameters that determine whether wood fuel is appropriate for the end user are the calorific value and the size distribution. In an ideal world, payment should be made on a £/GJ or £/heating value basis, but this is unlikely to happen in the UK because the timber extraction industry operates on a weight or volume basis rather than a GJ basis. The currently favoured payment structure in the timber extraction and haulage industry is based on weight, and there are precedents whereby final payments for the quantity of material supplied are based on weight measurements carried out by the end user. In these circumstances, a degree of trust and independent testing would probably be required by the two parties if the value of the load is in doubt (as would be the case with biomass).

It is impracticable to test for the value of the wood whenever it changes hands, but if responsibility remains with the end user, perceived differences in value could cause problems. The study examined four possible methods of sampling forest residues, the best of which proved to be regular sampling after central comminution. To resolve the problem of some material being unloaded to store prior to comminution, it would be important to pay on long-term averages from particular sites. Samples of comminuted material would then be tested for calorific value, oven dry weight and ash content.

Environmental impact

Although not all biomass is removed in whole tree harvesting, residue removal is a significant factor in site nutrient loss, particularly where material is removed immediately rather than in a second pass operation that allows much greater needle fall. The lack of a residue mat could remove any mulching effect and also give rise to greater erosion and compaction during subsequent harvesting. On the other hand, the lack of a residue mat facilitates restocking.

Nutrient recycling

Ash from wood fuel combustion is produced both as fly ash and, at the back end of the boiler/conversion process, as either a dewatered sludge or dry dust and clinker. It is possible that, because wood ash has a value as a nutrient supplement, Forest Enterprise may require the return of wood fuel power station ash to the forest sites from where the residue was harvested. If this is the case, then wet slurries should be avoided as they are expensive to transport and difficult to spread on most Northern UK forest sites. The ash should therefore be processed into tablets or “prills” to reduce transport costs and improve handling properties. The cost of processing can be between £1 and £3/green tonne of residues delivered, equivalent to between £16 and £45/dry tonne of ash processed.

Fuel supply cost

Wood fuel is currently available at about £25/green tonne, using conventional transport methods. However, compression of the fresh brash could give significant savings in transport costs, and costs could fall to below £20/green tonne.

2.2 Harvesting

Report No: ETSU B-1081 (9) Publication date: 1984

THE LOUGHRY COPPICE WILLOW HARVESTER

Department of Agriculture for Northern Ireland

Background

The fuel supply crisis in 1973 focused attention on alternative energy sources, particularly biomass. In early trials involving three energy crops, New Zealand flax, bamboo and willow, willow was found to give the best results. The best yields to date are with triennial harvesting, although other trials are determining the effect of four-, five- and six-year cycles. However, in order to assess the full potential of the crop a mechanised harvesting system was required. A trailed harvesting machine was developed at Loughry College, Northern Ireland, between 1977 and 1979. The crop was cut using twin circular saws, gathered and conveyed using belts, and tied into bundles by two twines. Problems were experienced with the belts, and a subsequent reassessment concluded that the system could cope with one-year-old basket willows but not with three-year-old *Salix x aquatica* Gigantea. A new design was therefore formulated.

Project Objective

- To develop a mechanised harvester that would:
  - harvest 2-3 year old willow coppice growing in rows one metre apart and produce bundles approximately 30kg in weight, tied with two twines
  - be operated by a moderately powered agricultural tractor
  - operate in small plots and on hilly ground if required
  - be relatively inexpensive.

The Mark II Harvester

The Mark II harvester was mounted on the three-point linkage of a tractor with modified controls that allowed it to operate in reverse. The power for cutting, conveying, bundling and tying is taken from the tractor power take-off shaft.

As the tractor and harvester move along a row, the crop is continuously harvested and tied into bundles which are ejected from the side of the machine.

The sticks are cut by a saw with a diameter of 760mm and a 45mm tooth pitch. Minimum height of cut is 100mm above ground level. The cut sticks are then conveyed to the bundling chamber by a two-stage conveying system. The first stage consists of two vertically disposed sets of rotating solid tines at 500mm and 1800mm above the saw blade, respectively. These move the cut sticks off the saw blade at right angles to the direction of travel of the harvester. The second stage packers place the sticks into the bundling chamber through a pair of spring loaded checks. When the bundling chamber is full, two twines are tied around the bundle in a modified version of the system used for straw baling. The twines are tied 900mm and 1400mm from the butt of the sticks. The bundle is then ejected through a spring-loaded tailgate.

Harvesting Trials

Harvesting trials were undertaken in March 1981, April 1982 and October and November 1983, the first two resulting in modifications to the saw speed, intake guide bars, and knotting equipment. There were also problems operating with row spacings of 0.7m: a 1m spacing would be more appropriate.

The harvester was estimated to handle 0.135 ha/hour, equivalent to between 8.6 and 10.8 tonnes of three-year-old *Salix x aquatica* Gigantea per hour.

The trials have demonstrated that the general objectives have been achieved: the harvester will cut the crop, tie it into separate bundles and eject each tied bundle from the machine. However, there are deficiencies in the strength of the machine when harvesting a heavy crop of three-year-old *Salix x aquatica* Gigantea, and a larger frame structure with stronger components is required. Adjustable tying points would also be an advantage.

Report No: ETSU B 1382 Publication date: 1992

LOUGHRY COPPICE HARVESTER - AN ENGINEERING ASSESSMENT

AFRC, Silsoe Research Institute, Bedford

Background

Loughry College has been involved in the development of a coppice harvester for more than ten years, and details of early models are given in interim Report No: ETSU B-1081 (9). By 1983, it was clear that an improved design was necessary, and this was agreed in 1986. The general principles of operation were similar to those of the preceding model, but a more reliable stop and tie regime was adopted. Bigger bundles were required to make the system economic and this, in turn, dictated heavier duty crop handling mechanisms and a trailed rather than a mounted machine. The target bundle weight was set at 300kg although, in practice, 200kg has been the heaviest produced so far.

Project Objective

- To assess the performance of the Mark III coppice harvester in terms of its design and operation.

Findings

The authors of the report spent two days with the Loughry development team, watching and discussing the harvester’s performance in a trial plot of willow coppice that had been planted on very marginal, wet and sloping land at Castlearchdale.

The machine weighs 3.5 tonnes and requires a tractor of at least 75kW to pull and power it. The machine has an overall length of 5m and a height of 3.2m. The 2.2m spacing between wheel centres allows it to straddle two rows of coppice planted in rows 1m apart. The tyres provided are probably adequate for 95% of sites but on very wet or soft soils the machine will sink in, making it very difficult to control cutting height.

The components used to make the crop gathering device are suitable for the job. The twin augur gatherer works by collecting the sticks and pressing the side branches together as it feeds them into the machine. This works very effectively when the crop is upright or leaning towards the machine. However, odd sticks may be left uncut where shoots are very widespread, and there are particular problems when the harvester is cutting up steep inclines or when wind blow causes sticks to lean away from the machine. In both cases, the cutting saw severs the sticks before they are secured by the gatherer. The sticks fall forward, but the cut end progresses into the machine, causing a blockage.

Reducing the diameter of the saw from 914mm to 830mm has considerably improved cutting efficiency and reduced stoppages. Poplar stems up to 100mm in diameter have been successfully cut at a forward speed of 0.5-1.0 m/second. A floating saw could be a more efficient way of achieving the 100 mm target cut height, particularly on rough, marginal land, but it may be unnecessary on more traditional arable fields.

The three sets of rotary/reciprocating packer mechanisms used to transport the cut coppice through the machine cause acceleration and deceleration from near zero to 1 m/s in succession. This will often cause the stick to break, allowing trash to fall into the machine.

Although the machine was designed for a 300kg bundle, it is unlikely that the packing fingers would exert enough force to generate a denser bundle than the typical 175kg bundles currently being achieved.

A second operator (apart from the tractor driver) is used to activate tying and ejection of the bundles, which is controlled from the back of the machine. Tying the bundles caused a considerable number of problems on this machine, despite improvements to the knotters, until knot stripper fingers were fitted. Movement between the two halves of the machine, particularly at the top knotter position, can cause the needle to move 20mm or more out of alignment with the knotter.

Apart from occasional twine hang-ups and the slow speed of operation, the ejection system worked well.

The machine does have some deficiencies. It generates excessive noise; the hydraulic circuits that drive all the rotating/moving parts are complex; and the number of moving parts is large.

Overall, trial records show that the machine has cut and bundled coppice sticks at the rate of 0.5 ha/day - around 170 bundles with a crop weight of some 35 tonnes. When compared with other stick-harvesting machines demonstrated recently in Sweden, the Loughry harvester is more complicated, although it does perform a superior task in that it ties the coppice into bundles. It also works rather slowly, taking about 45 seconds to make a bundle and the same time to tie and eject it. The Loughry machine will also be more expensive than the Swedish machines.

Conclusions

A machine based on this concept could be built to work effectively, using a tidied-up design and one-man operation. However, it is questionable whether tying in bundles is necessary. A simpler approach would be to adopt a cut, collect and carry principle that would allow sticks to be deposited in convenient stacks for drying on the field headland or suitable standing.

Report No: ETSU B 1273 Publication date: 1993

WHOLE TREE HARVESTING SYSTEMS FOR WOOD FUEL

Wood Supply Research Group, Department of Forestry, University of Aberdeen

Background

A study of wood fuel supply strategies carried out in 1990 (Report No: ETSU B 1176) showed that integrated harvesting systems offered the greatest long-term potential for the cost-effective harvesting of wood fuel. At the same time, whole tree comminution systems were found to have potential in the small tree sizes associated with early thinning and premature clearfell, while residue harvesting systems offered the greatest short-term potential given improved comminution techniques.

If these techniques are to be more widely adopted, further information is needed about certain production functions, notably wood fuel yields and the costs of harvesting wood fuel across an extended range of crop types and terrain conditions.

Project Objectives

- To refine, through a series of trials, whole tree harvesting practices, and to extend whole tree harvesting production functions over a range of crops and terrain conditions in Great Britain.

- To investigate, on the basis of the trial findings, the application and financial implications of whole tree harvesting.

- To examine market and supply considerations, including the fuel resource, the markets available, moisture content and transport issues.

Methodology

Eight integrated harvesting and whole tree comminution trials were carried out using combinations of equipment and systems. The sites chosen were located throughout Great Britain and involved a range of representative forest crops. The purpose of the trials was to establish production functions in terms of harvesting productivity and cost for the harvesting of wood fuel from commercial conifer plantations.

The trial data obtained were incorporated into a computer-based Harvesting Decision Support System (HDSS), and the wood fuel yields necessary for estimating the potential resource and determining harvesting costs were established as a function of individual tree stem volume and the wet weight of the wood fuel. The HDSS was then used to determine harvesting costs for a series of representative whole tree harvesting systems for harvesting wood fuel from commercial conifer plantations. Both integrated harvesting and whole tree comminution systems were costed for early thinning, and integrated harvesting systems for clearfell.

Findings

Wood fuel harvesting costs

The cost of harvesting wood fuel from early thinnings varied with the type of system used. The lowest costs were achieved by terrain-based whole tree comminution systems (between £3.46 and £6.01/green tonne (gt). Landing-based whole tree comminution generated costs in the £6.68-£15.12/gt range, while integrated harvesting was usually the most expensive, with costs in the £8.41-£13.94/gt range.

In clearfell crops, the wood fuel harvesting costs of integrated harvesting systems ranged from £5.51 to £13.77/gt, lower than in the integrated harvesting of early thinnings. The findings show that, as individual tree size increases, so the costs of harvesting both roundwood and wood fuel fall. The considerable variation in costs within each tree size range is very dependent on the comminution equipment chosen, being lowest for the trailer-mounted chipper.

The costs of harvesting wood fuel from conifers were found to vary geographically as a result of the variation in species composition and terrain. For each Forestry Authority Conservancy, harvesting systems for early thinning and clearfell were allocated to each of the major categories of species on the basis of terrain conditions, existing and potential markets, the contractor base and the current level of mechanisation. Weighted mean regional harvesting costs for early thinning for wood fuel ranged from £4.93/gt in the East Anglia Conservancy to £11.20/gt in the Highland Conservancy. Weighted mean regional wood fuel harvesting costs for clearfell varied from £5.77/gt in the Greater Yorkshire Conservancy to £7.41/gt in the Strathclyde Conservancy.

Potential application of whole tree harvesting

The application of whole tree harvesting systems will depend on several factors:

Harvesting industry investment

The ability of the industry to invest in and operate whole tree harvesting systems will depend on:

- the existence of long-term contracts to allow the necessary investment in equipment to take place
- existing levels of mechanisation (these determine investment in equipment for wood fuel harvesting systems).

Capital requirements for integrated harvesting and/or whole tree comminution systems range from £38,850 to £458,000 for early thinning, and from £205,350 to £585,000 for clearfell operations.

Technical constraints

Both soil and terrain impose limitations on the application of some whole tree harvesting systems in Great Britain. There are particular environmental concerns about whole tree harvesting, including nutrient depletion, damage to the soil structure, water run-off and potential site erosion. Although the long-term effects of depleting the nutrient status of a site is not yet fully known, research findings to date indicate that there is cause for concern, particularly on infertile soils and peats. The nutrient losses can be overcome - at a cost - and there are certain positive benefits of whole tree harvesting such as reduced restocking costs, improved establishment of the restocked crop and improved visual amenity of the clearfell site. However, the overall effect of the constraints is to reduce the realisable resource from between 3.26 and 3.53 million green tonnes (gt)/year to between 1.42 and 1.77 million gt/year.

Markets

Earlier studies have shown that existing industrial and commercial markets for wood fuel in Great Britain are confined to the forest products industry and a few scattered small-scale industrial and commercial users. Total consumption of wood fuel by the former is estimated at 0.40 million gt/year, solely from wood processing wastes. The use of wood fuel from primary arisings will therefore depend on market development. There is potential, using combustion conversion technology, in the forest products industry; in other forestry and timber-related industries; in rural industries and institutions that currently use coal-fired boilers; and in the electricity supply industry (with support under the Non-Fossil Fuel Obligation).

The emerging markets will set the feedstock requirements for the wood fuel, the most important of which are particle size and moisture content. Moisture content is the major factor in wood fuel quality: it determines the need for storage and drying, the energy content of the fuel and the price paid by the end user. Drying can take place prior to comminution, thereby reducing both energy losses and the potential health hazards from fungal spores during storage.

Conclusions

It is now important to demonstrate to the forestry industry that using integrated and whole tree comminution systems for wood fuel harvesting is feasible, and that the costings shown in the trials can be achieved in practice. However, this will depend on the establishment of a stable market for wood fuel, and this, in turn, will require a greater understanding of both the end user's requirements and the ability of the harvesting and delivery systems to meet those requirements.

Supply strategies will need to be developed on a regional basis. These should take into account regional variations in crops, terrain and climate and their effects on delivered wood fuel costs, including the costs of transportation, drying and storage. It is also necessary to set up supply contracts between the wood fuel supplier and the user to ensure payment terms and delivery to consistent standards. Only continuous wood fuel monitoring will ensure that standards are met and maintained.

Report No: ETSU B/W1/00136/REP Publication date: 1993

FOREST RESIDUE HARVESTING SYSTEMS

Wood Supply Research Group, University of Aberdeen

Background

Current forestry harvesting practice in the UK removes stemwood only in the form of roundwood products, sawlogs and small roundwood for the pulp and panel product industries. The tops and branches (residues) are left behind and provide organic matter and nutrients for subsequent crops. They also impede site preparation and restocking operations.

Residues can represent a considerable proportion (up to 50%) of the final crop, with total quantities varying with species and site. Spruces may generate 50-100 oven dry tonnes per ha (odt/ha): equivalent figures for pines are 25-35 odt/ha. This considerable resource is largely unutilised at present, although earlier studies have shown that the extraction and processing of these residues in a second-pass operation is close to being economically viable.

Forest residues contain a proportion of white wood that is suitable for use as fibre in industrial processes. If this higher-value industrial fraction can be separated out, the remaining wood fuel fraction may be made available at a more competitive price.

Project Objectives

- To find ways of recovering forest residues as economically as possible using modified versions of existing comminution technology.
- To investigate how screening technology can be used to separate the fibre fraction from the residue chip.
- To examine the economics of siting the screening operation at the source of chip production using mobile screening units.
- To investigate varying combinations of comminution and screening equipment for residue harvesting.

Methodology

The equipment used for comminuting forest residues was studied to identify options for improving its efficiency and reducing costs. The main problem identified was associated with feeding the residue material into the chipper. Low-cost modifications were therefore made to the infeed systems of a forwarder-mounted chipper and a trailer chipper to improve the feeding process. These modified machines were then tested in several trials of two residue harvesting systems:

- terrain residue harvesting in Thetford Forest using a forwarder-mounted chipper to process pine residues at the stump and extract the chips to the roadside

- landing residue harvesting in Kielder Forest, where spruce residues were extracted by forwarder to roadside or landing and then chipped using both forwarder-mounted and trailer chippers.

Screening technologies were reviewed to determine the most suitable method for separating wood chips, while screening plant used in existing operations was investigated to determine screening effectiveness. The information gained was used to design and construct a mobile screening plant. This allows screening to take place at the site where chips are produced, thereby eliminating one leg of the transport process (between the site of chip production and the screening plant) between forest and market.

Several screening runs were completed, using wood chips from a variety of sources. Both mobile screens and a modified static gravel screen were tested to determine production rates, product proportions and operational costs. The screening trial results were analysed using a spreadsheet program to determine the yields and costs at which the wood fuel fraction could be made available.

Several residue harvesting system options were devised and costed, based on standardised conditions.

Findings

Comminution

Analysis of time study data taken during the comminution trials indicated that the productivity of the modified individual chippers was better than that of those tested previously. The forwarder-mounted chipper achieved a throughput of 5.17 green tonnes per productive machine hour (gt/pmh) while terrain chipping pine residues in Thetford Forest, and 6.75 gt/pmh when processing spruce residues at roadside in Kielder Forest. The trailer chipper was able to process spruce residues at a rate of 9.64 gt/pmh when situated at landing in Kielder Forest.

The lowest costs for wood fuel production from terrain chipping of pine residues in Thetford Forest have been calculated at £31.33/odt delivered to the utilisation plant. This is based on standardised extraction distances of 100m and a 50km haulage distance to the utilisation plant. Because the terrain is sufficiently easy and the soils sufficiently firm, vehicles can approach the site of operations, and a maximum extraction distance of 100m is feasible.

The landing chipping systems processing spruce residues in Kielder Forest are capable of producing wood fuel at a lowest cost of £22.86/odt delivered. This assumes the same extraction and haulage distances as above. However, the rougher terrain in Kielder limits access, and extraction distances are often in excess of 200m: this will reduce the productivity of the forwarder used to extract the residues. Nevertheless, because the chipper is the limiting factor in the processing chain, the costs of production will increase only when forwarder productivity falls below that of the chipper.

Although the landing chipping systems gave lower delivered wood fuel costs than the terrain systems, it must be remembered that the two systems operated in completely different conditions.

Screening

Screen productivity varied with the moisture content of the infeed chip, with wetter chips generally having a slower screening rate.

The cost of the static screening operation was £24.39/pmh, assuming a ten-year equipment life.

The equivalent value for the mobile screens was £32.11/pmh, reflecting the additional design costs of transportability and the fact that periods of time would be spent in transit. Assuming the mobile screen can process comminuted material at the rate of 5.93 gt/pmh, the infeed cost at a chipping cost of £10/gt is £59.30/pmh. Adding this to the screen operating cost gives a total operational cost of £91.41/pmh.

The cost of producing the energy chips is based on the above costs plus two assumptions:

- product proportions of 25% mulch, 60% energy chips and 15% fibre
- market values of £25/gt for mulch and £23/gt for fibre.

This shows that the energy chip is available from the mobile screens at a price of £10.05/gt when the operation is set up to break even. However, in practice, values can vary.

Screening reduces the amount of wood fuel produced, incurring increased haulage distances to supply the same amount of wood fuel as a system without a screening operation. To determine whether the inclusion of screening can be economically justified, it is important to assess individual circumstances in relation to the availability and requirements of local markets for screened products.

Report No: ETSU B/W2/00262/REP Publication date: 1996

HARVESTING AND COMMINUTION OF SHORT ROTATION COPPICE

Technical Development Branch, Forestry Commission

Background

Wood is an environmentally attractive energy source, being both renewable and broadly carbon neutral. Research has shown that short rotation coppice (SRC) could become an important renewable source of energy for the future. Some 200ha or so of SRC already exist in the UK , and it is likely that about 5000ha could be planted to meet requirements under the third tranche of the Non-Fossil Fuel Obligation (NFFO), with additional planting for NFFO-4.

It is envisaged that SRC will be grown on farms as part of the farm business. It will be harvested in winter when many farmers have machinery and labour that is not fully employed, and there is now a need to demonstrate that harvesting, handling and processing can be carried out in a mechanised and technically viable manner.

Project Objective

- The overall objective of the project is to establish cost-effective and practical options for the harvesting and comminution of SRC in the UK. This involves:

  - assessing the likely effectiveness of existing harvesting machines in UK SRC supplying UK markets

  - field testing the most appropriate machines, both cut-and-chip and stick-harvesting devices, and assessing the performance and economics in each case

  - identifying crop issues that impinge on harvesting, eg age of harvesting, clonal selection, plantation layout.

Methodology

- Literature review and preliminary selection of equipment potentially suitable for use in UK conditions.

- Field trials of both stick and cut-and-chip harvesting systems on ten sites producing willow and/or poplar. The trials were conducted in three concentrated periods: January 1994, December 1994 and November 1995.

- Ancillary trials of large- and small-scale comminution machinery for chipping both green and dry poplar and willow.

- An experiment, with Silsoe Research Institute, to investigate the effects of various harvesting machinery configurations on soil compaction and crop growth.

- Assessment of the benefits of using tracked systems, especially for extraction (carting) equipment.

Findings

Harvesters

The outputs in hectares harvested per standard hour (ha/shr) and costs in £ per oven dry tonne (£/odt) achieved in the harvesting trials are summarised in the table below for each type of harvester tested.

Output and costs for different types of harvester

System/Harvester	Output range (ha/shr)	Cost range (£/odt)
Cut-and-chip system		
Austoft	0.26-0.56	£7.48-£15.91
Claas	0.34-0.52	£7.10-£11.16
John Deere	0.21-0.36	£7.98-£15.86
Salix Maskiner	0.16-0.22	£7.76-£15.00
Cut stick system with separate chipping at £8.22/odt		
Empire 2000	0.16-0.61	£16.26-£24.84
Frobbesta	0.09	£28.17-£33.54
Loughry	0.13	£30.35-£36.55
Nicholson	0.10	£30.45-£36.69

These figures exclude blockages and are based on "twin row" spacing (1.5m + 0.75m) and crop yields of 26-36 odt/ha.

Weed infestation at some sites and row spacings of either 1m + 1m or 1.5m + 1.5m caused difficulties with all harvesters. Blockage time accounted for between 20% of productive time for the Austoft to 412% for the Loughry.

Initially, poplar was perceived to be difficult to harvest because of stem size. In practice, its very rapid growth made it less dense and it therefore cut more easily. However, it did prove to be brittle and to snap easily when harvested with the Frobbesta.

The harvesters caused minimal apparent site damage except where trafficking was intense, eg on headlands. Unit traction was good, particularly on the Austoft, which was able to operate uphill on wet slopes up to about 20%, but wheeled harvesters appear to be limited to a maximum slope of about 15%.

The tractor/trailer units used for chip removal caused significant rutting on the wettest ground, and traction problems here limited the harvestable area.

Four of the machines tested were found to be suitable as possible contractor machines. With minor modifications for use in the UK, both the Austoft and the Claas could be used to harvest 2-3 year old poplar and willow at single (1m + 1m) or twin row spacings, preferably the latter. In the case of the Austoft, the consumer must be able to handle the larger chip produced (90% in chunks 50-100mm long). The Claas produces smaller, more fragmented material, 72% of which is 15-35mm long and 4-6mm in diameter. The John Deere forage harvester could be an alternative to the Claas, but only if fitted with a Claas rather than a Kemper header (the latter does too much damage to stools). For stick harvesting, the Empire 2000 could be used at twin row spacings, provided some modifications are made for use in the UK.

The other machines tested have different potential applications. The Salix Maskiner is an alternative to the larger self-propelled machines for the growers' co-operative or small contractor. Designed to fit the front three-point linkage of an agricultural tractor, this machine could encourage the winter use of existing machinery. For the farmer operator, the Frobbesta stick harvester is a possible alternative to contract harvesting, with twin row planting recommended. The machine could be modified relatively simply for use with poplar, and other modifications would permit the direct loading of trailers, thereby eliminating the costly extraction operation. The New Holland trailed forage harvester with maize header could possibly offer the farmer a small-scale cut-and-chip unit, although the costs of modification are significant and might be better spent developing a new machine.

Both the Loughry and Nicholson stick harvesters would require major modification before being able to work in a safe and economical manner.

The Claas can be used to harvest 2-3 year old poplar and willow SRC, operating best at twin row spacings.

Chipping

The chipping trials generated costs ranging from £8.22/odt for the Sasmo HP-30 to £38.92/odt for the Siba 745 RCX. Chip material and consistency varied with the material involved. The comminution of green material produced a higher percentage of material in the > 50mm class. Greater consistency was achieved when comminuting dry material using disc chippers, with most of the material falling into the 15-35mm category.

Impact of machinery use on soil compaction and crops

Machine trafficking, eg on headlands, causes ground compaction, but no difference was observed between planted and unplanted headlands, and compaction did not appear to have any effect on crop yield. Although wheeled and tracked vehicles gave similar levels of compaction, the latter caused less rutting.

Report No: ETSU B/W2/00518/REP Publication date: 1996

AN ASSESSMENT OF THE COMMERCIAL COST OF FARM SCALE WOOD FUEL PROCUREMENT AND PROCESSING

Border Biofuels Ltd

Background

The capital cost of small-scale biomass-fired systems is currently significantly higher than that of fossil-fuel-fired systems of equivalent rating. If the cost of producing fuel from willow coppice can be shown to offer significant savings over the cost of conventional fuel alternatives, the total cost of energy production could be significantly less. It has not yet been shown that small-scale coppice plantations can produce wood fuel cost-effectively, thereby displacing bought-in fuel.

There is a lack of practical knowledge of the methods and costs of fuel procurement and processing at the farm scale. Few trials have been carried out, and farmers are unwilling to convert to coppice-fired heating unless they are convinced, by demonstration, that the change will not increase costs or cause greater inconvenience. This report identifies appropriate systems and sets out both the relevant costs and the statutory requirements of employers.

Project Objectives

- To assess the work rate and costs of a range of manual harvesting systems and of manually and mechanically cutting back willow coppice.
- To assess the practical limitations to the machinery and to establish the level and cost of in-field maintenance necessary.
- To compare the cost implications of farm-based and contractor-based chipping operations.

Findings

Cut-back

Cut-back can be carried out either manually using secateurs, motor-manually using brush cutters or clearance saws, or mechanically with the aid of equipment such as rape swathers and tractor-mounted flail mowers. The simplest method for most growers is to adopt a motor-manual approach. This is not the most cost-effective, but it does leave the stools in good condition. The cheapest option for the small-scale grower is to use a tractor-mounted flail cutter. This does not leave the stool in good condition.

The cost of cut-back varies considerably with the method chosen, as does the condition in which the stool is left. On a small scale, the cost of cut-back varies from £16/ha for tractor-mounted operations to £110/ha for manual methods.

Harvesting

Harvesting willow coppice on a small scale at three-year intervals can be achieved either using a chain saw or employing a clearance saw or brush cutter fitted with a blade consisting of teeth similar to those found on a chain saw. The technique required for a clearance saw is broadly similar to that required for chain saw operation. Brush cutters are capable of cutting stems up to 100mm in diameter, equivalent to poplars up to three years old. The material can be felled neatly into windrows by carefully controlling the angle and movement of the blade.

The cost of harvesting willow coppice grown on a three-year rotation ranges from £250/ha to £350/ha for contractor operations and from £200/ha to £240/ha using on-farm labour. Farm costs should always include machinery as well as labour costs. Stacking poorly felled stems can add significantly to costs (£200-£300/ha) if the material is to be stored as rods or bundled manually.

Although cost savings can be achieved with longer crop rotations, growers may tend to go for shorter rotations because of the need for fuel and stable cash flows.

Bundling

The cost of bundling three-year willow coppice, using a combination of a loader with a suitable grab and manual labour for strapping, was shown in this study to be £200-£250/ha. Although these costs vary with crop yield, there is a significant fixed cost element that reduces proportionally as yields increase.

The range of harvesting, bundling and on-farm transport costs that a small-scale grower might incur are summarised in the table below.

Chipping

The study costed and compared farm-based and contractor-based chipping of 50, 100 and 200 gt/year of coppice material.

The cost of on-farm chipping was found to vary considerably depending on the type of machine used and the skill of the operator. The lowest cost system was one with a capital investment in the chipper of £5000, a productivity of 2 gt/hour, and an output of 200 gt/year. This gave a chipped cost of £9.12/gt. As capital investment increases, as productivity falls and as output is restricted, costs rise - to a maximum of £33.23/gt. Such costs are not an economic proposition.

Costs for small-scale harvesting, bundling and on-farm transport operations

Operation	Three-year willow		5-7 year poplar	
	Contractor	Own labour	Contractor	Own labour
Cutting (£/ha)	350-490	200-280	297	68-85
Stacking (£/ha)	250-300	200-240	330	112-140
Machinery hire	-	125	-	76
Bundling	226	226	240	240
Transport to farm buildings (£/site)	62	62	50	50
Totals	888-1078	813-933	917	546-591
Yield	48	48	58	58
Total cost (£/gt)	18.50-22.00	16.90-19.50	15.00	9.40-10.00

Contractor costs are based on the assumption that chipper use will be extended beyond the farm-based operation. The costings are based on three levels of use (100, 150 and 200 days/year), four levels of capital investment (£15,000, £20,000, £25,000 and £35,000) and production outputs related to the sophistication of the equipment of 2.5, 3 and 4 gt/hour. The lowest costs were achieved by maximising the use (200 days) of a £35,000 chipper with a productivity of 4 gt/year. This gave a chipped cost of £9.30. The contractor-based system with the highest cost involved a £20,000 chipper with a productivity of 2.5 g/hour and used for only 100 days/year.

It is clear from this that contractor-based chipping is typically cheaper in the long run. However, the trials demonstrated that this cost is highly variable, depending on the quality of the material being presented to the machine.

Report No: ETSU B/W2/00548/04/REP Publication date: 1997

THE EFFECT OF HARVESTING TIME ON STOOL SURVIVAL AND SUBSEQUENT YIELD OF SHORT ROTATION COPPICE: PHASES 1 & 2

Long Ashton Agroforestry Consultants

Background

Coppice crops are traditionally harvested in the dormant season between leaf fall and bud break. Where short rotation coppice is grown to meet a year-round demand for fuel, harvesting out of season would spread production, facilitate drying and storage and allow harvesting machines to work in drier conditions. However, summer harvesting is traditionally held to be detrimental to the health of the stool and to its productivity.

Project Objective

- To test the effect of out-of-season harvesting on the survival and subsequent productivity of two-year and rising three-year willow and poplar stools.

Methodology

Two willows, *Salix viminalis* Bowles Hybrid and *S. viminalis x caprea x cinerea dasyclados* were compared with the poplar *Populus trichocarpa x deltoides* Boelare. The stools were planted in January 1992 at a 1 x 0.5 metre spacing and using consecutive rows of the three varieties. The initial growth was cut back during the following winter. The regrowth was therefore two years old at the start of the trials in January 1995.

Control plots were harvested normally in January 1995 to establish the productivity of the site's two-year-old crops. Other plots were harvested out of season, at the end of April, in mid-June, at the end of July and in mid-September. The "A" sub-plots for both control and out-of-season plots were then harvested again in December 1995.

In December 1996, the second regrowth on the A sub-plots and the rising two-year-old crop in the "B" sub-plots was harvested and the results compared.

Findings

Regrowth and yield

In January 1995, the standing crop consisted of vigorous willows that had outgrown and overshadowed the poplars. Crop yield averaged 12.11 oven dry tonnes (odt)/ha/year, which represents good growth. The two willows achieved yields of 15.72 odt/ha/year (Bowles Hybrid) and 15.25 odt/ha/year (*dasyclados*), while the poplar Boelare only achieved 5.35 odt/ha/year. Shoot length also varied, with Bowles Hybrid having significantly longer shoots (5.51m) than either *dasyclados* (4.92m) or Boelare (4.24m), but there was little variation in diameter. Overall, Boelare had not grown as well as the two willows, and 19% of its stools were either dead or missing.

The harvests made between January and September 1995 are summarised in the table below. The figures show a near-consistent increase in dry weight as the crop grew through its third year. The increase, which averaged 10 odt/ha ranged from 8 odt/ha for Boelare to 12 odt/ha for the two willows.

Plots cut in January, April and June resprouted vigorously and grew well. Regrowth was slow to appear in plots cut in July. Of plots cut in September, neither Boelare nor *dasyclados* resprouted, while Bowles Hybrid produced only a negligible amount of regrowth.

The final column of the table shows total productivity for the three-year period since cut-back. It includes the regrowth obtained by December 1995. The mean is 11.86 odt/ha/year. The figures for June and July are significantly above those for January and April because of the weight of leaf harvested.

Harvest data for various harvesting dates

Harvesting date	Average yield	% dry matter content			Total growth Dec. 1992-Dec 1995
	(odt/ha)	Stem	Leaves	Overall	(odt/ha)
January 1995	22.4			44.5	33.4
End April 1995	25.2			39.0	30.8
Mid-June 1995	35.6	41.2	31.5	38.7	38.1
End July 1995	38.7	50	39	47.6	39.4
Mid-September 1995	34.9	50	39	48.6	36.2

Despite cutting all the stools in the A sub-plots in December 1995, all treatments resprouted well in the spring and were harvested again in December 1996. The mean yield of these one-year crops was 9.16 odt/ha/year, with poplar contributing only 2.28 odt/ha/year, *dasyclados* 13.54 odt/ha/year, and Bowles Hybrid 11.66 odt/ha/year. When these values were compared with equivalent figures for the stools in the B sub-plots, where regrowth was permitted for more than one season to allow stools more time in which to recover from any possible ill-effects of out-of-season harvesting, the conclusion drawn was that such caution was not essential, although probably good practice. However, the July treatments produced multiple stems 10cm above the stool, which could create harvesting difficulties.

In neither the A nor the B sub-plots had out-of-season harvesting reduced the total yield over the four seasons of growth. Mean yields were 5.4 odt/ha/year for Boelare, 16.7 odt/ha/year for *dasyclados* and 14.0 odt/ha/year for Bowles Hybrid. However, the overall yield of 12.05 odt/ha/year for the B sub-plots was significantly more than that from the A sub-plots (11.19).

The results confirm that cutting out of season did not reduce yields but that it would be prudent to allow two, or better still three, growing seasons between harvests.

Other issues

Whether out-of-season harvesting can be sustained through repeated cutting cycles depends on whether cutting results in stool death and also on whether stool vigour is maintained if leaf removal in the summer cuttings reduces the nutrient status of the site.

Out-of-season harvesting removed 5.4odt of leaf/ha in June 1995, 3.38 odt/ha in July 1995 and 1.33 odt/ha in September 1995. If this pattern were to be repeated over a number of harvesting cycles, soil fertility could fall.

Five assessments during the 1995 season failed to show that harvesting dates had any significant effect on the number of dead or missing stools. A final assessment in December 1996 showed no dead *dasyclados* stools and only four dead Bowles Hybrid stools. By contrast, 76 (10.5%) of the poplar stools were dead, most of them in the September cut treatment. Stools cut in July or earlier did not die. It is clear from this, and from experiences in the Somerset basket willow industry, that August/early September is the most damaging period for harvesting coppice.

There are numerous practical advantages of extending the safe harvesting period from the current December-March period to one that lasts from late September to July:

- Harvesting in very wet periods can be avoided, reducing soil compaction and rutting.
- The product will dry more quickly, particularly if harvested as bundles.
- Labour and machinery requirements can be spread more evenly over the year.

Conclusions

There seems to be no reason why UK producers of short rotation coppice should not introduce an extended harvesting period.

One specialist German producer with 20 years' experience has found that harvesting cycles can be manipulated so that the same willows are not harvested out of season in consecutive harvesting cycles, and that even August harvesting can be successfully integrated into a sustainable commercial programme.

2.3 Storage and Drying

Report No: ETSU B/W1/00146/REP Publication date: 1993

STORAGE AND DRYING OF COMMINUTED FOREST RESIDUES

AFRC, Silsoe Research Institute

Background

Forest residues represent a considerable potential energy source, and a vital link in the chain from forest to combustion site is the storage and, if necessary, drying of the comminuted residues. Drying to a moisture content of 25-30% would produce a fuel that could be burnt efficiently, would not be too dusty and would store without excessive self-heating or loss of dry matter. This project assumes that storage and drying will take place within or at the edge of the forest, where facilities are minimal and energy supplies are limited to the solar energy of ambient air and the heat released in the residues by respiratory action.

Project Objectives

- To establish economic methods for the long-term storage/drying of comminuted forest residues using natural or forced ventilation with near-ambient air, or a mixture of both.

- To achieve this objective by:

  - quantitatively determining those properties of the chips that affect their drying and storage behaviour

  - adapting existing and developing new mathematical models and computer simulations of the processes involved

  - carrying out practical experiments to validate the computer models.

The final report is in two volumes, the second of which contains the Appendices.

Findings

Material properties

A key property for drying wood is the rate at which the moisture leaves the particle under the varying conditions to which it is exposed. Drying tests on exposed layers of spruce and birch chips, both as-chipped and sorted into size grades, defined the drying rates as a function of vapour pressure deficit and particle size. The chips used in the project had geometric mean sizes of around 10mm for spruce and 15mm for birch, and these were reasonably typical of the sizes of chip derived from survey data.

A second important property for drying is the equilibrium moisture content. This was measured both within the exposed layer tests and in separate experiments. The findings showed that, for a given relative humidity, the equilibrium moisture content of wood chips was higher than predicted by published values for clean wood. Even so, the values are such that it would be difficult to avoid overdrying the lower layers of a deep bed or pile dried by conventional near-ambient ventilation.

Pressure resistance, or air permeability, is an important determinant of drying cost since it determines both the power necessary to provide artificial ventilation and the extent to which a stack might be penetrated by wind or natural convection. The work found a strong correlation between pressure resistance and chip size: resistance increased with reducing particle size and rose steeply when chip size fell below 20mm. However, the laboratory tests may have underestimated the effect of compaction in large piles, and this, combined with the variation in chip size that occurs in practice, will make it more difficult to predict airflows and fan power consumption, and therefore to select the appropriate equipment. Knowledge of chip size in any particular application will ease the problem, but further work is required before confident advice on best practice can be given.

Although drying is desirable for efficient combustion and to reduce transport costs, it will almost certainly be too expensive to remove large amounts of water in this way. The primary objective must therefore be to control, exploit or prevent the respiratory action that causes self-heating and dry matter loss. Experimental work carried out in Eire and as part of this project measured respiration rates in the 12-34°C range. The resulting data suggest that temperatures above 35°C are only likely to occur in very large chip piles involving some degree of compaction. It is also likely that the findings, even allowing for a temperature response, overestimate respiration at the lower temperatures and long storage periods that would be typical of many forest sites.

Pilot-scale experiments

Data from pilot-scale drying beds were obtained in four experiments carried out in Aberdeen. The first three were carried out in a custom-built drying bin, 3m deep and 2m in diameter, which provided an approximately one-dimensional drying profile. The fourth experiment attempted to reproduce, on a small scale, the two-dimensional profile of a covered and uncovered section of a pile ventilated using a central duct. The first three experiments, which used airflows generated by air pressures typical of agricultural fans, confirmed not only that the chips could be dried in deep beds with near-ambient air, but also that the bottom layers were likely to overdry. Specific energy consumption was shown to be too high to be economic. The experiments also gave some indication on spore production from deteriorating organisms.

Modelling

A "psychrometric" model was used to examine differences in drying time and energy consumption between wheat and wood chips arising from differences in bulk density, pressure resistance and moisture removal. The analysis showed that the lower bulk density and pressure resistance of wood chips could help to compensate for the higher moisture removal required, and that specific energy consumptions of less than 1 MJ/kg water evaporated might be feasible. This suggests that drying wood chips might be economic. The model also showed that increasing the depth of chips in the drying bed increased the energy cost. However, the balance between energy cost and the cost of floor space was not explored.

For problems of one-dimensional drying, the grain drying model STOREDRY was modified to take into account the properties of wood chips ascertained in earlier phases of the study. The model predictions matched the general trends observed in the pilot-scale drying experiments, particularly the overdrying of the lower layers and the high specific energy consumption. It also predicted faster drying than was observed: this may relate to non-uniformity in the air flow in the bed, or it might indicate that the equations used in the model are at the limit of their validity. Nevertheless, the model can help to assess the importance of variability in specific parameters of either materials properties or drying bed configurations.

A more sophisticated drying sub-model has been incorporated in the new model. This calculates the movement of air, heat and moisture in three dimensions and will be a powerful tool for investigating problems such as self-heating and natural convection in forest piles, where the processes are not easily approximated to one or two dimensions.

Conclusions

The combination of experimental and modelling work allows the performance of potential drying and storage configurations to be estimated with confidence. Cost constraints in wood chip drying mean that the process will only be economic with minimal use of ventilation and the optimal use of self-heating of the bed by respiration. Prediction of respiration rates is the most difficult aspect of the problem and requires further consideration in relation to practical storage control.

Report No: ETSU B 1366 Publication date: 1993

AIRTIGHT STORAGE OF WOOD CHIPS FOR USE AS A FUEL

The Scottish Agricultural College

Background

If chipped wood is to be used as a fuel for power generation, safe and economical storage will be required for large quantities of chips. Conventional uncovered stacks of chips can, over time, lose significant amounts of dry matter as a result of rotting, and research into the application to wood chips of well tried methods of reducing moisture content are in hand elsewhere. While drying is applied extensively to agricultural crops to ensure safe storage, airtight storage and ensiling is also used. If these methods could be used for chipped wood fuel, they would not reduce the moisture content of the wood, but they might be a cost-effective method of storage at harvesting sites or for boilers designed to use a feed with a high moisture content.

Project Objective

- To ascertain whether airtight storage is a possible alternative to drying as a procedure for the successful storage of chipped wood for fuel.

Methodology

Twelve insulated bins, each with a capacity of approximately $0.1m^3$, were filled with freshly cut Sitka spruce wood chips. Ten of the bins were sealed immediately after filling. The remaining two were left unsealed throughout the experiments.

Two of the sealed bins were equipped with sampling ports so that gas samples could be taken for analysis by gas chromatography. A further two of the sealed bins and one of the unsealed bins were monitored continuously for temperature. All the bins were weighed at approximately monthly intervals.

Two of the sealed bins were opened every three months and measurements were taken for:

- the percentage of carbon dioxide (CO_2) near the bottom of the bin - measured using “Gastec” sampling tubes

- moisture content - 12 samples, three from each of four positions throughout the depth of the bin

- calorific value - samples from the bin surface and from near the bottom, for the bins opened after three, six and nine months

- microbiology - one sample from each of the four depths for analysis of fungal and bacterial flora.

Fungi were analysed at the delivery of the wood chips and then for all samples at three-month intervals. Bacterial counts were made at the end of three months: counts plus identifications were made at six, nine and 12 months to detect the presence of coliforms and of sulphite-reducing clostridia, and to count the viable population before and after pasteurisation. The latter count effectively gives a count of aerobic spore-forming bacteria.

Once a sealed bin was opened and sampled, the trial for that particular bin ended.

When the last two sealed bins were sampled at 12 months, the unsealed bins were sampled at the same time.

Findings

The unsealed bins lost weight much more rapidly than the sealed bins, with an increasing rate of weight loss in the unsealed bins after eight months. The temperature in the unsealed bins also began to rise above ambient after eight months.

Average monthly dry matter loss was just under 1% for the sealed bins and just over 2% for the unsealed bins. This compares favourably with losses of around 3% per month which have been reported for open stacks of chips with much lower initial moisture contents than that used for these experiments.

The calorific value of oven-dried samples of the wood chips showed a slight reduction after storage, and the mean loss of gross energy per month was 1.4% for the sealed bins and 2.3% for the unsealed bins. Net energy loss per month was 2.0% and 2.9% for sealed and unsealed bins, respectively.

The moisture content of the wood chips increased during storage. After storage, the highest moisture content for all bins was at the bottom of the bin, while the unsealed bins showed the greatest difference in moisture content between the top and the bottom. The average standard deviation of the moisture content samples from the two bins opened after 12 months was 3.8 for the sealed bins and 10.0 for the unsealed bins.

The CO_2 levels, measured at the bottom of the bins, also differed between treatments. The sealed bins opened after 12 months gave readings of more than 20% CO_2 compared with 5% and 8% for the unsealed bins. While the sealed bins opened at three, six and nine months did not have a consistent CO_2 level, there was a strong negative correlation between the level of CO_2 and the dry matter loss per month.

Typical field fungi were observed on the material, including *Penicillium*, *Cladosporium*, *Aureobasidium* and other saprophytic yeasts, notably *Trichoderma*, which may be responsible for some of the dry matter loss. The recalcitrant nature of this material has precluded the development of thermotolerant fungi such as *Absidia*, *Mucor pusillus* and greater numbers of the Thermoactinomycetes that would normally succeed the yeasts. *Asperigillus fumigatus*, a potentially harmful species, was present and attained numbers that would present a risk at six months. As a precaution, personnel handling this material in bulk following storage should wear appropriate face masks.

The potential costs for sealed storage vary widely, from £1.27/m^3/year for a plastic-covered outdoor stack to £11.72/m^3/year for a vitreous enamel tower silo. From about £1.50/m^3/year to £2.50/m^3/year, there is a choice ranging from specially constructed concrete domes to stacks of various sizes on concrete floors.

Further research is needed:

- to test the practicability of airtight storage for commercial systems
- to determine the performance of wood chips at different initial moisture contents
- to compare, concurrently, the performance of airtight storage with that of uncovered heaps
- to obtain accurate data on bulk density, angle of repose and angle of internal friction as a precursor to the accurate design and costing of suitable stores
- to determine the degree of seal integrity necessary, the rate at which wood chips deteriorate when exposed to air, and the seriousness of any potential effluent production
- to determine the potential health hazard of the bacterial population.

Report No: ETSU B/M3/00388/08/REP Publication date: 1994

COPPICE WOOD DRYING IN A GASIFICATION POWER PLANT

Stamford Consulting Group

Background

The presence of too much moisture in the wood chip feedstock to a gasification power plant would significantly reduce the efficiency of the generation cycle and, in the extreme, would interfere with the operation of the gas engine by reducing the calorific value of the fuel.

Project Objectives

- To assess the heat flows and thermodynamic demands involved in drying coppice wood from 35% to 15% moisture content.

- To assess the waste heat flows provided in terms of both their ability to remove moisture without becoming saturated and their economical use in the process.

- To evaluate available drying methods and recommend the best option for this purpose.

Findings

The drying process

When a natural cellulosic material is cut down (eg when a tree is felled), its initial moisture level is easily reduced. Under natural conditions, this reduction takes place slowly. If the process is accelerated by forced drying at elevated temperatures, the adjacent air quickly becomes saturated during the early stages of drying (the psychrometric drying period). As the moisture content of the material falls, so does the rate of drying. Eventually a point is reached when the evaporation of moisture is determined not by the ability of the air to take up water vapour but by the rate at which the water molecules diffuse through the mass of solid material. At this stage the drying process is known as the thin film or diffusion process.

The waste heat potential

A preliminary process flow sheet for the drying process gave the following information:

Wood flow rate @ 35% moisture: 2.148 kg/second
Wood flow rate @ 15% moisture: 1.6426 kg/second
Moisture evaporation rate in dryer: 0.5054 kg/second

Waste heat at 80°C from the engine cooling water: 2.24MW thermal
Waste heat at 80°C from engine oil cooling: 1.34MW thermal
Waste heat at 120°C from engine exhaust: 1.42MW thermal

The heat required to dry the wood chips is 1.3MW. The low grade heat available is 5MW. However, because the low grade heat is quoted above a datum of 0°C, not all the energy is available in practice.

Calculations show that, assuming an ambient temperature of 15°C, the total heat required to dry wood chips to a final temperature of 55°C is 1490 kj/second.

If the waste heat from the engine cooling water and oil cooling were to be captured in a heat exchanger, it would be possible to generate an air flow rate at 70°C of 64.87 kg/second. However, the final air temperature would fall to 47°C and, while drying at these temperatures is certainly feasible, the power consumption of fans and the size of the equipment needed suggests that heat from the engine exhaust should be used. This has a higher temperature, and the quantity of heat is unlikely to decline.

Combining the exhaust gas with air from the water and oil heat exchangers would give a combined air flow of 76.18 kg/second at 77°C and a dew point of 23°C. However, the exhaust gas contains contaminants such as carbon monoxide (CO) and oxides of nitrogen (NO_x). Any build-up of the latter could cause corrosion in the dryer. Furthermore, reducing the absolute humidity level in the system improves the rate of mass transfer in the drying process. The recommended option is therefore to install a heat exchanger between the exhaust gas and clean dry air.

Using a heat wheel of the type now being applied to large gas-fired boilers would produce 9.61 kg/second of clean air at 115°C.

Adding the mass flows of low grade heat gives 74.48 kg/second at 76°C.

Dryers and dryer operation

The average rate of feedstock at 35% into the dryer is assumed to be 35.8 m^3/hour or 10.6 litres/second.

The overall drying time is assumed to be one hour.

The air flow through the dryer would be 73.5 m^3/second, and air would leave the plant at an estimated relative humidity of 18% at 56°C.

Many types of dryer are unsuited to wood chip drying: the rotary kiln dryer is only applicable to relatively high temperatures; drying floors and tray drying tend to be labour-intensive; fluidised bed drying is unlikely to be successful because of the difficulty of maintaining the fluidisation of irregular particles; wood chips do not flow freely and are therefore unsuited to drying silos.

The best type of dryer for wood chips is one comprising mass flow drying beds in which the material to be dried is spread out on a travelling belt in a uniform layer. The required rate of evaporation (0.5054 kg/second) can be achieved given the following parameters:

Volume of wood chips: 25.8 m^3/hour
Thickness of chip bed: 300mm
Length of bed of chips: 28.6m or three layers each 9.6m long
Width of bed of chips: 3m
Area of bed exposed to chips: 86m^2

Air flow entering dryer at 76°C: 73 m^3/second
Air velocity through bed: 0.85 m/second
Air exhausted at 56°C and 18% relative humidity

The travelling belt can be woven or perforated material. If designed in three layers, the wood chips can be arranged to cascade under gravity from layer to layer, disturbing the material during the drying process and presenting fresh surfaces to the incoming air. The air is normally passed downwards through the bed to prevent air pollution.

An alternative novel configuration that might be considered is a double flow inclined bed dryer in which the wood chips move by gravity over inclined, louvered surfaces and are collected at the bottom by a travelling screw discharger.

Power consumption

Assuming travelling belt beds and an overall pressure drop of the drying air of 1500 N/m^2, the power requirements of the plant would be 146kW at a fan efficiency of 75%.

Implications of initial moisture content

An increase in initial moisture content above the 35% envisaged for this project would have two significant effects:

- it would increase the drying time substantially (to ten hours at 60%)
- in a dryer of fixed size, it would increase the final moisture content of the wood chips.

Conclusions

It is feasible to use the waste heat from the proposed gas engine to dry the wood chips from 35% to 15% moisture content. An economic design would involve harnessing heat from water and oil cooling and from the exhaust gases, in the latter case via a heat wheel. The recommended dryer design is a multi-pass travelling belt dryer. Chip residence time is one hour.

Report No: ETSU B/M3/00388/21/REP Publication date: 1994

DRYING OF COPPICE WOOD IN STORE

Stamford Consulting Group

Background

Report No: ETSU B/M3/00388/08/REP has shown that drying wood chips using waste heat from the engine cooling and exhaust systems of a gasification power plant is feasible. However, power plant operation normally requires a five-day strategic store of comminuted wood chips, and it may therefore be possible to dry the material during storage using low-grade heat from the air-blast condensers of the generating plant.

Project Objectives

- To examine the potential for drying comminuted wood fuel during storage during the period immediately prior to use.

- To use computer modelling to assess the effects of varying individual storage parameters.

Methodology

Storage and drying

A sensible storage philosophy involves dividing the wood pile into one-day lots and using it on a “first in first out” basis. This would allow the material to be dried for up to four days by passing air through it in the manner of a drying floor such as that used in the malting industry.

The use of ambient air as the drying medium requires large quantities of air and a considerable energy input to power the fans. Raising the temperature of the air reduces its relative humidity and increases its capacity to absorb moisture from the wood chips. If waste heat from the air-blast condensers were used, the air temperature could be raised to around 45°C.

The storage of wood chips is accompanied by biological decay. This is caused by fungal attack, and the associated release of energy raises the temperature of the wood pile. Biological decay increases with wood water content and decreases rapidly as that water content falls below 20-25%. Decay also falls off rapidly at temperatures above 40°C. It follows, therefore, that holding dried wood chips at a temperature of about 40°C carries no penalty in terms of further material loss.

Standard conditions and variations

Standard conditions have been assumed as follows:

Air temperature: 5°C or 15°C
Relative humidity: 65%
Moisture content of wood entering plant: 50%
Final moisture content of wood: 15%
Consumption of dry wood: 1.62 kg/second (5.84 tonnes/hour)
Temperature difference across air-blast condenser: 20°C
Thickness of wood pile: 2m
No of days drying in wood pile: 2
Enthalpy available in low-grade heat: 13,000kW
Dry bulk density of wood chips: 150 kg/m^3

The project examined the effects of varying several of these parameters.

Findings

Ambient temperature

At an ambient temperature of 5°C, the required air flow through the bed is more than 280 m^3/second, and the associated fan power requirement is almost 300kW. As the temperature rises to 20°C, these values fall to just less than 200 m^3/second and 120kW. The loss of dry matter, on the other hand, increases substantially, from just over one tonne/day to 3.2 tonnes/day.

Relative humidity

At a relative humidity of 60-64%, the equilibrium moisture content of the wood, ie the target figure at the end of the drying process, is 15%. It is therefore clear that air with a relative humidity of 65% has virtually no drying capacity until it is warmed up and the humidity reduced. Furthermore, the higher the ambient relative humidity, the greater the air flow required and the greater the power necessary to push that air through the bed.

Wood moisture content

Air flow and power requirements are also closely related to the initial moisture content of the wood. If this is allowed to rise significantly above 50% on a total basis, the air flow and power requirements rise steeply. Below 15%, the relative humidity demanded by the equilibrium moisture content determines that the process is self-limiting. The physical limit on dryness is around 12% moisture.

Drying floor depth

Varying the depth of material on the drying floor showed that power requirement increases significantly as the depth of the pile increases.

Number of days drying

Although a drying time of two days is taken as the standard in this project, the implications of reducing or extending this period were examined. Reducing the drying time incurs a huge power penalty. Increasing it beyond three days dramatically increases the material losses.

Variation in cooler temperature differential

A constant temperature differential across the air blast cooler of 20°C allows the generating plant to work at maximum efficiency in the coldest weather. Reducing this differential increases the air flow and power requirements in the wood pile: increasing it reduces these requirements.

Conclusions

A drying floor is a feasible and appropriate method of drying coppice wood for feeding a gasification plant. The floor has a permeable base through which warm air is blown. This air permeates up through the bed of wood until it is released into the atmosphere at a temperature of 15-28°C and a relative humidity of just under 60%. The wood, which has an initial moisture content of 50% is readily dried to a moisture content of 15% using, typically, 40-50% of the waste heat available from the air-blast condensers of the generating plant.

Operation is highly sensitive to ambient conditions, and it is essential that the system is sufficiently flexible to follow any short-term climatic variations.

Report No: ETSU B/W2/00548/10/REP Publication date: 1996

REPORT ON THE LONG-TERM STORAGE OF COPPICE WHIPS

Banks Agriculture

Background

Renewable energy power generation requires a constant flow of fuel throughout the operating period to maintain efficiency. However, coppice material is harvested over a three-to-four-month winter period and, at the time of harvest, has a moisture content well above the 20% required for many wood fuel combustors. The storage and processing phase has the difficult job of matching these two scenarios for the minimum cost, since the value of the material is low.

Project Objective

- To try and establish a link between the dryness of coppice whips (sticks) stored in the open on a sealed surface and weather conditions over a 12-month period of storage

Methodology

The coppice was harvested as whole sticks rather than chips, and was loosely bundled before being stored in heaps 3-4 feet high on a concrete ground surface. The site was open to the elements and had no artificial ventilation. A high hedge provided shelter down one side face and across the rear of the site.

Mean moisture content was determined monthly by taking eight moisture samples from randomly selected points. Weather data - rainfall, hours of sunshine, relative humidity and maximum and minimum temperatures - were acquired for the period of storage.

Findings

Multiple regression analysis showed close correlation between the moisture content of the whips at the mid-point of each month and weather conditions over the preceding four weeks. However, other factors also have an effect. For instance, if the samples are very dry, as was the case in August of the trial year, they can be quite difficult to wet. So, although September was the wettest month, there was only a limited increase in moisture content over August, partly because the moisture was only taken up in the outer layers and partly because September also had a high number of sunshine hours, and the rapid evaporation rates allowed these outer layers to dry out again easily. January, on the other hand, had a high rainfall and gave rise to the single largest increase in moisture content because the whips were already wet, sunshine hours were low and so were evaporation rates.

Conclusions

Storing whips in this way is practical: the whips require little attention and no artificial ventilation. However, as well as offering a low-input method of drying, this type of storage, when extended throughout the year, can also be a very effective method of rewetting. It would therefore be appropriate to move the whips under cover by the end of August. The space required would be equivalent only to about four months' supply.

Report No: ETSU B/W2/00391/REP Publication date: 1997

STORAGE AND DRYING OF SHORT ROTATION COPPICE

Silsoe Research Institute

Background

If short rotation coppice (SRC) wood is to be used as a fuel for power generation, it must be available throughout the year. However, the normal harvesting period is after leaf fall, and difficult ground conditions may restrict operations to a 1-2 month period between December and March. Some storage is therefore essential.

Storage has the advantage of reducing the moisture content of the wood. The wet basis (wb) moisture content of freshly harvested wood is normally 45-60%, which significantly reduces its net calorific value as a fuel. The required moisture content for effective power generation is 15-30%, and this can readily be achieved under properly controlled storage conditions.

Project Objective

- To provide information on the practicalities and costs of commercially storing and drying short rotation coppice wood for fuel.

This report is presented in three volumes, comprising a summary report, the full report and appendices.

Findings

Wood chip storage

The high moisture content of freshly harvested wood chips means that they are likely to self-heat when stored in bulk. The combination of high temperature (50-60°C), high moisture content and small particle size encourages decomposition through respiration and fungal/bacterial activity. This, in turn, reduces the quantity of material available for power generation, creates potential health problems for handlers, and increases the risk of spontaneous combustion/explosion. Some form of cooling during storage is therefore essential, and this can be efficiently and effectively achieved by brief periods of forced ventilation using ambient air.

On-farm storage

The site chosen for storage should, ideally, offer protection from the elements. It should also be level, free-draining and unlikely to flood, and located away from other combustible materials and from buildings. Other specific requirements include a concrete base to prevent contamination of the chips with stones and earth, sufficient space (70-80 m^2/ha of coppice harvested), accessibility, and a three-phase electricity supply to power ventilation fans.

The wood chips are normally stored in heaps contained within low, light retaining structures such as Heston-type straw bales or high tensile steel wire fencing covered with wire mesh. To ensure adequate ventilation, the practical width of any stack with a central ventilation duct should be no more than ten metres. Its length will depend on the size of the ventilation ducting.

Trials and computer modelling have shown that an average ventilation rate of 0.02 m^3/second per wet tonne is sufficient to keep stack temperatures under control. This can be achieved using a high efficiency axial fan with relatively low working pressures (100-500Pa).

The ventilation duct itself should have a total perforation area of at least 20% and a cross section that gives a maximum air speed of 10-12 metres/second (m/s) and an escape velocity from the duct into the chips of 0.1 m/s. To prevent excessive ventilation at the two ends of the heap, the first two metres of duct wall should be unperforated, and the duct should terminate two metres short of the end wall of the store. To ensure adequate air flow at the edges of the heap, the side retaining walls need to be permeable.

A 200-tonne heap of wood chips 10m wide and 22m long can be effectively cooled using a 3kW fan with an expected operating duty of 4.0 m^3/s against a static pressure of 280Pa, and a duct section of at least $0.4m^2$.

Ventilation control can be achieved manually. It can also be achieved by installing either a differential thermostat to switch the fan on and off when stack temperatures achieve certain levels, or a time switch to operate the fan for set periods.

Actual fan operating time will vary with the season and the moisture content of the chips. A typical ventilation operation might involve using the fan for a 2-6 hour period each night in the winter and early spring, and for three hours in the early afternoon and 3-4 hours each night during June, July and August.

It may be possible to make use of existing potato or grain store fans, although care will be needed to ensure that fan duty is appropriate for use with wood chips.

Large-scale storage

The same principles can be applied to large-scale industrial wood chip storage, although the structures involved may need to be more durable and permanent. Smaller installations are best ventilated using a single-stage axial fan. Where total pressure exceeds 700Pa, a centrifugal fan in the better choice. Large-scale storage will be easier to manage if the wood chips are held in several smaller heaps rather than one large one.

Storing sticks and billets

Coppice sticks, although difficult to handle and expensive to transport, experience less self-heating than wood chips and do not require forced ventilation. However, they tend to reabsorb moisture after drying, unless covered, and the subsequent chipping process is likely to require more energy.

Trials have shown that billets can also be stored successfully in bulk without forced ventilation. Billets 220mm long were stored in naturally ventilated bins for 36 weeks. No measurable heating occurred, there was no mould growth, and the moisture content fell from about 50% to around 17%.

Using heat for drying

The use of heat for drying wood fuel can usually only be justified where a site has ready access to large quantities of reject heat. However, there may be times when a continuously operating power plant needs to burn freshly harvested fuel. This will need to be heated in a batch or continuous flow dryer to reduce chip moisture content to around 15%.

An effective batch dryer supplies warmed air through a ventilated floor. The resulting moisture gradient through the chip bed is eliminated during subsequent handling and short-term storage prior to use. Drying time, evaporative capacity and ventilation rate will vary with bed depth.

Wood chips can also, in principle, be dried on a moving bed. Drying time increases approximately linearly with bed depth at constant air speed, and modelling suggests that the optimum bed depth is 0.3-1.5m. The moisture gradient that arises between the top and bottom of the drying bed is eliminated during subsequent handling and short-term storage.

Storage and drying costs

The findings suggest that effective storage and drying requires only a modest capital investment. Operating costs, however, will vary with parameters such as the value of the fuel, the level and value of any dry matter loss, the specific energy consumption for drying, and the associated energy cost. These operating costs can vary widely, with figures quoted ranging from £2.34/original dry tonne where the wood has a value of £30/tonne, dry matter losses are limited to 4%, and energy costs are £15/GJ (5.4p/kWh), to £13.72/original dry tonne where energy costs are the same but the wood has a value of £50/dry tonne and there is a 25% dry matter loss.

Overall, the lowest costs are associated with systems that maximise the natural drying power of ambient air. Energy input is limited to the fan power requirement, and energy costs are relatively low. Dry matter losses are limited because of the ventilation system. Where a storage system uses no artificial ventilation at all, its energy cost savings will be outweighed by the value of the dry matter losses sustained.

Report No: ETSU B/TI/00512/REP Publication date: 1997

STORAGE AND DRYING OF SHORT ROTATION COPPICE WOOD FUELS

Mitsui Babcock Energy Ltd

Background

Project ARBRE is a biomass renewable energy joint venture that is being supported under the EC THERMIE programme and the UK Non-Fossil Fuel Obligation scheme. The project involves building and operating an $8MW_e$ power generating plant that will feed chipped short rotation coppice (SRC) willow to a circulating fluidised bed gasifier. The low calorific value gas will be cooled, cleaned and compressed before being fired in a specially modified industrial gas turbine generator. Heat recovered from the fuel gas cooling section and the gas turbine exhaust will be used to generate steam for a steam turbine-generator.

The UK Department of Trade and Industry is helping to fund a supporting programme of development work, including work on fuel storage and drying. The requirement for long-term storage arises because SRC wood is harvested over a relatively short winter period, while the power station requires a continuous supply. In addition, the fuel must be dried to a moisture content of 20% wet basis (wb) or less prior to gasification if the calorific value of the fuel gas is to be at an acceptable level for firing into the gas turbine.

Project Objectives

- To prepare a conceptual design of the long-term fuel storage facilities required for Project ARBRE.
- To provide computer predictions of the performance of the storage facilities over periods of up to 12 months and to support these predictions via a series of long-term storage experiments using SRC in chip, billet and long stick form.
- To examine the options for drying the fuel using waste heat from the power plant.
- To provide computer predictions of the performance of the preferred on-site drying option and to support these with experimental work.

Methodology and findings

Wood chip storage

The harvesting and handling of wood fuels in chipped form have several practical, mechanical attractions. However, long-term storage of wood chips has major drawbacks:

- At moisture contents above 20% wb, relatively rapid biological activity can cause heating in the chip pile, loss of dry matter and a significant deterioration in the physical quality of the chips.

- High dust and spore concentrations can create health and safety problems during subsequent fuel handling.

In 1994, bin-scale wood storage experiments at Silsoe Research Institute showed that intermittent air ventilation can control bed temperatures and maintain biological respiration at an acceptable level, thereby reducing dry matter loss and preserving the physical quality of the fuel.

A longer-term chip storage experiment, on a larger scale, was carried out at Woodmancott during 1995 using mixed hardwood chips. This involved creating four similar storage piles, two under cover and two open. The piles were roughly semi-circular in profile, with a 9m base and a height of 2.5-3.0 metres. They had side walls 1.5-2.0m high and closed ends. A central ventilating duct was installed along the length of each pile, and a forced draught fan was located at one end of each duct.

Intermittent ventilation was used to maintain maximum bed temperature within 4°C of ambient air temperature.

The wood, which had a mean initial moisture content of around 44% wb, was weighed when the piles were constructed and when they were dismantled. Two piles, one covered and one uncovered, were dismantled after a storage period of 90-95 days. The remaining two were dismantled after 217-225 days.

The results showed that intermittent air ventilation had controlled overall dry matter losses at less than 10% and largely preserved the physical quality of the wood chips. The mean moisture content had also fallen to below 35% wb.

Data from this longer-term trial have been used to develop the design for a practical, large-scale chip store for Project ARBRE. Based on the Project's expected fuel requirement, the design assumes that all the fuel will be stored in chip form. Main design features include more than 100,000m^2 of hard standing, good road access, and a power supply for the ventilation fans. The unit would store 34,100 dry tonnes of wood chips.

Storage as chunks, billets or whole sticks

Consideration has also been given to the storage of wood fuel as chunks, billets or sticks. The reduced surface area in each case, and particularly the reduced cut area, is expected to experience lower respiration rates and dry matter losses.

A series of unventilated storage experiments was carried out in 1995 using cylindrical covered bins. These units, 3m high and 2.3m in diameter, had perforated floors to allow natural air circulation through the fuel bed. They were filled with 22cm long chunks or billets of SRC willow and poplar, prepared using a Patu III firewood processor. The experiment began in early March, and the bins were emptied in mid-November.

A parallel series of trials involved the uncovered storage in simple heaps of 10.05 tonnes of uncut poplar sticks and 9.40 tonnes of uncut willow sticks.

The findings are summarised in the table below.

Moisture content and dry matter loss for different crops and storage conditions

	Chunks and billets		Uncut sticks	
	Poplar	**Willow**	**Poplar**	**Willow**
Initial moisture content	49.7%	45.6%	49.7%	45.6%
Final moisture content	17.1%	17.6%	22.8%	21.4%
Dry matter loss during storage	11.9%	5.7%	15.7%	4.3%

In the case of both chunks/billets and uncut sticks, the physical properties of the fuel were preserved and a satisfactory reduction in moisture content was achieved (although the initial moisture contents were low for SRC). The variation in dry matter loss is not understood.

On-site drying

The main focus of the on-site drying work has been on a modified grain dryer approach. This would involve using air at 28°C above ambient from an air-blown cooler. The option has been studied both experimentally and by computer simulation. The latter was carried out using the program XBATCH, which was developed originally for grain drying and has been adapted for this study.

A small-scale bin trial was carried out in 1995 at Silsoe Research Institute. A cylindrical drying bin with a cross-sectional area of 0.38m^2 was filled to a depth of 0.8m with 49.2kg of wood chips (dry weight) with an initial moisture content of 38%. The bin was ventilated for 200 minutes at a constant air flow rate of 1.51 m^3/second/tonne dry matter, a constant temperature of 51°C and an absolute humidity of 94%.

The mean moisture content of the bed fell to 14.4% wb, and moisture content and temperature profiles showed the establishment of a well defined drying front that moved up through the bed over time. This front was 0.6-0.6m from the bottom of the bed by the end of the experiment. Below the drying front, mean moisture content was 5-10% wb. Above the front, mean moisture content increased sharply, to values in excess of 25% wb. The temperature profile mirrored the moisture content profile, and the lowest 0.5m or so of the bed had attained the drying air temperature of 51°C. Towards the top of the bed, where material was still being dried, the temperature fell sharply.

There was very good agreement between the experimental findings and the XBATCH predictions, which means that the latter can be used with a reasonable degree of confidence to predict the performance of the warm air drying systems envisaged.

The practical, on-site fuel storage drying system envisaged for Project ARBRE can store up to 720 dry tonnes of wood chips on a drying floor arranged in 20 bays, each with a floor area of 145m^2. The system is based on a bed depth of 2m, and can dry fuel from an initial moisture content of 50% wb to one of 15% wb in four days using air at 23°C. The throughput rate is six tonnes/hour.

Conclusions

The results of this project have allowed conceptual designs for the practical long-term storage and on-site drying of chipped wood fuel for Project ARBRE to be prepared on a reasonably sound technical basis. The capital and operating costs of these systems will be highly site-specific and cannot be estimated with any confidence at this stage.

2.4 Wood Fuel Standards

Report No: ETSU B/W3/00161/REP Publication date: 1994

WOOD FUEL STANDARDS

FEC Consultants Ltd

Background

Both forestry residues and the short rotation coppicing of willow and poplar show considerable economic potential as a source of wood fuel. However, one of the most significant difficulties in introducing wood-burning into the UK on a commercial or industrial scale is the perceived problem of fuel specification.

The value of wood fuel depends on factors such as moisture content and ash content, both of which have a major influence on effective heating value or net calorific value. However, wood fuel can come from a variety of sources and, because climatic conditions, harvesting and storage will vary geographically, the quality of the wood will also vary.

The need exists for a series of guidelines on wood fuel quality which can form the basis of supply agreements that are satisfactory to both suppliers and users.

Project Objective

- To establish a set of guidelines for wood fuel standards that is appropriate for use in the UK.

Methodology

The project has maintained links with other Department of Trade and Industry wood fuel projects. It is also involved a study visit to Sweden and literature searches for other Scandinavian Countries and North America.

Findings

Overseas experience

In Scandinavia and North America, where the wood fuel market is well developed, there is no common standard for assessing wood fuel quality, although all the standards applied use the measurement of moisture content as the basis for determining the effective heating value (net calorific value) of the fuel.

In most cases moisture is the only parameter measured. Ash content (dry basis) and the dry ash-free (daf) hydrogen content and gross calorific value are assumed to be constant for fuel from the same source. Full fuel analyses are only carried out on an exceptional basis, ie when there is disagreement on fuel quality, or when plant operational problems arise.

Numerous different formulae are used to compute effective heating value. All depend on subtracting the heat required to evaporate both inherent moisture and moisture formed from the oxidation of hydrogen in the fuel, from the gross calorific value of the fuel.

Recommendations for the UK

Moisture content

Fuel moisture content affects not only heating value but combustion plant efficiency. However, there can be difficulties measuring plant efficiency to the satisfaction of both fuel supplier and purchaser, and it is recommended that fuel purchase contracts should be based on the effective heating value of the fuel, calculated using the formula in BS 1016: Part 16: 1981, the derivation of which is given in BS 7420: 1991 - "Guide for the determination of calorific values of solid, liquid and gaseous fuels".

It is envisaged that all contracts between supplier and user will specify a maximum limit on fuel moisture content. If this is exceeded, the fuel will be rejected, or accepted without payment. The moisture content limit for large plant is likely to be in the 50-60% range: for smaller combustion plant and wood fuel gasifiers, the range will probably be 25-40%.

Particle size distribution

The size distribution of wood chip particles can also affect fuel quality and value, with the proportion of oversize and undersize particles being the most important factors.

To ensure the satisfactory conveying of wood fuel to and from bulk storage and to combustion plant feeding systems, chips should not be too long, and maximum acceptable chip length is determined by the type of conveying system in use. Small plants tend to use screw conveyors, while large plants use belt conveyors, and discussions with plant suppliers indicate an acceptable maximum chip length of 50mm for small plant rising to 125mm for large plant.

Small particles (fines) are less likely to have an effect on handling systems but could have a major effect on combustion and on the likelihood of heat exchanger surface fouling. Discussions with plant suppliers indicates that the maximum fines content should normally be between 10% and 20%.

These limitations mean that fuel screening is necessary. This can be carried out:

- by the fuel supplier, prior to delivery, thereby increasing the delivered price of the fuel;
- by the fuel user, which would involve on-site screening - and possibly comminution - equipment and an increase in capital, operating and maintenance costs.

It is difficult to determine the effect of particle size on the value of delivered fuel. There is no evidence from overseas to indicate any specific price variations relating to the proportions of oversized and undersized material, and discussions in the UK suggest that the required particles sizes could be supplied using minimum screening facilities at the point of use. The conclusions drawn is that particle size distribution analysis should only be carried out on an exceptional basis.

Load sampling

There is no universally accepted common method for obtaining wood fuel samples from load deliveries, and sampling techniques in Scandinavia and North America vary widely in terms of sampling frequency, point(s) of sampling in the load, and size of sample.

The number of samples taken in Scandinavia and North America varies between one and five per delivery. The accuracy of moisture content determination will increase with the number of samples, but work done elsewhere suggests that errors in excess of 2% are widely accepted and a "swings and roundabouts" approach needs to be adopted.

In the UK, the number of samples taken will depend on the level of accuracy required - and also on the practicality and cost of sampling and testing at individual wood-burning plants. Plant size will probably be the main determinant. While sampling can be done manually or mechanically, there is consensus that BS 1017: Part 1: 1989 "Methods of sampling coal" should be used as a guide.

Ideally, moisture determination should be carried out before the delivery vehicle tips its load. This means that testing must not take more than about 15 minutes. The currently accepted method of determining moisture content requires 24 hours, although test work using a combination of fluid bed drying and a microwave oven suggest that the required short time period may be an option in future. At present, the only way of rejecting deliveries because of excess moisture content is to apply a maximum limit on bulk density, ie on kg/m^3.

Pricing

The delivered fuel price would need to be agreed between user and supplier on the basis of:

- the supplier's costs, eg harvesting, comminution, storage and transport
- the supplier's profit requirement
- the customer's required rate of return on investment
- the price of competing fuels - fossil fuels or biofuels
- available incentives, eg the Non-Fossil Fuel Obligation scheme, for using wood as fuel.

2.5 Transport and Supply

Report No: ETSU B/W2/00399/REP/1 Publication date: 1996

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

Transport Studies Group, University of Westminster
Scottish Agricultural College

Background

Biomass offers certain advantages as a fuel: it is sustainable; its use will help to reduce pollutant gas emissions, ensure the security of UK fuel supplies and contribute to employment creation; and it can offer visual and wildlife benefits in the form of coppice crops and forestry.

The production and use of biomass also faces certain problems, notably the economic cost of supply and environmental issues relating to transportation and power stations. Some of these problems will need to be addressed by managing the operational logistics (transport, storage, handling) in an integrated way.

Transport is the key link in the biomass fuel supply chain, linking discrete activities such as harvesting, storage, handling and delivery to the power station. Transport arrangements will be determined by storage facilities at the power station, while factors such as vehicle size, transport distance and time spent loading and unloading vehicles will have a significant effect on transport cost. Road transport will nearly always predominate, accounting for up to 70% of total delivered fuel costs, depending on the biomass type under discussion.

Project Objective

- To present the options for supplying biomass-fuelled electricity generating stations with fuel of the right specification, in the right quantities at the right time from resources that are typically diverse and often seasonally dependent.

The report examines forest fuels, short rotation coppice (SRC) crops, straw, miscanthus and animal slurries. This summary focuses on the findings as they relate to forest fuels and SRC.

Methodology

To help investigate the supply chain as a whole, the project has developed a series of spreadsheet-based supply chain option models. These are designed to incorporate and cost in detail all the activities involved in the supply of fuel from harvesting to final delivery to a power station. The models have been developed for a range of different biomass fuels and provide details of:

- total delivered cost to power station
- the constituent components of total delivered costs and an assessment of how they accumulate along the supply system

- activity costs for each supply system - ie the contribution of each cost category to the total delivered cost.

Findings

Delivered costs

Forest fuel

Modelling has shown that the supply system with the lowest delivered cost at the power station is one in which unchipped residues are transported to the power station for centralised chipping and use. The costs of chipping have not been included in the model but, provided these remain below £5.00/tonne of dry matter, this system would still be the cheapest.

The system with the highest delivered cost of those considered is a terrain chipping system with double handling (at the source and at an intermediate storage location) and two road transport stages (from the forest to the storage location and from storage to the power station).

Short rotation coppice

The difference in delivered cost between the cheapest and most expensive supply systems modelled is not very great (13%) for SRC. The cheapest system is one that involves direct cut and chip harvesting and on-farm storage of chips prior to delivery to the power station. The most expensive system in terms of delivered cost is one in which whole sticks are harvested and then transported in an unchipped form to the power station for chipping and use.

Comparison with other biomass fuels

When the costs of different biomass fuels are compared, certain straw delivery systems are cheaper (around £28.00/tonne of dry matter for Heston bales) than forest fuel systems (£32-£37/tonne of dry matter). Short rotation coppice is the next most costly (£47-£54/tonne of dry matter), with costs about 50% greater than those for forest fuels. The reason is that growing costs are included for SRC whereas forest fuel is a waste by-product and the cost of growing this material is not borne by the biomass industry.

In all cases, the use of intermediate storage facilities with double handling and transportation adds 10-20% to delivered costs. However, the use of such stores is likely to be essential to the provision of a year-round supply of fuel.

The effect of road transport distance on delivered costs

Delivered costs are relatively insensitive to transport distance for most of the biomass fuels studied, including forest and SRC fuels. Modelling has shown that doubling the transport distance from an 80km round trip to one of 160km adds only 5-15% to the delivered costs. There are three main reasons for this:

- transport already accounts for 15-40% of delivered costs
- average trip speed is likely to increase as distances increase
- terminal costs remain the same, irrespective of transport distance.

Nevertheless, cost savings can be achieved by sourcing fuel from closer rather than more distant locations, and such savings may be crucial to the financial viability of the electricity generation scheme.

Transport systems

Factors influencing transport distance

The catchment area for the biomass, and hence the transport distance over which biomass will have to be moved, will depend on several key factors:

- the size of power station and the conversion technology used

- the crop yield achieved

- the proportion of land adjacent to the power station that is forested, or that is planted with biomass energy crops (SRC and miscanthus) or with crops that have biomass as a by-product (straw)

- the degree of competition for the crop or by-product.

Modelling the transport systems to meet power station requirements

Transport system requirements for biomass power stations have been modelled in terms of the number of vehicle deliveries (per day and per year); the maximum number of round trips per vehicle per day; the number of vehicles and drivers required; and vehicle kilometres travelled (per day and per year).

A 10MW coppice-fired power station would, for instance, require six vehicles and 24 vehicle deliveries/day, giving a total of 480,000 vehicle kilometres/year.

Environmental implications of biomass schemes

Although biomass offers a number of environmental benefits, there are negative environmental impacts that need to be considered. As well as the negative impacts of constructing and operating a biomass power station, these include the fuel consumed during harvesting, transportation, processing and handling; possible effluent run-off from stores; the fire risks associated with storage; the health risks associated with mould growth during storage; and the environmental impact of transportation - emissions, noise, traffic levels etc. The significance of these environmental impacts will depend on the specific location and the physical and human geography of the surrounding area. Public perception is also an important factor in the development of energy from biomass.

Conclusions

All the supply systems modelled in the report are plausible and have the potential to be used to provide fuel for power stations. It is critical that a balanced fuel supply strategy is adopted that is capable of meeting power station requirements in terms of quantity, timing and quality. In practice, minimising costs is not the only issue, and several supply systems are likely to be operated to ensure security of supply.

Report No: ETSU B/W2/00399/REP/2 Publication date: 1996

TRANSPORT AND SUPPLY LOGISTICS OF BIOMASS FUELS
VOLUME 2 - BIOMASS AND STRATEGIC MODELLING

Transport Studies Group, University of Westminster
Scottish Agricultural College

Background

This report is the second of two reports examining the transport and supply logistics of biomass fuels. It contains the biomass resource analysis and the strategic modelling of power stations in relation to resources.

Project Objectives

- To examine existing and potential biomass resources in terms of the total quantities available and their geographical distribution throughout Britain, and to consider seasonality of supply.

- To use strategic modelling to describe the distribution of the biomass resource in terms of its supply potential for power stations.

The report examines forest fuels, short rotation coppice (SRC) crops, various types of straw, and animal slurry. This summary focuses on the findings as they relate to forest fuels and SRC.

Findings

Resource distribution and availability

The total amount of forest fuel available was estimated in 1986 at approximately 2.3 million wet tonnes/year. Furthermore, forecasts suggest that total timber production, and hence forest fuel output in the UK will increase until 2025, so the estimate given is conservative. The harvestable yield may be only around 50% of the total resource.

Areas of concentrated production of forest fuel are the main conifer forests of the UK, which are located in upland and Western Scotland, upland Wales and relatively small areas of England - mainly the north and east. Broadleaved woodlands of all sizes also have the potential to contribute to any local demand for energy.

Short rotation coppice is not yet a commercial crop in the UK, so the estimate of 9.3 million wet tonnes is only a potential figure. The development of SRC will depend on the willingness of farmers to devote land to a relatively long-term crop and on the ability of SRC to outcompete, by a significant margin, the more traditional land uses associated with farming. Recent research into farmer attitudes (Report No: ETSU B 1322) suggests that the maximum level of take-up of SRC, given the prices likely to be paid by the energy market, is about 5% of the total crop and improved grassland area. The species involved are likely to be mainly willow and poplar.

Short rotation coppice can, in theory be grown on any existing arable or improved grassland, and production could be widespread, particularly on set-aside land on large arable farms in Eastern England. However, in reality, the crop will only be grown in areas in which power stations are established, and where farmers have entered into contracts with station operators and fuel suppliers. Large arable farms in Eastern Britain are considered best suited to SRC production and, under current financial regimes, the crop is most likely to be grown on set-aside land.

Both forest fuels and short rotation coppice are normally harvested in winter, depending on ground conditions and harvesting techniques. Both can be stored to maintain supplies.

Strategic modelling

The project has involved the development of a strategic modelling program that allows various factors affecting the number and location of potential power stations to be examined. The program can:

- alter the biomass resource data set to reflect different scenarios for resource availability
- change the catchment area around the power station from which the biomass can be sourced
- alter the size (MW capacity) of power stations to explore the effect on power station numbers and location.

The model assumes that each power station lies in the middle of a catchment area from which the biomass is sourced. Implied in this is that, once a catchment size has been defined, the power station constructed would be sized to consume all the resource available in that catchment, thereby avoiding transportation between catchments.

Calculating a “total tonnes/km” value for each catchment provides an indication of the “goodness of supply” and allows decisions to be made as to the order in which catchments should be allocated power stations.

Results of strategic modelling

Forest fuel

The potential forest fuel resource in Britain would be capable of fuelling approximately 200MW of electrical generating capacity. If a catchment area of 90 x 90km is assumed, the UK could support seven 5MW stations, three 10MW stations and three 20MW stations. These would be located in and around the most concentrated areas of forest fuel in Britain.

Short rotation coppice

The potential SRC resource in Britain would be capable of fuelling approximately 700MW of electrical generating capacity. However, this assumes an even distribution of the crop and it is more likely that SRC will be grown close to a relatively small number of power stations in the short term, probably in areas with significant proportions of arable land. The capacity would therefore be well below 700MW.

When the strategic model is run with a 90 x 90km catchment area, it produces twelve 5MW power stations, eleven 10MW stations and thirteen 20MW stations.

Conclusions

Significant quantities of several biomass resources, including forest fuels, already exist in Britain. In addition, large quantities of SRC could be produced. There is a marked variation in the geographical distribution and degree of concentration of these resources, which means that different solutions in terms of power station location and size will be needed for each resource.

The work has also demonstrated that there is sufficient biomass resource to achieve relatively low transport distances in supplying the fuel to biomass power stations in the capacity range currently being considered by power station developers. For example, in areas with a high concentration of forestry in Britain, a 20MW power station could be built that would be able to source sufficient fuel from within a 90 x 90km catchment area, ie a maximum transport distance of 64km.

Finally, the transport distance over which biomass resources would have to be transported depends on resource availability. This, in turn, is determined by demand from non-biomass users and the price they are prepared to pay, by annual production, and by other factors such as the willingness of farmers and forest owners to grow and/or supply biomass. Further work is required in these areas.

Although the project has achieved its objectives and contributed to the understanding of power station size and location in relation to the resource base, the findings do have their limitations because of the simplifying assumptions that have been necessary for the strategic modelling.

Report No: ETSU B/W2/00548/01/REP Publication date: 1996

UK INDUSTRY RESIDUE AND SRC BALING

Forestry Contracting Association Ltd

Background

A major cost element in supplying wood fuel from both forest residues and short rotation coppice (SRC) is transportation to the end user plant. Recent UK trials have indicated the potential for transporting uncomminuted residues, with the higher transport costs being offset by the much reduced costs of large-scale comminution at the end user plant. Recent trials in Sweden indicate that a substantial reduction in the costs of transporting forest residues can be achieved by compressing the residue first, using baling techniques. The combination of baling and large-scale comminution offers considerable potential for cost savings in the supply of wood fuel.

Project Objective

- To determine the potential for baling both fresh and air-dried forest residues and air-dried SRC willow bundles, and to ascertain the likely impact on transportation costs.

Methodology

Test baling was carried out in 1996 as follows:

Baled at landing:

- Clear-felled lodgepole pine:
  - freshly felled
  - air-dried over two working weeks.

- Air-dried willow coppice bundles.

Baled at stump:

- Clear-fell lodgepole pine, air-dried over two working weeks.

The main product of the lodgepole pine harvest was high quality white wood chips for chipboard manufacture. The residues comprised limbs, bark and tops collected from the output conveyor of a chain flail delimber/debarker and stock-piled. A forward-mounted Bala Press baler, incorporating an integral grapple, self-loaded the bale chamber with residue from the stock pile. The completed bales, 1200mm in diameter, were automatically wrapped in a layer of conventional “net wrap” (as used for straw bales), stacked, weighed, loaded and transported to a storage site.

Further tests at a different site involved baling fresh clear-felled Sitka spruce residues with a moisture content of 28%.

The bales were moved to storage in batches of 38 using a conventional 15 metre, flat-bed trailer. The highest percentage of maximum permitted load was achieved with wet lodgepole pine bales (94%). It should be possible to load 40 x 575kg bales with careful loading.

Baling must be considered as part of an integrated supply system that maximises the logistical and practical benefits in relation to transport distance. The study therefore examined system costs over 100km and 300km transport distances for three fuel supply options:

- residue baling of "wet" lodgepole pine at landing, with comminution at the end user plant
- chipping at the forestry landing followed by chip transportation
- transportation of uncomminuted and unbaled residues, with chipping at the end user plant.

Findings

Baling and baling costs

The results of all the trials are summarised in Table 1 below. Production costs were calculated per green tonne and per bale. They were based on the capital investment of the baler mounted on a carrier base, operating costs, including net wrap at £1.00/bale, labour costs and overheads. An element covering the risk and profit motive for the baler owner/operator was also included. The high cost of the net wrap (25% of baling costs) indicates that there is scope for developing/finding a cheaper alternative material to bind the bale.

The baler coped satisfactorily with the freshly felled lodgepole pine residues at landing, and the ability of the baler to slew to allow a multi-directional feed avoided the need to move the forwarder during feeding. Compression of the willow sticks proved less satisfactory. The very dry nature of the sticks resulted in the production of "log basket" bales with hollow centres, and bale weights were not economic.

Baling at stump also proved practicable, and the baler coped with ground conditions and terrain. However, baling at stump is not an economic option when extraction costs are added to baling costs.

Table 1 Results of baling trials

	No of bales in trial	Av. bale weight	Moisture content	Energy content	Productivity based on zero rest allowance		Costs based on 15% rest allowance		
		kg	(%) wet	MWh	gt/hr	bale/hr	£/gt	£/bale	p/kWh
Phase 1 - Landing									
Lodgepole pine, wet	70	569	35	1.77	11.40	20.00	6.94	3.95	0.22
Lodgepole pine, dry	25	391	23	1.56	7.40	18.90	10.69	4.18	0.27
Willow, dry	20	265	12	1.18	4.82	18.20	16.71	4.43	0.38
Phase 1 - Stump									
Lodgepole pine, dry	15	435	23	1.56	7.3	16.80	10.91	4.65	0.30
Phase 2 - Stump									
Sitka spruce, wet	31	484	28	1.71	8.69	17.95	9.06	4.39	0.26

Transportation and comminution costs

Transportation and comminution costs for the various fuel supply options are based on wet lodgepole pine residues at landing, and are summarised in Table 2 below.

Table 2 Transport and comminution costs of various fuel supply options

	Bale	Transport	Comminution	Total	
	£/gt	£/gt	£/gt	£/gt	p/kWh
System costs, excluding extraction, for a transportation distance of 100km					
Bale transportation, chip at end user	6.94	7.41	1.20	15.55	0.50
Chip at landing, transport chip	0.00	9.16	4.22	13.38	0.43
Transport uncomminuted residue, chip at end user	0.00	10.27	1.65	11.92	0.38
System costs, excluding extraction, for a transportation distance of 300km					
Bale transportation, chip at end user	6.94	10.87	1.20	19.01	0.61
Chip at landing, transport chip	0.00	13.40	4.22	17.62	0.57
Transport uncomminuted residue, chip at end user	0.00	17.18	1.65	18.83	0.61

The benefits of baling as distances increase are clear, with the costs of all three systems being almost the same at 300km. At these distances, the increased costs of baling are offset by the reduction in costs elsewhere. This makes it possible to consider both longer distance transportation and rail transport over large distances.

Report No: ETSU B/U1/00549/24/REP Publication date: 1997

UK INDUSTRY WOOD FUEL BALING MANAGEMENT AND LOGISTICS

Forestry Contracting Association Ltd

Background

A major cost element in the supply of wood fuel from both forest residues and short rotation coppice (SRC) is transportation from the point of production to the end user plant. Trials in 1996 (Report No: ETSU B/W2/00548/01/REP) indicated that the transportation costs of forest residues can be substantially reduced by using baler techniques to compress the residue prior to transport. While the industry supports the concept of baling forest residues and SRC, additional work is needed.

Project Objectives

- To test the concept of integrating centralised timber transfer and primary processing stations with baling operations and transport options to reduce transport costs.

- To establish the logistics and management practices involved in the introduction of baling into harvesting operations.

Methodology

The trial was carried out in two parts:

- Part 1 involved testing the role of baling at a centralised timber transfer and primary processing station. The station produces wood fuel, sawlogs and woodchips for forwarding to mills and fibre processing plants from poles, short wood and whole trees. Baling was carried out on short rotation willow and poplar coppice materials of varying age, diameter and moisture content.

- Part 2 involved the baling of 40 tonnes of Sitka spruce residues on forest roads and landings at a clearfell harvesting site.

A Bala Press baler was used for baling. This was skew mounted on an OSA 250 forwarder equipped with integral loader and grapple.

Bale transport was undertaken using a six-wheel Foden rigid timber transport lorry and trailer, with an integral load cell for weighing in its loader.

The baler operator picked up the materials to be baled using the integral grapple and dropped them on to the feed table. The completed bales, 1200mm in diameter, were automatically wrapped in a layer of conventional “net wrap” (as used for straw bales), before being removed from the baler, weighed and moved to the stacking area.

The moisture content of the material to be baled was analysed.

Studies were carried out to ascertain the time elements involved in baling, and to determine production costs, operating costs, labour costs and overheads.

Findings

Baling SRC material

The movement of SRC material to central processing sites for preparation prior to onward transport to the end user was shown to have very limited potential. The coppice material was transported via articulated timber lorries from the coppice collection site to the central baling depot, where it was stacked. The cost of this process, assuming a 100 km distance, is high at £10.37/gt (£20.74/odt). The baler worked along the rows of stacked coppice material, and the finished bales were then transported to the end user in batches of 30 by rigid timber lorry and trailer. The costs of baling (assuming a 15% rest allowance) and secondary transportation (assuming a distance of 100 km) were, respectively, £12.29/gt (£24.58/odt) and £7.41/gt (£14.82/odt). Total costs are therefore £30.07/gt and £60.14/odt.

Baling SRC material has problems:

- Large diameter poplar does not bale well: the diameter and length of individual pieces generates handling problems for the baler operator and slows down feed speed to such a level that baling is not an economic proposition.

- The flexibility of willow stems is such that the stems form an outer ring, forming the “log basket” effect: as a result cost-effective weights cannot be achieved.

Further work is necessary to establish whether there is any potential for introducing baling at the point of production, perhaps in a single cutting/baling process.

Baling as part of whole tree harvesting

The introduction of a baling element into the whole tree cable crane harvesting of Sitka spruce did not present a problem, and no logistical or management problems were encountered. The ability of the baler to move about the forest road and work in tandem with the processor enabled it to fit into the existing harvesting system with the minimum of disruption. However, space for stacking the completed bales proved limited, and this raises the need for an additional on-site transport element - unless the bales can be move directly away from the site to the end user. Additional on-site transport, moving the bales to, say, a lower unused landing, provides a case for introducing a low-cost, second-hand rigid lorry for bale movement only.

Conclusions

Overall, the project has established that baling technology is proven and reliable. Productivities in the 12-21 bale/hour range have been achieved, with bale weights varying between 340kg and 542kg, depending on the moisture content, type, size and degree of compressibility of the material baled. Bale density varied from a low of 254 kg/m^3 in willow to a maximum of 400 kg/m^3 for Sitka spruce. Production costs ranged from £9.99/gt (£22.7/odt) to £14.85/gt (£41.25/odt).

Former baling trials during harvesting have been of "hot" systems, ie systems in which the baler is directly dependent on the extraction and processing operations, and where an additional transport element is needed to keep roadsides clear for the stacking of industrial roundwood. If a "cold" system were to be operated, the baler could enter the site when cable crane extraction had finished. This would eliminate interdependence between harvesting systems, allow bales to be stacked beside the road for transpirational drying, and allow the baling unit to be mounted on a rigid lorry unit, thereby reducing the capital outlay. Furthermore, by locating two baling units on one lorry bed, productivity would improve and there would be a reduction in production losses. Balers mounted on lorry beds are easier to transport, and greater distances can be covered economically.

3. RELEVANT CASE STUDIES

Report No: ETSU B/1187 - P1 Publication date: 1989

MONITORING OF A COMMERCIAL DEMONSTRATION OF HARVESTING AND COMBUSTION OF FORESTRY WASTES

Ove Arup & Partners

Background

Large quantities of forestry residues are available in the UK in areas with a sizeable forestry industry. These can be harvested and used as a fuel, and represent a potentially valuable renewable energy resource.

In 1985, Fibroheat set up a commercial operation in the Grantown on Spey area. The operation comprised an integrated forestry residue harvesting and combustion project, with the steam generated being sold to the Tormore Distillery of Long John International under a utility contract. The project was monitored for the entire 1986/87 season, and the findings are summarised below.

Project Objective

- To harvest and chip forest residues, burn these plus chipped sawmill residues in a boiler plant, and generate sufficient steam to meet Tormore Distillery's steam requirements.

Findings

Woodchip harvesting

Fibroheat own and operate the woodchip harvesting plant. This comprises a Bruks 800 CT terrain chipper mounted on a Kockums forwarder. This can travel into the forest to harvest the residues, producing woodchips that are then transported to the combustion plant site at the distillery by a haulage contractor.

During the monitoring season, the chipper produced 3452 tonnes of fuel from forestry wastes and another 870 tonnes from sawmill residues. A further 907 tonnes of chips were purchased from sawmills. These figures compare with a predicted residue availability in the area of approximately 15,000 tonnes, and a boilerhouse demand of nearly 7000 tonnes.

The sites on which harvesting took place varied widely in terms of size, species of residue and distance from Tormore. The average amount of residue harvested was 34 tonnes/ha swept by the harvester, with spruce residues giving up to 88 tonnes/ha. However, because not all the sites were completely cleared, average recovered density measured against total site areas visited was only 20 tonnes/ha.

Time studies undertaken at all the sites visited gave the following results:

- Machine availability was 59%, with 65% of that time actually spent chipping.
- Chipping windrowed forest residues took 30% less time than terrain chipping.
- The static chipping of pre-harvested residues took 53% less time than terrain chipping.
- Chipping at a sawmill took 58% less time than terrain chipping.

The fuel consumption of the chipper and forwarder combined was found to be 6.7 litres/tonne of chips (approximately 3% of the net energy content of the fuel produced).

The average cost of hauling the chips to Tormore was approximately £4.00/tonne over a road distance of 40km.

The total cost of harvesting and delivering chips to the boilerhouse averaged £24.00/tonne (£2.72/GJ - net basis). Of this, the chipper unit (largely the amortisation of capital) accounted for 64%, haulage for 17%, labour for 14% and fuel for 5%. The cost of forest chips varied widely, from £19.00/tonne to £40.00/tonne. There was also a significant variation in cost/GJ (between £1.80/GJ and £4.90/GJ), with the adverse effect of chip moisture content being very significant.

Combustion operation

Fibroheat own and operate the woodchip handling and combustion plant, which is located at the Tormore Distillery.

Between October 1986 and June 1987, the boiler plant operated at an average load factor of 35% and produced 21,115 tonnes of steam, 70% from 5040 tonnes of woodchips, and the remainder from gas oil (because of the shortage of chips).

Monitoring showed that, despite the variable quality of the fuel, with chips ranging in moisture content from 30% to 60%, the plant achieved a high level of overall efficiency (67.5% gross CV basis and 82.8% net CV basis). Apart from a few minor problems, plant reliability was good, and average availability over the season was 98%. Furthermore, the environmental impact of the plant is likely to be minimal, particularly in relation to flue emissions: emissions of oxides of nitrogen and sulphur, unburnt hydrocarbons and smoke were negligible, as was the production of ash.

The boiler readily achieved its rated output of 15,000 lb/hour of steam from fuel with a 50% moisture content, although output did fall with moisture contents nearer 60%. Increases in fuel moisture content have a significant effect, increasing the bulk density of the chips, and reducing calorific values, boiler efficiency and available output.

Costs

The costs of the project are dominated by capital charges. Assuming normal financial criteria, fixed costs (80% of them associated with capital) account for 50% of the combustion operation cost.

The cost of producing steam during the monitoring period averaged £16.72/tonne, which is not competitive with production using heavy fuel oil or coal. This could be reduced to £14/tonne given a favourable fuel supply and improvements to the harvesting regime. The harvesting operation would benefit in particular from stronger management control and operator training. This would result in better site selection, improved liaison with felling contractors, and improved availability, machine utilisation and work load factor. Consideration should also be given to static chipping at a forest landing instead of terrain chipping. A further reduction in steam costs, to £10/tonne, could be achieved by increasing the steam load factor from 35% to 70%.

Future projects should be able to achieve steam costs of about £9/tonne by reducing capital costs through the design optimisation process. A steam cost of this order would be comparable with that achieved when producing steam from conventional plant burning oil at around 10p/litre or coal at around £60/tonne.

Report No: ETSU B/W5/00347/REP Publication date: 1993

ASSESSING THE GAME AND CONSERVATION VALUE OF WOODLAND MANAGEMENT ON THE DRAYTON ESTATE

The Game Conservancy Trust

Background

The Drayton Estate is one of the few UK organisations to use wood-chip-fuelled heating systems. Wood chips from a cheap local wood supply are supplemented by existing woodland resources within the estate, and coppice management is being reinstated to provide a future source of supply. In addition, a small trial area of short rotation willow and poplar coppice has been planted for assessment as a future source of fuel.

Proper woodland management can enhance numbers within various woodland butterfly and insectivorous migratory songbird species that are currently in decline. It can also enhance the value of an estate for pheasant shooting.

Project Objectives

- To assess the impact of current woodland management on wildlife and game.
- To assess the wildlife value of short rotation coppice (SRC).
- To assess environmental impacts relating to the storage and drying of wood chips.
- To recommend ways in which the wildlife value of the system could be improved.
- To assess opportunities for using SRC as game cover.

Methodology

Surveys were carried out in three existing woodland areas that have been used for wood chip production, and in the recently established biomass plot.

The botanical survey involved laying out quadrats in six areas of managed woodland and in neighbouring unmanaged woodland areas. All plant species growing in or overhanging each quadrat were recorded, together with the estimated area covered by each species. Similar quadrats, but without the control areas, were laid out in the biomass plot.

The songbird survey used the Common Bird Census method of mapping registrations over a number of visits during the spring and early summer to locate birds on their territories. Five 1ha plots were located, two in coppiced sections of existing woodland, one in adjacent unmanaged woodland, one in the SRC, and one in an unmanaged woodland area that included some coppice. Each plot was visited on eight occasions between April and July and the total number of bird registrations per species was calculated.

Seven transects, totalling just over 1000 metres, were established through managed and unmanaged sections of ride, coppiced areas and around the boundary of the SRC site. Butterfly counts were conducted on two occasions, at the end of May and in mid-July.

Pheasants were counted during three morning and evening sessions during March 1992 to provide an estimate of the number and position of territorial males and of the number of females associating with each male. In addition, the potential of the biomass plots to overwintering pheasants was assessed using a pheasant habitat suitability model. In July 1993, a professional Game Conservancy advisor visited the estate to assess the likely effects of woodland management on pheasant flying quality.

Findings

The botanical survey showed that the managed woodland areas contained a greater number of plant species and higher levels of cover than the unmanaged areas. The effects of management varied, depending on the degree of increased light penetration and previous site history. In general, there was an increase in woodland species associated with the early stages of succession, some increases in weed species, and a decline in shade-tolerant poorly competitive woodland species.

Woodland management increased songbird density, particularly along the borders of cut and uncut areas, and resulted in the introduction of new bird species to the woods, particularly migratory warblers. Butterfly populations increased in both density and the number of species after ride widening. The changes here and in the coppice plot were due largely to increases in grassland species.

The cutting of wood in the managed woodlands appeared to have increased the number of pheasant territories, again particularly along the edges of cut and uncut sections. The managed areas had been selected to improve the flying quality of pheasants on shoot days, and this appears to have been successful.

The SRC plot was heavily sprayed with herbicides, reducing its botanical interest. Ground flora consisted mainly of herbicide-resistant species and species with wind-borne seeds. Plant cover and species number was higher under willow than under poplar, and in longer established plots rather than in those established more recently. The plot proved moderately attractive as pheasant cover and for migrant songbirds, but the lack of any newly cut areas limited butterflies to the grassy areas surrounding the crop.

The study showed that the storage of wood chips is not associated with any pest or pollution problems and appears to be benign.

Conclusions

The overall conclusion is that woodland management has increased the number and density of species associated with the early stages of woodland succession. It has also improved the quality of the pheasant shoot. These benefits are likely to be extended as more woodland is brought under management and the cut areas regenerate to give a mixed age structure. Any further cutting will need to be carefully planned to maintain the quality of the pheasant shoot, with new cutting in strips in the direction of drive, uncut tall trees retained at the end of each drive, and priority being given to cutting the edges of woods to increase their attractiveness as pheasant habitat.

The SRC plot proved more attractive to game and wildlife than previous land use. New plots of this crop could provide a valuable pheasant habitat if planted away from existing woods and surrounded by a wind-proof hedge.

Report No: ETSU B/W5/00241/REP Publication date: 1993

ENERGY FORESTRY IN THE FOREST OF MERCIA

The Forest of Mercia

Background

The Forest of Mercia in Southern Staffordshire is one of the first three forests identified in the Forests for the Community programme, which was launched by the Countryside Commission and the Forestry Commission in 1990. The proposed forest covers about 23,000ha in an area comprising agricultural land, current and former coal and mineral extraction sites, and other industrial activities.

Within this context, the planting of short rotation coppice (SRC) appears to present a real opportunity for fulfilling many of the Community Forest objectives in terms of providing settings for recreation, sustaining farm employment, increasing the ecological value of farmland, and developing co-operation and partnerships. Furthermore, the development of better markets for wood fuel could help to provide an economic rationale for the better management of existing small and neglected woodland areas.

Project Objective

- To assess the constraints and opportunities for SRC within the Forest of Mercia area, and the possible mechanisms for developing production and markets.

Findings

The viability and likely nature of SRC in the Forest of Mercia

It is clear that SRC does offer a practical, alternative agricultural crop if markets and product are developed in tandem. It has also been shown that the kind of technological expertise or training necessary to produce the crop would put little extra strain on the modern farmer. Furthermore, the modifications required to existing machinery and storage would require little additional capital investment. Short rotation coppice is an agricultural crop, and the expertise of farmers will undoubtedly be the main driving force in its establishment.

There is real potential for the development of SRC within the Forest of Mercia area. There appear to be no constraints on its production across at least 30% of the area. Because of the nature of the landscape and land ownership, it will, in most instances, be most appropriately grown on a farm scale, in small blocks rather than in very large areas. Eventually, SRC might occupy up to a maximum of 20% of each farm, but conversion is expected to be slow, possibly starting off with 0.5-1.0ha trial plots.

Weaving SRC into existing landscape and farming patterns, rather than using it as a mechanism for radical change, is more likely to provide positive environmental benefits. It will be easier to accommodate within existing farm structures; there will be few implications for local hydrology; and there could be an improvement in water quality. There would also appear to be mutual benefits of linking SRC and sewage sludge disposal.

Given this scenario, it will almost certainly be necessary for harvesting, and possibly planting and management, to be carried out on a contractual/co-operative basis.

The kind of farmer taking up SRC production as a successful commercial venture is likely to be both entrepreneurial and flexible enough to take advantage of a range of value-adding exercises, from the incorporation of shooting and recreational activities through to marketing and even using the products. There will also be opportunities for the development of direct links with markets (eg a local school) and for the possible development of co-operative contract energy management.

Economic success will depend on entrepreneurial skills, on the ability to obtain sufficient grant aid; on maximising existing labour, buildings and machinery resources; on the establishment of guaranteed markets within an acceptable distance of the production area; and on developments in the relevant technologies.

Tailor-made local schemes for the supply of heat/hot water will be able to develop more quickly than national schemes, and there is a real need for local demonstrations of both crop and energy production to precipitate the necessary learning curve, particularly in relation to markets. The organisations and industries in the Forest of Mercia that have already shown interest are sufficiently well respected and well placed to become involved in demonstration projects and collaborative efforts.

Recommended Development Programme

The Forest of Mercia Project is already receiving considerable Government funding. Furthermore, many of the issues of utilisation, marketing and environmental quality that relate to wider forestry expansion are also very relevant to the development of SRC as a viable agricultural crop. It would therefore make sense to allow the already well established Project Team to expand its activities to include the promotion of SRC alongside other forestry and agricultural initiatives, and to encourage the development of a local network of growers linked to users.

Joint initiatives would be highly desirable:

- to encourage the take-up of SRC, in tandem, by both landowners/growers and the energy markets, and to stimulate understanding on the part of the general public

- to encourage energy users who are planning to change/renew their boilers to consider converting to wood fuel, and to make waste wood fuel available in the short term, where appropriate

- to establish appropriate links between growers and energy users, so that the latter are aware of the production process and become convinced of the real possibility for sustainable fuel supplies for the future

- to involve children in the development process, and to provide an appropriate educational programme.

The first phase should involve the development of one or more demonstrations, both for growing and for utilisation. Staffordshire College of Agriculture could handle both demonstrations and provide training and advice. An alternative would be to link a growing area with a local school to provide more public and educational interest. In addition, different farms might be able to demonstrate different aspects of development.

It will be important for the necessary expertise to be available. Some financial pump priming may also be required in the early stages of development.

Report No: ETSU B/M4/00532/10/REP Publication date: 1996

RENEWABLE ENERGY PILOT PROJECTS

West Wales Task Force

Background

The West Wales Task Force was set up by the Secretary of State for Wales in 1992. Its purpose was to combat the downturn in the economy resulting from the closure of local defence establishments. Its specific objectives were to strengthen and support existing businesses and business opportunities in the area; to develop skills for existing and emerging businesses; to encourage self-reliance; to secure effective land-use and infrastructure improvements; and to promote partnerships between Government departments, agencies and local businesses and organisations.

In spring 1995, a renewable energy audit was carried out in the West Wales Task Force area. This examined:

- the current extent of research into the conversion of biomass and natural elements into usable energy
- the working technology already in existence
- the financial, environmental and physical considerations essential to the establishment of actual projects
- the potential for new projects within the West Wales Task Force area.

The audit identified gaps in the knowledge and understanding of renewable energy and showed that this lack of understanding was affecting the possible take-up of renewable energy resources.

In 1996 a study of three separate pilot projects designed to bridge these gaps in the understanding of renewable energy systems was completed. This focused on three areas:

- wood fuel storage, handling and usage
- the composting of fibre from the anaerobic digestion of farm waste
- the establishment of an anaerobic digester kit.

This summary focuses on the first of these projects. The other two are discussed in a later volume in this series.

Project Objectives

- To assess the handling, storage and drying of wood fuel on a representative working farm.

- To examine the maintenance and operating requirements of the boiler unit installed.

Findings to Date

The project has identified a farming business prepared to participate in the project. The farm is a 230-acre dairy farm with approximately 33 acres of woodland. It is located a few miles north of the A40.

Marick International, a company specialising in the design and installation of gasification boiler units linked to electrical generators, believe the site to be appropriate for the installation of a 30kW gasification unit fired by forest waste, firewood and short rotation coppice. Electricity will be generated through a coupled generator set and fed into the milking parlour through the existing emergency generator switch gear.

The unit will require five tonnes of wood per week, and this will be bought in and tipped into a 30 x 15 foot bay of an existing shed. It will, if appropriate, be further cut to size and stored. A hopper adjacent to the boiler will be filled with wood every three/four days. This wood will be dried using surplus heat from the boiler and exhaust system, and will then be fed directly into the boiler.

The boiler will operate during the working day. The electricity generated will be stored:

- in ice banks in the dairy unit (required for cooling the milk)
- in existing conventional electric storage radiators in the farmhouse.

The project will be closely monitored and reported on until June 1998. The unit will then be decommissioned and returned to the installers from whom it will be hired.

Total costs are estimated to be just over £140,000, 85% of which are capital, hire and installation costs. Operating the unit is expected to cost more than £6000 over the two years; fuel will cost around £6750; and monitoring and reporting a further £6400.

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MONITORING THE PROGRESS OF NFFO-3 PROJECTS: SHORT ROTATION WILLOW COPPICE - AGRONOMY AND ECONOMICS

Sidney C Banks plc

Background

The EC's implementation of its set-aside programme, requiring arable farmers to set aside, on a rotational basis, 15% of their arable land, had serious implications for many farmers, and Sidney C Banks plc and its subsidiary company, Banks Agriculture, considered a range of possible alternatives, including industrial crops which emerged as strong contenders.

At the same time, prior to the third tranche of the Non-Fossil Fuel Obligation (NFFO) scheme, it was clear that there were companies looking at the possibility of developing biofuelled power stations based round the production of short rotation coppice (SRC).

Sidney C Banks plc therefore linked with South Western Power to act as their sole fuel supplier on projected biofuel wood power stations. Two such stations, at Eye in Suffolk and Cricklade in Wiltshire, were approved under NFFO-3 in December 1994. Willow was chosen as the SRC fuel crop, and recent proposals to grow SRC on set-aside land have been agreed by the EC. Crops will also be eligible for the Woodland Grant Scheme Establishment Grant. There is therefore considerable incentive for growers to establish this crop.

Project Objectives

- To establish a network of SRC growers to produce fuel for a NFFO project.
- To monitor the success of the enterprise.
- To implement a programme of constant improvement to optimise the fuel supply strategy.
- To provide valuable information about the performance of the SRC crop under large-scale commercial production.

Methodology

Commercial-scale trials were established at seven sites in the East of England - in Bedfordshire, Suffolk, Norfolk and Northamptonshire - in 1994 and 1995. The farmers approached were all innovative farmers, who recognised the potential of SRC as a new crop and were curious to see how it grew. The sites encompassed a wide range of soil types, altitude and climate, and included reclaimed gravel pits and flint quarries on the basis that future growers were more likely to plant on poorer land, thereby improving its fertility and/or drainage and increasing its profitability. The trials examined the whole range of production and supply issues and also assessed the environmental implications of SRC growth.

Prior to the NFFO-3 awards, Banks Agriculture actively recruited potential SRC growers in those areas where wood-burning power stations were expected to be built. Details of all interested parties were taken, and "Letters of Intent" to grow and supply SRC to Banks Agriculture were signed and collected. These, in theory, could have been turned into supply contracts once the NFFO-3 contracts had been awarded, and planting could have gone ahead immediately. In practice, no further progress was made in this area up to 1997 because of the current high profitability of arable farming and uncertainty over the building of the power stations at Eye and Cricklade. Growers were actively discouraged from becoming involved because of the volatile/non-existent nature of the wood chip market and the impossibility of guaranteeing any return on the crop.

Findings

The establishment of SRC willow requires a fine seedbed in which to plant the cuttings. Furthermore, a suitable weed control programme is essential and must begin during the autumn prior to planting. Weed control varies with soil type, but is crucial during the first two years of growth, with both the growth rate and the form of the willow being influenced by the level of weeds. By the end of the second year, the willow had outcompeted most of the arable weeds as a result of shading, competition for moisture and nutrients, and willow root growth. However, creeping thistle and nettles were major weeds that did continue to grow.

Plantation yield is heavily influenced by the choice of clone/variety. Decisions on clone suitability cannot be made on the first year's growth as growth rates and forms vary during the first 2-3 years. However, while a mix of varieties must still be used to reduce disease and insect pressures, new clones have been bred in the UK and Sweden during the last five years, and these either yield better or have better disease and pest resistance than those planted during the Banks Agriculture trials.

Yield is also influenced by the availability of moisture. The lower than average rainfall figures for Eastern England between April 1994 and April 1997, and the correspondingly low soil moisture levels, certainly influenced trial yields overall.

Self-propelled harvesting machines such as the Claas or Austoft proved to be the most reliable chip producers, and harvesting is probably best carried out as a contract operation. However, tractor-mounted forage harvesters are worth considering for those farmers with small areas of SRC who wish to carry out the operation in house.

If a power station is to be fuelled by SRC, it is most appropriate to use a cut-and-chip harvesting system to supply the wood relatively soon after harvest, and stick harvesting for the material that is to be supplied after a significant period of storage.

Transportation and handling costs may account for between 25% and 50% of the total delivered cost of the wood chip. These costs are highest where sticks are delivered to the power station for chipping. The handling costs of direct cut-and-chip systems are far lower than in stick-harvesting systems: stick bundles are difficult to handle and have a lower bulk density.

Conclusions

Prior to the NFFO-3 contracts, the economics of SRC production were based on plantations of more than 10ha. This scale of operation allowed farmers to use larger machinery for planting, spraying, cut-back and harvesting: it also reduced fencing and labour costs. The current situation is very different for three reasons:

- a lack of interest in developing specialised, modified or purpose-built harvesting and planting machinery because of the lack of a significant SRC market
- the reduction in set-aside levels between 1994 and 1996
- the upturn in the agricultural economic scenario over the same period.

Currently, the SRC plantations being developed are smaller in scale - usually no more than 2ha in size - and the economics of production at this scale have not shown that it is possible to produce cost-effective wood fuel that can displace either fossil fuel or bought-in wood fuel.

Furthermore, high establishment costs and an income-gap of four years between planting and the first harvest mean that SRC is not attractive to the majority of arable farmers in the areas around the NFFO-3 wood burning power stations. There are, however, niche opportunities for coppice-derived wood fuel to replace fossil fuels in small-scale local heating markets.

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THE FARM WOOD FUEL AND ENERGY PROJECT

R H and R W Clutton

Background

Short rotation coppice (SRC) comprises closely planted, fast-growing willow and poplar clones. The crop is coppiced one year after planting and is then harvested at intervals of 3-5 years. The harvested product consists of chips, billets or whole stems for use as a renewable fuel source for the generation of both heat and electricity. The crop is a substitute for fossil fuels and, being “carbon dioxide (CO_2) neutral”, can contribute to an overall net reduction in CO_2 emissions at the local, national and global level.

The Farm Wood Fuel and Energy Project was launched in October 1991 as part of the UK Government’s strategy to develop potential sources of renewable energy. Its specific aim was to break the “no market, no crop - no crop, no market” cycle that existed for SRC.

Project Objectives

- To demonstrate how SRC could be grown as a commercial farm enterprise that was economically attractive and environmentally acceptable.

- To develop and demonstrate energy markets for the SRC crop.

This report summarises the project’s main activities and findings. Report No ETSU B/W2/00199/REP summarises the ADAS findings on crop performance. An environmental monitoring report is currently in preparation.

Methodology

Five sites, plus a sixth reserve site, were selected from a large number of applicants. The sites were located in Cornwall, Devon (2), Somerset, Oxfordshire and Essex, and covered a range of farming systems and soil types.

Ten hectares of SRC were planted at each of the five main sites over a three-year period between 1992 and 1994. Yield assessments were undertaken on the poplar clone Beaupre and the willow clone *dasyclados*. Harvesting trials were carried out by the Forestry Commission and by Aberdeen University. Two storage trials examined the potential for conditioning the crop using cheap, low-volume fans. The growers themselves attempted to penetrate the energy market.

Findings

Crop production and yield

Growers made their own management decisions about how to grow the crop and hence developed different systems, many of which are now considered as "standard" by the industry.

There were wide variations in the productivity of the two clones for which yield assessments were made. The mean for both species was 7 oven dry tonnes per ha per year (odt/ha/year), with actual yields varying from 2 odt/ha/year to 15 odt/ha/year. Yields are expected to increase in subsequent harvesting cycles.

Growth and productivity was found to be affected by a range of factors including site exposure, climate, soil type (reduced yields in shallow soils, shorter crops on gravel outcrops), quality of cuttings, planting method, plant density, weed control (especially control of perennial weeds prior to planting and general weed control during the establishment phase), pest control (rabbits, deer, hares and squirrels all caused some damage) and disease. The highest standards of husbandry were required during the establishment year to ensure maximum productivity in subsequent seasons.

The costs of establishing an unfenced crop are around £1350/ha (exclusive of grant). The provision of rabbit fencing for a 4ha field costs about £2/metre and increases the total cost to around £1750/ha. The growers have already achieved significant savings over early indicative costs by developing the appropriate expertise and techniques. Costs are expected to fall further as the price of cuttings declines.

Harvesting and storage

Harvesting trials, using a range of mechanical harvesters, were undertaken by the Forestry Commission and by Aberdeen University. In the opinion of the growers, none of the systems used was considered to be ideal, and a range of problems was identified:

- the size and weight of the harvesters, which could result in soil compaction, difficulties in negotiating lanes and gateways, and high operating costs
- the inability of non-tracked machines to climb even shallow inclines
- the required size of headland and the associated damage and compaction
- rutting within rows
- transportation from the field.

Some crop areas were harvested by the growers using motor-manual methods (chain saws or clearing saws). These techniques were relatively expensive and, in some cases, regarded as "hard work", but they may be suitable for the small grower producing for home consumption.

The choice of harvesting technique (direct cut and comminution to the required size (chips or billets) or whole stem harvesting) will depend on the end user's fuel specification. Growers preferred whole stem harvesting because the crop can be left to dry naturally with the minimum of dry matter loss. They also recognised that double handling would increase costs. Storage trials showed that it was equally effective to "blow" or "suck" air through heaps of chips using low-volume fans. However, the degree of air movement is important: where air flow is inadequate, there are problems of heating, dry matter loss and spore production. Billets stored better than chips.

Market development

Initially the growers investigated the formation of farmer co-operatives for supplying energy markets. When this approach proved unsuccessful, they acted as individuals to develop both energy and non-energy markets for their crops.

Despite considerable effort, growers' attempts to penetrate the energy market were limited. One grower installed a heating plant at his farm; one won an ALTENER contract to develop heating systems in the South-west; and one developed a tractor-mounted SRC planter.

The growers and members of the project team were also involved in the preparation of a national marketing strategy for SRC. This advocated the replacement of fossil fuels equivalent to one million tonnes of oil each year. Although the strategy was not adopted by Government at the time, these activities did result in the creation and development of the trade organisation, British Biogen, which is following up many of the strategy strands developed in the proposed marketing strategy.

The inability of the growers to achieve more in the local heating market was attributed to lack of confidence in the systems and an unwillingness on the part of potential users to forego the convenience of fossil fuels. In addition, the overall price advantage of SRC fuel was too low: combustion units were several times more costly than fossil fuel burners, and the price of oil in the mid-1990s was very low.

Several growers entered bids for electricity generation contracts under NFFO-3 and NFFO-4, but were unsuccessful.

Some non-energy markets were developed for the crops, including cuttings, mulch, chipboard, hurdles and river-bank protection, but these were all small-scale.

Conclusions

- The project has demonstrated that SRC can be grown under normal conditions within a variety of farming systems, with growers developing commercially based, environmentally sound husbandry techniques that have driven down establishment costs.

- The project has shown that wood fuel has the potential to be competitive with fossil fuels.

- The project has been responsible for creating the industry trade association and its marketing strategy. It has also been the catalyst for other initiatives, eg improving public awareness.

- Harvesting and storage methodologies need to be re-examined, and methods for capturing a share of the energy market need to be reappraised.

Report No: ETSU B/W2/00199/REP Publication date: 1997

FARM WOOD FUEL AND ENERGY PROJECT - CROP PERFORMANCE MONITORING

ADAS

Background

Details of the project background are provided above in Report No: ETSU B/W2/00197/REP. ADAS was retained to provide assistance in selecting the five project sites, to monitor and record growers' activities in the production of short rotation coppice (SRC), and to observe the progress of crops in the field.

Project Objectives

- To demonstrate how SRC could be grown as a commercial farm enterprise that was economically attractive and environmentally acceptable.

- To develop and demonstrate energy markets for the SRC crop.

This report summarises the ADAS findings on crop performance. Report No: ETSU B/W2/00197/REP summarises the project's main activities and findings.

Methodology

Thirteen short-listed sites were visited, and five were selected on the basis of criteria agreed between all the parties involved in the project, including ADAS. These criteria were strongly influenced by the need for the sites to be demonstration farms. The sites chosen were ideal in terms of grower interest, location, access, variation in farm type, soil and climate, and opportunities for different types of market development. At the same time they were atypical of farming businesses in their locality. As a result, instead of using the five farms to monitor the impact of SRC on whole farm business, effects were modelled for several farm types.

ADAS monitored and recorded growers' activities in the production of SRC and regularly observed the progress of crops in the field.

ADAS recorded all items of income and expenditure and assessed the contribution of SRC to farm profit. Figures derived from the project sites were applied to typical farm enterprises in the modelling exercise referred to above.

Findings

Agronomy

Although the project has shown that SRC can be grown on a commercial scale within the South of England, the likely yield performance of the crop would at best have been marginal. There were several contributory factors:

- The crop was largely grown on a trial and error basis, and not enough was known about important aspects of crop husbandry at the outset.
- Water and nutrient levels can have a significant impact on production levels, and growing SRC on marginal sites with inadequate resources can result in uneconomic yields.
- The growers seemed to lack any economic motivation to produce viable crops.

Several agronomic lessons were learned:

- Considerable attention must be paid to detail at the establishment stage.
- On vulnerable sites, the crop must be protected from rabbits.
- The crop remains vulnerable to worsening pest and disease attacks.
- The advantages of cutting back poplar after Year 1 appear to be heavily outweighed by the disadvantages.
- Willow outperformed poplar in the longer term and, with the development of more and better clones, willow may become the more favoured species for SRC production.
- Mechanisation can give cost savings, but the opportunities are limited and are vulnerable to weather conditions.
- The economics of producing cuttings from extensive field systems is dubious.

Overall, there is a need to develop site/clone interaction and to improve general husbandry techniques.

Project site economics

The project provided no information on harvested yield or price. There was no proper harvesting operation to give useful yield estimates. No sustainable markets were developed for the product.

Differing levels of support for agricultural enterprises and SRC mean that the latter does not compete, in economic terms, with mainstream enterprises. It does compete on set-aside land because the options are more limited. However, the reduction in the set-aside figure from 17.5% to 10% in 1995/96 and to 5% in 1996/97 is encouraging farmers to think that set-aside will remain at low levels in the future. They are therefore wary of planting long-term crops with a limited potential, eg SRC, on set-aside land.

A farm-gate value for wood chips of £35-£40/oven dried tonne (odt) would, over the life of the crop, give a gross margin of about £100/ha/year.

Crop establishment costs fell by £568/ha over the three plantings. Spread over a potential eight harvests or 24 production years, this would increase the gross margin by £24/ha/year.

The crop integrates well with other farm enterprises in terms of labour and machinery use. Fixed cost requirements are low as the main operations are carried out by contractor.

Grant aid

All project sites received the maximum grant aid available to them at the time. This had a considerable influence on choice of enterprise size but did not necessarily coincide with the most effective use of the land or the most economic size of enterprise.

Whole farm economics

At current yield and price expectations (12 odt/ha/year and £38/odt), farmers growing SRC on mixed farms will normally have their income reduced. This is also true for the dairy farmer and the typical lowland cattle and sheep farmer growing SRC on arable land that is peripheral to the main enterprise, although the crop could relieve farmers of the management problems associated with cereals as a minor enterprise.

Cereal farms and general cropping farms, which tend to carry some livestock at low levels of intensity, might opt to minimise the livestock enterprise in favour of SRC, although this would also take some land out of arable production.

The future of SRC depends on the availability of a market with long-term price guarantees of at least £45/tonne. It will be influenced by changes in arable margins, and the medium-to-large-scale arable farmer’s perceptions of future set-aside rates. Farmers may also find it more appropriate to spread the risk, increase flexibility and maximise opportunities by growing SRC in conjunction with other biomass enterprises.

Farm diversification

Contrary to expectations, energy coppice does not seem to provide multiple land use opportunities, other than sporting, that can be widely exploited.