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SECTION 3

STRAW & PERENNIAL GRASSES AS ENERGY CROPS

PROJECT SUMMARY LISTING

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Report Ref: B/U1/00612/REP Publication date: August 1999

ESTABLISHING FUEL SPECIFICATIONS OF NON-WOOD BIOMASS CROPS

Rothamsted Research

OBJECTIVES

- To evaluate a range of herbaceous grasses for their agronomic attributes as biofuel crops and construct a list of the most promising species.
- To prepare an outline costing for the establishment and production of the species.
- To analyse the biomass for fuel specifications and ash characteristics.

SUMMARY

Plant species selected for study were chosen because they have attributes that make them potential energy crops. From the plot studies agronomic requirements and yield measurements were obtained. Outline costs of establishment and production excluding transport costs were used to select two species in terms of their overall suitability for long-term production. A third species was identified as suitable for short-term production situations.

Cost analysis was based on actual operations carried out on the crops, and used current prices for the operations and materials. These were obtained, where possible, from breakdown costs published in farm management guides. Costs of seeds and plants were obtained from specialist suppliers.

Biomass from five species was collected at harvest in 1998 and analysed for specific combustion qualities. The results are compared with the specification for a suitable fuel. Volatility and ash analysis determined their burning characteristics. Mineral content analysis provided information on flue gases. Methods used were generally based on standard BS 1016.

COST

The total cost of the project, £34,945, was met by the Department of Trade and Industry (DTI).

DURATION

5 months – March 1999 to August 1999

BACKGROUND

Energy from biomass presents a significant opportunity to widen the source base of UK renewable energy. It will create new uses for farmland. One crop, coppiced willow grown on a short rotation, is at the point of commercial exploitation.

However, reliance on a monoculture for primary energy source carries a significant risk from pests and diseases to the reliability of production. Also, in some areas it may have an unfavourable impact on the local environment.

Developing new crops as biofuels would serve to minimise these risks, improve the resource base and increase biodiversity. In recent years several plant species, particularly grasses, have been evaluated. Yields similar to those from coppice have been obtained which make them promising alternatives. However, there is a need to evaluate them further using criteria important to fuel crops.

THE WORK PROGRAMME

Using data from plot experiments established in 1993, the characteristics of each species were evaluated for its suitability as a biofuel crop. The criteria chosen for the evaluation were:

- Agronomic aspects of management.
- Cost of establishment and production.
- Yield of dry matter and seasonality of supply.
- Moisture content.
- Suitability in baled or chopped form.
- Fuel characteristics and ash analysis.

RESULTS

Conventional tillage proved adequate for establishing the species, either from plantlets or seed. However, plot-scale planting provides insufficient information to assess how appropriate methods are for field-scale operations. Furthermore, except for rye, planting occurred only in one year so seasonal influences were not tested.

In their first year the perennial grasses competed badly with weeds on account of their slow growth. The threat from weeds was greatly reduced in older crops because of rapid stem extension or the formation of a litter layer on the soil surface. Herbicides used in maize have been found suitable for use in the species studied. Low usage of herbicides once the crops were established reduces the cost of production and is beneficial to the environment.

So far, pests have not been a problem except in reed canary-grass where they are potentially serious. Disease was not found except for Barley Yellow Dwarf Luteovirus (BYDV) in Miscanthus.

The small plots of exotic species rare to Britain may not provide the best conditions for pests and diseases to develop.

In the rhizomatous grasses, no yield benefits came from applying nitrogen. The reason for this is the ability of these species to retain a large proportion of the nutrients applied in the rhizomes, and only small amounts of nutrients are exported in the harvested biomass. Nitrogen requirements for reed canary-grass and Spartina were not tested.

Miscanthus giganteus (M. giganteus), some varieties of switchgrass and Spartina all reached yields of 14-15t/ha/year of dry matter but M. giganteus produced more biomass overall than the other species. The yield of all the grasses exceeds those reported for short rotation coppiced willow in the UK.

There were differences between the species in the build-up in productivity. Reed canary-grass reached maximum productivity in the second year whereas M. giganteus and switchgrass require at least 4-5 years. No yield plateaux were found, except for rye and reed canary-grass, therefore yields of Miscanthus, Spartina and switchgrass may continue to increase.

The slow development of yield in perennial grasses is a drawback to achieving profitability in the short term. This is also true of short rotation coppice.

Crop lodging occurred from the fourth year in all species except Miscanthus. In Spartina, reed canary-grass and some species of switchgrass it was quite serious.

The optimum harvest date for the species was not determined. This is because at the start of the experiments there was insufficient knowledge about their growth characteristics in the UK environment.

In flowering varieties senescence starts at the completion of flowering and results show that in switchgrass early flowering types have lower yield. Early senescence can improve the quality of biomass by providing more time for drying and for minerals to leach out. However, some biomass is also lost.

The experiments have shown that species cannot be selected solely on yield. The cost of establishing the heaviest-yielding species, Miscanthus, prevents its selection as the best choice. At present it will cost about £1000 to establish a hectare of Miscanthus using nursery produced stock compared with about £200 for switchgrass. However, at the current commercial price for rhizomes it would cost £4000-£6000 to plant a hectare of Miscanthus at two rhizome pieces/square metre.

All the species of perennial grasses are suitable as alternative fuels having similar combustion and ash characteristics to straw. With the exception of M. giganteus all the species had an initial ash deformation temperature in excess of 1100°C.

CONCLUSIONS

In conclusion, on the basis of this study switchgrass is the most favourable option with low input costs and good yield. Miscanthus, although having higher yields than switchgrass suffers from high establishment costs and a higher moisture content. If these could be reduced it would be a viable alternative. At present, Spartina offers few benefits over Miscanthus and less is known about how to grow it. Furthermore, it may suffer more weed and lodging problems. Reed canary-grass is potentially useful for short-term production, but pests and problems from lodging and possibly volunteers need to be overcome. Reed canary-grass biomass quality can also be reduced by green shoot contamination. Enough is probably known about how to grow rye without the need for further work. However, if full costs are included it is unlikely to be profitable at £30/t dry matter.

POTENTIAL FOR FUTURE DEVELOPMENT

Establishment cost is the key problem with Miscanthus. The following actions could address this:

- Establish nurseries for Miscanthus rhizome propagation.
- Set up experiments that will identify the best methods to maximise rhizome productivity and rhizome recovery.
- In parallel, set up experiments to determine rhizome size, planting depth and planting density for optimal yield.

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ELY STRAW PROJECT: DEVELOPMENT ISSUES OF A GENERIC NATURE

Energy Power Resources Ltd (with Abel & Imrie, Silsoe Research Institute, Northern Straw, Lawrence David Ltd)

OBJECTIVE

- To develop and trial equipment to overcome generic problems associated with the storage and transport of baled straw for use as a biofuel. Notably these include the need to accurately measure the moisture content of the harvested crop, to economically prevent moisture ingress during storage and to restrict nuisance of fly borne material during transport.

SUMMARY

There exists the possibility of utilising a proportion of the UK's straw crop for renewable energy. It would be possible for straw to produce 1% of the UK's energy requirements.

However, at present there are a variety of generic problems associated with the transport and storage of baled biofuels, including straw and as such this report was commissioned to look into the following:

- Development of a moisture probe.
- Development of a modular bale Stack Covering System.
- Assessment of stack and HGV hard standings.
- Development of a HGV vehicle covering system.

COST

The total cost of this project was £91,000 with the Department of Trade and Industry (DTI) contributing £45,500 and EPRL the balance.

DURATION

21 months – April 1999 – December 2000.

BACKGROUND

The UK produces around 15 million tonnes of straw each year of which approximately one half is used for animal feed and bedding. A renewables industry based on straw could utilise the remaining half for energy production and provide up to 1% of the UK's energy requirements.

Energy Power Resources Ltd (EPRL) have a 36MWe, 200,000tpa, straw fired power station at Sutton near Ely, Cambridgeshire. This is the UK's first and the World's largest straw fired plant. The principle fuel being cereal straw, delivered in large Hesston bales, each weighing 0.5 tonne. Fuel deliveries to the plant have been contracted for a period of 13 years to

Anglian Straw, a subsidiary of EPR Ely. Anglian Straw is the UK's largest biofuel logistics company with a responsibility to overcome the following fundamental problems, which inhibit the development of the industry.

The moisture content of baled biofuel is measured in the field, using hand held devices originally intended for use with hay. The density and moisture levels encountered in Hesston bales are typically so far removed from the original hay calibration set points that they are effectively outside the range of these instruments and inaccuracies of up to 50% are not uncommon leading to the unnecessary rejection of potentially acceptable biofuel.

Historically grain from cereal crops has been the farmer's main source of income and there has been both little income from straw and an unwillingness to invest in long-term infrastructure, such as storage barns. The general practice has been therefore, not to protect harvested straw from the elements and not to cover loads during transport. The result is a biofuel wastage rate of between 10% and 20%, as the top and some bottom bales of large straw stacks are deemed unfit and have to be discarded.

Traditionally, the farming community has viewed windblown fly straw as an inevitable consequence of straw transport. Whilst it may be acceptable on short rural journeys, the nuisance rapidly becomes dangerously intolerable on trunk roads and motorways.

If the UK is to achieve this Governments objective of a 10% contribution from renewable energy by 2010, it is clear that biofuel utilisation will have to increase substantially and the cumulative impact of this wastage will be significant and unacceptable.

THE WORK PROGRAMME

If straw or similar energy crops are to be fuels for the future, then there exists a definite need to develop the following solutions:

- The design and development of a robust and accurate moisture gauge, specifically engineered for determining the acceptability of baled straw and other energy crops after harvest. To minimise the level of biofuel rejected both in the field and at the point of use.
- A cost effective, portable and reusable system of bale stack roofing to protect harvested biofuel, during storage, from rain ingress considerably to minimise the number of bales rejected in the field.
- A cost effective, portable vehicle and stack hard standing system to protect harvested biofuel from ground moisture penetration, helping to minimise the number of bales rejected in the field. To also provide a stable, dry platform not only for stack construction but also for HGV access to wet and boggy fields.
- An 'easy to use' load covering system for HGV delivery vehicles and trailers. To minimise the level of nuisance of fly blown material produced during transit, making the road transport of greater tonnage over longer distances more acceptable.

For each of the above tasks, market research was carried out to identify the problem and to help with solutions. Trials were then carried out on a prototype, where appropriate. Then a final costing was produced for each item.

RESULTS

Development of a Moisture Probe

Results of the test work indicated a significant over evaluation of moisture particularly at the straw rejection level of 25%, for all three probes the error levels were found to be large; typically 4 to 5, and at worst greater than 10, percentage points.

Of the three meters the Delmhorst probe was the most accurate over the ranges tested and Protimeter the worst, although there was little to chose between them. When asked to assist in upgrading their meter only Protimeter offered to recalibrate.

After development of a modified meter by Protimeter, it was demonstrated that improved accuracy of +/- 1.3 percentage points was possible under most conditions. This improved accuracy will dramatically reduce the rejection rate of bales in the field.

The current price of hand held moisture meters is in the range £250 to £300. The price estimate for a new Protimeter is likely to be in the range £300 to £350, although this very much depends on what the market is prepared to pay and the volume of sales likely to be generated. The manufacturer may undertake further modifications and further testing to finally establish the retail price of a commercial version of the product.

Development of a modular bale Stack Covering System

Anglian Straw developed a number of concept designs in a range of materials with a number of specialist suppliers. The most promising combination was selected on lowest expected cost and produced in small numbers for the initial field trial and a further set of 40 produced for the large stack trial at Polebrook Airfield. These consisted of a set of wooden framed shapes, built in tiers that would sit on the top row of bales and covered with a plywood material to form a temporary roofing structure.

The final design of stack covering system has proved its ability to maintain a drier stack. The large 2000 bale straw stack at Polebrook Airfield, at a time of extreme wet weather and flooding, has reduced the amount of lost straw from unprotected stacks by 25%. This represents a substantial saving in the circumstances.

Improvements identified as a result of the field trials, were incorporated into the final design. The future retail price of a commercial version of the equipment was considered and it was concluded that such a covering system should cost less than £1.00 per bale, recoverable by the sale of the straw that would otherwise have been lost; with the potential at the farm of a 5% increase in revenue.

Assessment of Stack and HGV Hard Standings

It was established that there were no suitable cost effective solutions for stack bases, readily available, that would adequately prevent groundwater penetration.

Experience this year has shown that hard standing for a HGV and trailer would be required from mid-autumn to the end of spring, covering a period of 32 weeks. As a precautionary measure this may be considered as a requirement every year, although to keep costs down the trackway would not be hired until it was absolutely necessary.

Because of the high cost involved and the difficulty in obtaining a suitable system the field trial stage was not going to be undertaken. Extreme wet weather in 2000, however, forced the issue and out of desperation to supply straw to the power station a system had to be selected. The only available system that was deemed adequate for the task of proving a suitable access and hard standing was the Eve Trackway system (essentially a set of thick, heavy-duty aluminium sheets measuring 3m x 2.5m each).

Results to date have shown that apart from three difficult locations, where the bale loader cannot be used, all available straw has been collected. The cost of hiring and using the equipment for the 32-week period would be £33,600 and the saving in fuel recovered £28,200 giving a net cost to Anglian Straw of £5,400. This may seem expensive but has been essential this year to ensure continued operation of the power station.

Development of a HGV Vehicle Covering System

Northern Straw investigated the feasibility of a simple netting concept to identify if nets can be manually or mechanically handled to effectively cover loaded bales for transit. A close weave nylon material was decided on to suit both applications.

Anglian Straw proceeded to design a semi-automatic 'curtain sided' load covering system, with the specialist vehicle body-builders Lawrence David. This entailed the purchase of a suitable HGV tractor and drawbar trailer combination and the fabrication and fitting of the proposed load covering system. At the same time Andy Knight, of Silsoe Research Institute, designed a simpler manual system that could be placed on top of the vehicle, or trailer load, and manually strapped to the side of the transporter. A time constraint of 40 minutes for load restraining and netting was imposed for both systems, with a target of 25 minutes, if achievable.

The manual system was found to be slower than the semi-automatic system but preferred by hauliers for a number of reasons. The heavy, tilting rack at the end of the trailer section reduced fuel consumption by 2mpg, from approximately 10 to 8mpg, during the return journey, due mainly to the extra drag incurred. Further the risk of the winch jamming was seen as a major problem since it meant that the vehicle and trailer could not be used, incurring additional costs. The target time of 40 minutes was met with the semi-automatic system, average 35 minutes, but not with the manual system, average 43 minutes.

The semi-automatic system requires a capital investment of £156,270, which can be spread over the life of the transport vehicles. The manual system requires a capital investment of £27,200. Both systems will require new nets every year due to damage by overhanging branches at a cost of approximately £13,600. The initial capital investment was a further reason why hauliers preferred the manual system.

CONCLUSIONS

Existing moisture meters have inherent inaccuracies and require careful use if used for important measurements such as rejection levels. An acceptable recalibration of existing meters can be achieved and modified meters produced at an acceptable price.

A cost effective, portable stack covering system can be produced that provides an increased quantity of acceptable dry bales.

Hard standing exists for both stacks and HGV vehicle access to stacks but these are expensive and only of value at times of extreme wet weather.

The covering of transported straw bales can be achieved at a reasonable price and a manual system of sheeting appears to be the method most acceptable to hauliers.

This project has served as a practical demonstration:

- To the renewable energy industry and the farming community, of cost effective equipment to more accurately gauge the moisture level and acceptability of stored straw bales.
- To the farming community, of low cost portable equipment to successfully store baled straw on a commercial scale in the field.
- To the transport logistics industry, of a system that complies with requirements and does not result in wind borne fly material during transit and helping to minimise an obvious area of fuel waste.
- To provide continued access to good quality fuel throughout the year.

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EVALUATING GRASSES AS A LONG-TERM ENERGY RESOURCE

Rothamsted Research

OBJECTIVES

The main project was a continuation of previous projects monitoring yield and quality of various biomass species planted at Rothamsted between 1993 and 1997. The objectives of the project were as follows:

- Monitor crops for the presence of pests, weeds and disease.
- Measure biomass production and compare yields with previous years.
- Analyse mineral content of harvested biomass.
- Monitor nitrate leaching under mature Miscanthus.
- Investigate the causes of lodging in switchgrass.

Grasses monitored in the project were:
- Miscanthus grass (*Miscanthus x giganteus, M. sinensis, and M. sacchariflorus*)

- Switchgrass (*Panicum virgatum*) and a closely related species, coastal panic grass (*Panicum amarum*)

- Reed canary-grass (*Phalaris arundinacea*).

SUMMARY

This report covers the experimental programme carried out between 2001 and 2002. For completeness key results from the growing season for the year 2000 are added for comparison. These are from an interim report completed in November 2001.

Also in the report are the results from two subsidiary studies conducted during 2002. These are:

1. The potential to establish Miscanthus from seed.

2. Investigating reasons for the poor establishment of mechanically harvested rhizomes of Miscanthus x giganteus.

The crops were mostly planted in 1993. Some were found to be unsuitable and eliminated in 1996 and 1999.

Three perennial rhizomatous grasses (Miscanthus x giganteus, switchgrass and reed canary grass) were evaluated over the ten years of the project, and found to have potential for commercial biomass production.

Miscanthus had the highest biomass yield overall, but also the highest input cost because it is established from rhizomes, which are expensive to produce and store. Switchgrass and reed canary grass are established from seed at approximately 10% of the cost of planting.

The yield of Miscanthus increased for several years and was higher in the tenth year than in any previous year. No significant response to nitrogen

fertiliser was found, and the difference in total production over the ten years at the end of the study was only 5.8% between the highest and lowest yielding nitrogen treatments.

Switchgrass increased in yield for 5-6 years depending on the variety and then yield declined slightly until the ninth year. There were differences in yield between varieties, but nitrogen fertiliser did not affect yield.

Reed canary grass had the highest yield of the three species in the first and second year, but yield was lower in subsequent years. Because the species was grown in an observation plot yield cannot be directly compared to the Miscanthus and switchgrass grown in replicated plots.

Pests were not a problem in Miscanthus or switchgrass but stem borers occasionally damaged reed canary grass in the spring. Disease has been seen at low levels in all the species. Weed control measures were essential during crop establishment but herbicide requirement has been low in subsequent years.

Lodging occurred in all species, and is a potential problem in some varieties of switchgrass and in reed canary grass but was never serious in Miscanthus.

The results show that Miscanthus can maintain yield over a period of years, which is necessary to recover establishment costs and become profitable. Switchgrass also maintains yield but careful selection of varieties is required to maximise yield and minimise the risk of lodging.

Reed canary grass may be suitable for short-term production possibly as part of a rotation of crops, but further evaluation is necessary.

COST

The total cost of the project, £101,292, was met by the Department of Trade and Industry (DTI).

DURATION

28 months– January 2001 to May 2003.

BACKGROUND

The initial experiments were established in 1993 and conducted in collaboration with ADAS and the Camborne School of Mines, and ran for three years. There were replicated field experiments of: *Miscanthus x giganteus*, *Miscanthus sinensis* 'Goliath', switchgrass (*Panicum virgatum*) including a panic grass (*Panicum amarum*) , Sorghum (*Sorghum vulgare saccharatum*) 'Korrall' and Reed canary grass (*Phalaris arundinacea*), Whole crop rye (*Secale cereale*) 'Amundo', Wheat (*Triticum aestivum*) 'Maris Widgeon', Maize (*Zea mays*) 'Leader', and Triticale (*x Tritcosecale Wittmack*) 'Purdy'.

The growth of a number of the species was observed in unreplicated plots. The purpose of the unreplicated plots was to identify species that grew well enough to justify larger scale studies. The species were: Cordgrasses (*Spartina pectinata* and *S cynosuroides*), Japanese millet (*Echinochloa frumentacea*), Small globe thistle (*echinops ritro*), Jerusalem artichoke (*Helianthus tuberosus)*, Sudan grass (*Sorghum vulgare sudanese*), Reed canary grass (Phalaris arundinacea), Phragmites *(Phragmites australis*), and reference plots of Willow (*Salix alba*) 'Bowles hybrid' and Poplar (*Populus nigra*).

Species were not planted at all sites and details and results are presented in the final report, *Quantifying biomass production in crops grown for energy* (1996). ETSU B/CR/00387/00/00.

Many of the species were novel and there was no previous experience of growing them for biomass production. Some of the species grown at Rothamsted in observation plots were eliminated because the yield of biomass was too low (sudan grass, sorghum, millet and globe thistle) or biomass was too wet and frost caused it to rot (artichoke). The yields of these species are presented in figure 1.

Evaluation continued at Rothamsted during the period 1996-1999 on Miscanthus x giganteus, switchgrass, rye and observation plots of reed canary grass, spartina grass and perennial rye as a new introduction. Harvest samples were analysed for mineral content and results presented in *Monitoring growth and yield of crops grown as biofuels*. (1999) ETSU B/W2/00548/11/REP.

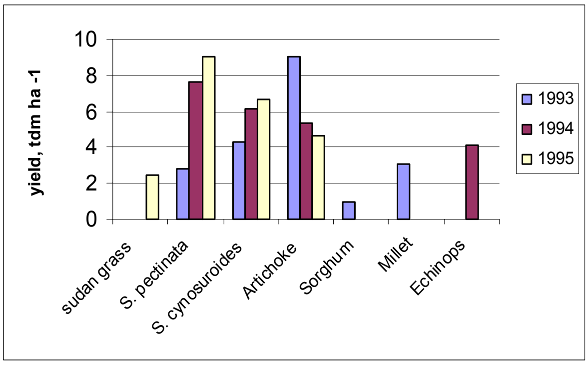

Figure 1. Yield of some species grown in observation plots at Rothamsted that were eliminated as unsuitable.

Rye, perennial rye, *M. sinensis* 'Goliath' and *Spartina* were also not selected for further evaluation. Rye had the highest dry matter content because it is harvested in summer but harvesting at this time could be a disadvantage by coinciding with grain harvesting activities and the cost of production is high due to annual planting and higher inputs of fertiliser compared to other species. Perennial rye deteriorated over time probably as a result of the infrequent cutting and it was not possible to harvest this species without some green leaf contamination. Spartina grass had high productivity but was seriously affected by lodging in later seasons. The species judged to have the best attributes were M x giganteus, switchgrass, and reed canary grass and evaluation of them continued so that the production profile over ten years could be measured. The production profile is important particularly with Miscanthus, which is expensive to establish.

THE WORK PROGRAMME

The aim of the project was to determine the suitability of a number of plant species as biofuel crops. In particular the yield of the crops and their quality as fuels were investigated. Since some of the crops were perennial, the project was conducted over ten years to determine the long term yield profile of the crops

Selection criteria were chosen to evaluate individual species on the basis of practicality and yield, and the criteria were as follows:

- Ease of establishment
- Length of the growing season and harvest time
- Incidence of pests and diseases.
- Fertiliser requirement
- Biomass production
- Dry matter content at harvest.

RESULTS

YIELD PROFILES OF THE SPECIES OVER TEN YEARS

Miscanthus x giganteus

Plots received no N, 60kg ha^{-1} yr^{-1} or 120kg ha^{-1} yr^{-1} as cumulative treatments. The plots were first harvested in the winter after planting in 1993. Biomass production was low but increased each year between 1993 and 1998 (Figure 2). Yield dipped in 1999 and 2000 compared to the previous years and in 2001 and 2002 biomass production was greater than at any previous harvest. There was no response to nitrogen fertiliser except in 1999 but this result is thought to be due to an anomalous value. The total amount of biomass harvested over the ten years was 126tdm, 120tdm and 127tdm for the no N (control), N60kg ha^{-1} yr^{-1} and N120kg ha^{-1} yr^{-1} treatments respectively.

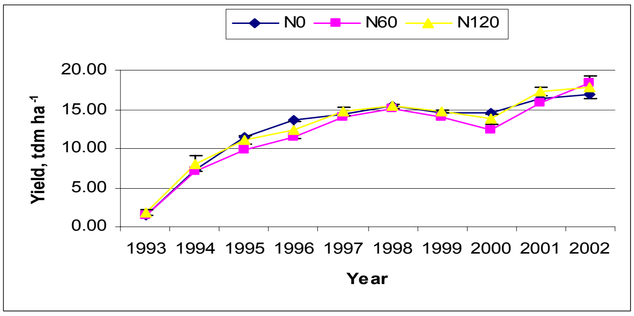

Figure 2. The yield of M x giganteus and the effect of nitrogen fertiliser, 1993-2002. Yield values are for the standing crop and do not include litter.

The difference in total production of the highest and lowest yielding treatments was only 5.8% and not statistically significant (SED 3.79df 4).

Switchgrass

Switchgrass had two nitrogen treatments, N0 and 60kg N ha^{-1} yr^{-1} applied as a cumulative treatment. No response to N was found except for one variety in one year, again probably an anomaly. The yield of varieties increased for 5-6 years but then generally declined until 2001 (Figure 3). Dacotah had the lowest yield every year because it has a shorter growing season than for example, Cave-in-Rock or Kanlow. The panic grass (APG), a species with close similarities to switchgrass, generally had the heaviest yield but its long growing season resulted in late maturity

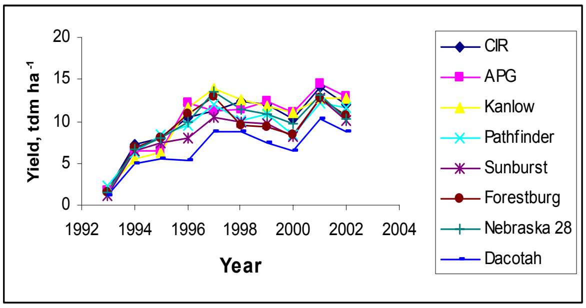

Figure 3. Yield of different varieties of switchgrass and panic grass (APG), 1993-2002.

and high moisture content at harvest. Cumulative yield for the ten harvests ranged from 66.82tdm ha^{-1} for Dacotah to 99.9tdm for Kanlow. The heaviest yielding varieties tended to have the highest average moisture content (Figure 4). The productivity profile of switchgrass is the same as Miscanthus (Figure 5).

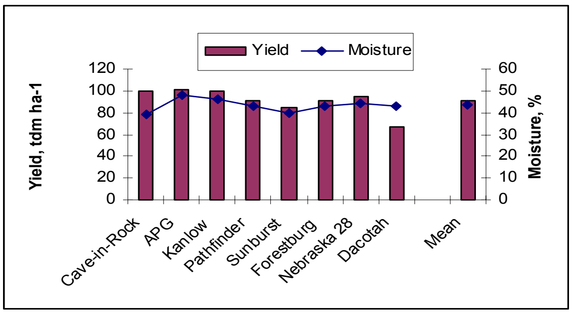

Figure 4. Cumulative yield of switchgrasses and panic grass over ten years and the average moisture content at harvest.

The yield of reed canary grass in the first and second year after planting was higher than Miscanthus or switchgrass but in subsequent years it was lower than the others (Figure 6). Because yield was measured on an unreplicated plot it cannot be directly compared with the other species. The plot received N60kg ha^{-1} yr^{-1} and this may have been inadequate for maximum yield, as it is known to respond to high rates of nitrogen when grown for forage. In 1997 and 1998 stem borer damage to early shoots and competition from weeds in 2000 may have contributed to the lower yield.

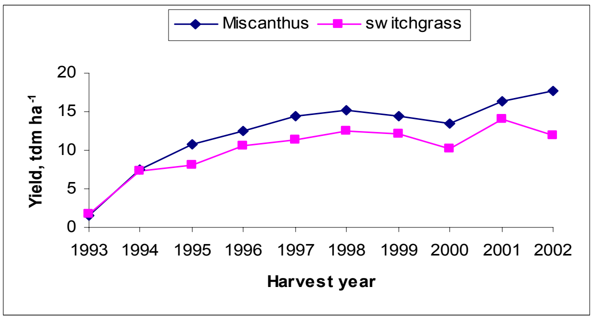

Figure 5. Productivity profile of Miscanthus x giganteus and switchgrass cv Cave-in Rock over ten years.

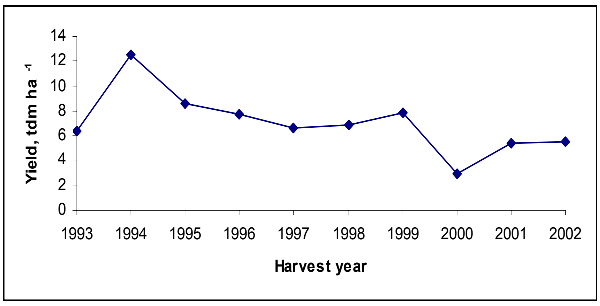

Figure 6. Yield of reed canary grass, 1993-2002.

Miscanthus had the highest productivity overall and highest input cost because it requires vegetative propagation for establishment. Switchgrass and reed canary grass are established from seed at approximately 10% of the cost of planting Miscanthus. The dip in yield particularly in 2000 was measured on all the species. This cannot be age related and is probably due to environmental factors.

All three species are perennials therefore planting costs only occurred once.

CONCLUSIONS

- M x giganteus, switchgrass and reed canary grass established well in this evaluation but other experiments have indicated that problems might occur as a result of using rhizome from old plants or planting in dry or coarsely aggregated soil.
- Miscanthus produced more biomass than switchgrass and reed canary grass but it is more expensive to establish.
- Nitrogen fertiliser did not improve the yield of Miscanthus or switchgrass but N response in all three species requires testing on less fertile soils.
- Weeds can be competitive during establishment but herbicide requirement was low in subsequent years. A range of herbicides commonly used in cereals and maize were used without harm to the crop plants.
- Pests have not been a problem in Miscanthus or switchgrass but stem borers damaged reed canary grass in several years and could be potentially serious.
- Disease has not been found at levels likely to affect yield. Barley Yellow Dwarf Luteovirus (BYDV) was identified in Miscanthus and sharp eyespot (*Rhizoctonia cerealis*) in switchgrass.
- All species have combustion characteristics that make them suitable for use as an alternative fuel in a modern industrial straw-fired boiler.
- After ten years Miscanthus continues to have a high yield, this is important in order to recover the cost of establishment and provide an income to the

grower. Switchgrass has also maintained high yields and there are significant differences between the yield of individual species. Reed canary grass may be useful for short-term production but further evaluation of it is necessary.

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MISCANTHUS - PRACTICAL ASPECTS OF BIOFUEL DEVELOPMENT

Energy Power Resources Ltd

OBJECTIVES

- To plant and establish an energy crop of Miscanthus.
- To monitor and record its growth.
- To harvest, bale, and deliver the straw to the power station for a combustion trial.
- To undertake a controlled trial and establish the key combustion characteristics.
- To evaluate any change in power station performance and IPC compliance with baled Miscanthus as the fuel.

SUMMARY

Work on this project has concentrated on three main areas:

- Modification of EPRL's Elean plant to accept and use Miscanthus as a fuel.
- Miscanthus production, concentrating on planting, growth monitoring and future harvesting of the Miscanthus fuel.
- Combustion trial of baled Miscanthus.

The work has shown that Miscanthus can be successfully grown and harvested, with reasonable yield rates, to provide a suitable alternative, similar-priced fuel to conventional cereal straw for power plant such as Elean.

COST

The total cost of the project was £256,000, with the Department of Trade and Industry (DTI) contributing £128,000 and EPRL the balance.

DURATION

4 years, 3 months – April 1999 to July 2003

BACKGROUND

EPRL is a leading UK developer of renewable energy projects and is actively seeking to encourage and assist with the development of commercially viable alternative biofuels. With its 36MW Biomass Power Station near Ely, EPRL could offer the opportunity of a long-term fuel supply contract if Miscanthus could demonstrate an ability to replace or supplement straw, without adverse restrictions.

Miscanthus is one of the most researched and most advanced, non-straw, biofuel crops. It has high yield, perennial growth and good disease resistance, although this has not been proved on a commercial scale. As a C_4

crop it is considered to be an efficient converter of solar radiation to biomass energy under the right conditions.

To promote the use of Miscanthus, it was essential that its production, storage, handling and combustion be demonstrated on a commercial scale. This project has attempted to achieve this. The integration of biofuel crops and energy conversion has presented a unique opportunity to demonstrate the benefits of Miscanthus to potential UK growers and a wider international technical audience.

THE WORK PROGRAMME

Work on this project has concentrated on three main areas:

- Modification of EPRL's Elean plant to accept and use Miscanthus as a fuel.
- Miscanthus production, concentrating on planting, growth monitoring and future harvesting of the Miscanthus fuel.
- Combustion trial of baled Miscanthus.

Modifications

One possibility was to modify the plant, allowing it to accept chopped Miscanthus. Provision would be made for a covered loading area with a large storage pit and a purpose-designed conveying system delivering metered volumes onto the straw feed lines and into the combustion system.

The capital cost of providing this system in its entirety would be close to the original total budget of £1.2M and would require a change to planning permission because of the revised building layout required.

A second possibility assessed the cost benefits and requirements of introducing Miscanthus in baled form into the plant. To achieve satisfactory operation, the design of the entire straw fuel handling system had to be modified to accommodate the physical differences between Miscanthus and cereal straw, ie, the material bulk density and its abrasion characteristics. The crane system and feed conveyor design needed to be uprated to accommodate possible 850kg Miscanthus bales.

This design was integrated with the existing plant layout and did not require any planning revisions. The capital cost to achieve this modification was £190k.

By moving Miscanthus in bales and firing as such into the main bale burners, any combination between 0 and 100% firing of Miscanthus could be theoretically achieved. The chopped fuel option would be limited to a maximum of 25% because of existing furnace feed design.

The introduction of an independent chopped fuel mechanism would create the need for a much more complex control system and flame protection system. Obtaining even combustion rates across the furnace could not be guaranteed. With the potential for slagging and fouling any localised high temperature zone could prove detrimental to plant performance and availability.

After careful consideration, it was decided that the project would go ahead with the baled system. The designs for the chopped system have been retained, should the market for chopped Miscanthus change and finance become more achievable.

Modifications for the receipt, transport and introduction of baled Miscanthus were implemented during the last part of the power station construction.

Production of Miscanthus

A suitable site for the trial plot was selected close to the Elean Power Station. The field was 12ha in total and had been in continuous wheat production for a number of years. Two hectares of the field was set aside for the Miscanthus growing trial. The intention was to grow the rhizomes for two years, then to harvest and split the rhizomes and replant an area of 7ha, so that at the end of the four-year project there would be sufficient Miscanthus for the combustion trial at the Elean Power Station.

In August 1999 planting of Miscanthus was carried out using an adapted muck spreader with a density at about 2 to 2.5 rhizomes/m^2. Conditions at the time of planting were poor - late in the season with dry weather and following a recent wheat crop.

Crop growth was poor and a definite need to replant certain areas was identified in Spring 2000. It was recognized that reestablishing at this stage meant that it would not be possible to plant an additional 5ha in Year 3 using existing rhizome stock, since the rhizomes would not increase sufficiently in bulk for splitting in one year. It was therefore agreed that additional Miscanthus plots established under other initiatives would also be harvested to produce sufficient material for the combustion trial.

The trial plot was replanted in May 2000 under an improved planting protocol. Progress over the late summer and autumn was slow, whilst in the winter period plant survival rather than growth is of importance. There was substantial growth over the summer of 2001, which continued throughout 2002.

Some valuable lessons have been learned from this experience of establishing Miscanthus at the commercial scale:

- The problems experienced with the establishment of the first phase of planting has illustrated that good quality rhizomes, stable soil conditions and appropriate commercial planting techniques are essential for good establishment. Rhizomes should be young, stored and transported under temperature-controlled conditions and kept cool to retain their quality. Good establishment is critically important.
- A muck spreader distributed the rhizomes satisfactorily, but no other spreader types were used and therefore no direct comparisons could be made. A problem noticed at the site was that the spreader knocked off some developing shoots and this could have been avoided if the rhizomes had been less advanced in shoot development at the time of planting. The planting method needs to be developed further.
- Plough design and depth control may not have been adequate for the conditions at the site. The late decision to go ahead with planting meant that the soil was prepared quickly, just before initial planting, without proper levelling and settling, which probably did not contribute to successful planting. The plough method used offers a cheap, quick and simple method of planting but more experimentation is needed to test the methods to identify improvements.
- Weed control measures are particularly important in the early stages of establishment.

- No significant pest or disease problems where identified, however inquisitive grazing by rabbits or hares was a problem in the first year of establishment.

The material for the combustion trial came from the trial plot at Witcham, which gave a yield of 7.3t/ha and an additional 7ha of Miscanthus from an ADAS site at Mepal and Anglian Straw sites at Ramsey and Willingham. The crops were 1 to 4 years old with a yield of 3 to 9t/ha (depending on age). These produced a total of 99 bales of material weighing 53.3t.

Handling trial

The handling trial took place on 23 April 2002 and lasted for approximately two hours. The fuel provided a short-term test on the ability of the power station to take the Miscanthus at the full 100% firing rate. During the test there were no noticeable changes in the plant operating performance. The bales were easily picked up by the crane and easily transported on the conveyor mechanism.

During combustion of the Miscanthus the plant did not lose any output, it remained steady, generating 36MW gross power at the turbine and exporting a net electrical power of 33MW. The boiler drum pressure and steam flow also remained steady indicating no appreciable difference between Miscanthus firing and straw firing.

Combustion trial

The combustion test was undertaken generally in accordance with DIN 1942, a Europe-wide accepted test code, for a continuous period of four hours. This required the supply of over 50t of baled Miscanthus in the fuel barn, which was provided well in advance, ready for use.

Assessment of how Miscanthus performed was undertaken by comparison with conventional cereal straw against the following criteria:

- ease of handling and conveying
- ease of chopping
- ease of entry into combustion chamber
- furnace temperature profile
- steam and Electricity production rates
- plant chimney emissions
- ash collection and removal
- operating stability
- sustainability and availability.

RESULTS

- Cereal and Miscanthus, in baled form, handled and conveyed in a similar manner.
- All baled materials were chopped successfully, although Miscanthus required a small increase in torque setting, indicating that it was slightly tougher to chop.
- The performance of Miscanthus was very similar to straw in the combustion trial in terms of the key indicators: steam flow temperature, combustion effeiciency, cycle efficiency and plant electrical input.
- No particular problems were encountered in either fly ash or bottom ash at any stage of the test.
- All hourly emissions were well within limits.

CONCLUSIONS

This work has shown that Miscanthus can be successfully grown and harvested, with reasonable yield rates to provide a suitable alternative, similar-priced fuel to conventional cereal straw for power plant such as Elean.

Operation of the Elean Power Station with Miscanthus caused no significant problems and performance was very similar to conventional cereal straw, providing much the same electrical export at much the same cycle efficiency. Baled Miscanthus straw has been shown to burn efficiently, meet IPC limits and plant output requirements.

Anglian Straw would be happy to contract for Miscanthus in the same way as cereal straw.

POTENTIAL FOR FUTURE DEVELOPMENT

Due to the limited nature of the test work, covering a one-day trial only, the question of availability and sustainability of combustion is more difficult to establish. Given the very similar results and performance of the mixed straws and cereal straw, one could expect Miscanthus bales to provide good long-term results and become a regular contract fuel.

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Report Ref. B/CR/00745REP (URN 03/1633) Publication date: December 2003

OPTIMISATION OF MISCANTHUS HARVESTING AND STORAGE STRATEGIES

Energy Power Resources Ltd (with Bio-Renewables Ltd)

OBJECTIVES

- To determine the most appropriate harvesting window (autumn or late winter) for efficient biomass recovery.
- To identify the impact of compaction on crop re-growth.
- To refine cutting and baling operations in order to collect the highest proportion of biomass from the field.
- To Identify the behaviour of chopped and baled miscanthus under long term storage, in field conditions, and the behaviour of the resultant feedstock.
- To quantify breakdown characteristics; moisture content, spore production and leachate production in bale stacks and chip piles.

SUMMARY

One of the major constraints to the utilisation of the energy crop miscanthus in the most efficient manner possible for energy production is the sub-optimal development of the harvesting and handling logistics. The report covers the first year of a three year evaluation of miscanthus harvesting and storage systems.

During the reporting period field studies at two sites were initiated, whereby different cutting/harvesting systems were compared, in factorial combinations of:

- Harvesting/ baling Machinery
- Timing (autumn or spring harvesting)
- Post-cut biomass treatment.

COST

The total cost of the first year of the project was £77,000 with the DTI contributing £11,500, the EC £27,000 and EPRL the balance.

DURATION

12 months – April 1999 to March 2000.

BACKGROUND

Miscanthus, a perennial grass that produces cane-like stems, is likely to be suitable for combustion in straw burning and mixed feedstock biomass boilers, and has a wide cropping range in the UK (Price *et al.,* 2003).

Preliminary studies have indicated that miscanthus can be direct cut and baled, or baled following swathing, using conventional grassland and cereal straw harvesting machinery.

However, there is still significant uncertainty about the most appropriate time to harvest, the extent of compaction in harvested soils, the chemical and moisture content of baled material and the optimum equipment to use. Early experience of harvesting miscanthus in the UK is that significant amounts of straw and cane remain uncollected.

Convention indicates that miscanthus should be harvested in February/March on frosted ground. However, an autumn harvest may increase the quantity of biological yield recovered, as more leaf will remain attached to the stems. There is also the likelihood it may provide more suitable soil conditions for harvest, thus providing a greater harvest window. The warmer autumn temperatures may also provide a better crop-drying environment. In contrast, autumnal harvests may increase the nutrient off-take of the crop, increasing the risk of power station fouling and increasing the need for additional fertiliser applications to replace crop losses. Very early harvests in autumn may have an effect on crop vigour, if the harvest is carried out before soluble carbohydrates have completely translocated to the rhizomes. This project will address all of these issues over a three year timescale.

THE WORK PROGRAMME

The field work in this study was undertaken in year 1 at two field-scale experimental sites that had been established for previous Defra-funded studies. The sites were harvested using either a Class Rape Swather or a John Deer 1365 mower conditioner in both autumn and spring. The biomass was then baled. Stem moisture content, harvested biomass yield, soil strength and moisture, swath dimensions and characteristics, and biomass remaining at the site after harvest and baling were measured .

RESULTS

It was clear that the mower conditioner/baler combination was the preferred harvesting system because it provided:

- More efficient biomass recovery
- Better swath dimensions
- More rapid activity
- Greater stem conditioning, enabling
- Better bale formation.

Within year, changes were implemented to the harvesting mechanisms, which significantly increased the quantity of biomass recovered.

The balance between leaving a high stubble, on which an aerated and rapidly drying swath is held, and choosing to cut as close to the ground to maximise biomass recovery (ie the compromise between quality and quantity) has not, within the first year of the work, been resolved.

CONTINUATION OF THE PROJECT

During the course of the first year of this project the industrial sponsor made clear their intentions to discontinue the project at the end of the first 12 month period The work is now being continued as DTI project B/CR/00797/00/00.

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SECTION 4

FUEL SUPPLY CHAIN

PROJECT SUMMARY LISTING

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Report Ref. B/U1/00576/REP Publication date: March 1998

DEVELOPMENT AND PROVING OF A ROLL-ON ROLL-OFF BIN HANDLING AND DELIVERY SYSTEM FOR WOOD-CHIP FIRED HEATING PLANT

LRZ Limited

OBJECTIVES

- To design, build and prove a wood-chip delivery and handling system and boiler interface, based on roll-on roll-off bins, in order to produce a cost effective solution for heating plant installations.

SUMMARY

Biomass is becoming an increasingly favourable fuel for energy production. In particular wood-chips seem to be a viable option. However, there are problems associated with cost and integration of wood-chip delivery and storage systems into existing power generation plants.

This report sets out work undertaken to develop such a system, based on placing a fuel handling mechanism within a roll-on roll-off bin. These containers (bins) are widely used for transporting bulk materials, particularly in the waste industry. Their primary characteristic is that the haulage vehicles used for moving them are self-loading and unloading. Specifically, they are equipped with a specialist chassis that has a hydraulic arm with a hooked end. This locks into a mate on the front of the bin, lifting and pulling it onto the chassis when loading, and pushing it off the rear of the chassis when offloading. Such a system offers the potential to containerise both the storage and handling functions within a bin, so that it obviates the need for any other materials handling equipment or storage. Each bin can be delivered full and exchanged for re-filling when empty.

Such a system has been designed for commercial production, and demonstration pilot equipment has been built and installed at the EcoTech Centre in Swaffham.

COST

The total cost of this project was £44,910 with the Department of Trade and Industry (DTI) contributing £20,910 and LRZ Ltd the balance.

DURATION

12 months – March 1998 – February 1999

BACKGROUND

The reception, storage and handling of wood-chips within a heating plant installation represents a key technical element of the overall energy supply chain, standing at the dividing point between fuel production and utilization. Within such a system, the interface between delivery and buffer storage, where wood-chips are transferred from the delivery vehicle into some form of storage facility, is a particular technical challenge. Above ground storage, such as a hopper or silo, may require either a dedicated delivery vehicle, such as a high tip trailer, or further handling equipment, such as a loader or a gantry crane. As an alternative, underground or partially underground bunkering allows use of a tipping trailer, but can prove extremely costly. It can also present issues relating to load size and discharge properties, since a trailer of wood-chips will tend to discharge as a mass.

For this reason, most fuel reception/handling systems form a significant area of capital cost, equaling and even exceeding the cost of the boiler plant itself. Thus, the development of cost effective, efficient and reliable handling and delivery systems is a significant area where development work is required to improve the market potential of wood-fuelled heating.

THE WORK PROGRAMME

The work undertaken consisted of the following related activities:

- Identification of key parameters and production of a design brief
- Design
- Fabrication and installation
- Commissioning, proving and modification.

RESULTS AND CONCLUSIONS

The key system parameters for the design brief were identified as

1. integration of the pilot system with the boiler and related plant at the EcoTech Centre in Swaffham, and
2. ensuring the maximum level of flexibility in the design that is practically achievable to maximise potential for replication.

The target capital cost for the pilot/demonstration system of two bins and outfeeder was £40k, however, this was expected to reduce to £25-30k with replication. The brief stressed that O&M costs should be minimised (eg focus on the use of standard, rather than one-off parts and accessibility of major components for ease of maintenance/replacement). The following specifications were agreed:

- A fuel feed rate of 500kg/hr (to allow the system to be used on boilers of up to 1,250kW)
- Integration with various designs of boiler interface
- The system will be provided with adequate controls/metering to allow effective interaction with the main boiler controls, led by boiler feed demand
- The fuel feed system is to have a reasonable degree of tolerance to particle size (average particle size is 50mm)
- An effective reception for the off-loaded bins
- Sufficient space around the bins to allow vehicle movements
- A form of guide/locating mechanism for the bins to facilitate accurate off-loading and positioning in relation to the transfer mechanism
- Appropriate road markings to allow the driver to position for off-loading or re-loading
- The bins should be capable of loading, transport and off-loading, using a standard roll-on-roll-off chassis without modification, they should also be weatherproof.

A detailed design was developed, focusing on: the exterior shell of the bins, the internal delivery and discharge mechanisms, the stands/locating mechanism, the delivery mechanism that transfers fuel from the bin discharge aperture to the boiler fuel handling system and controls.

A reciprocating scraper floor, based on parallel sets of wedge-shaped flights driven by push-rods, which would move the material in the bin towards a discharge opening at the rear, was chosen as the internal delivery mechanism.

An internal scraper floor discharging into a cross-auger was chosen as the most appropriate discharge and transfer system, with the bin placed on raised stands.

The first prototype bin and accompanying at-site items were manufactured by Nordist at their Shortgate workshop. These were subsequently installed on-site at EcoTech during the latter part of November 1998 and commissioned in early December.

The commissioning and running of the system was essentially trouble free: there were no operational problems associated with the fuel handling. A second bin was built and installed with only minor modifications (the inclusion of two perspex inspection panels to allow ready monitoring of the fuel level inside).

Commercial interest in the product is proving to be strong – already several potential applications have been identified, and costs will undoubtedly reduce if significant numbers of systems are produced.

POTENTIAL FOR FUTURE DEVELOPMENT

Further monitoring and evaluation of the pilot system is regarded as important and is planned. There are also additional opportunities for development of the system. In particular, fuel pre-conditioning is another crucial element of the supply chain for wood heating systems. Thus, it is believed that the options for incorporating drying into the bins should be assessed and, if appropriate, prototyped. Work is already being planned that would look at the use of both heat recovery from the flue gases at a heating plant and overnight heat when the boiler is at partial load to provide drying.

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Report Ref. B/U1/00674/REP (URN 01/1175) Publication date: July 2001

COMMERCIAL WOODCHIP STORAGE DRYING TRIALS

Kielder Forest Products Ltd

OBJECTIVES

- To portray to the renewable industry the importance of consistent production of a uniform, high-quality woodfuel.
- To test methods that ensure a high-quality woodfuel is achievable with the minimum amount of energy and cost.
- To minimise the handling of large volumes of woodfuel as a bulk product (both in the forest and the agricultural environment).
- To emphasise the role that the handling and drying system play in adding value onto the product.
- To consider the practical benefits of the drying method for the end user, and the impact of the fact that woodfuel is a low-value product with small margins.

SUMMARY

Following the recent positive steps into energy production from biomass in the North of England, Kielder Forest Products Ltd (KFP) is well aware of the importance of the supply of high quality woodfuel for the biofuel plants, as well as some smaller emerging installations. As the gasification systems in the larger plants rely on relatively new technology, it is very important to ensure that the fuel used is of the uniform highest quality, which should help to maximise the efficiency of the plant. It must be remembered the woodfuel is not simply to be burnt, woodchips are to be converted into energy. A clean, dry, uniform high quality woodfuel will thus produce more energy than a dirty wet sample having varying sizes.

Once the material is available, the efficiency of the chipper (as well as the type of raw material being chipped) will have a bearing on the specification of the woodfuel. Generally, if the raw material is chipped soon after felling, the specification of the chips will be relatively uniform (assuming that the chipper is set up properly). The one disadvantage is that the moisture content will be quite high. Drying the woodfuel before it is sent to the power station can, however, rectify this problem.

Power companies always want woodfuel to be as dry as possible, while woodfuel suppliers want to supply the woodfuel at around 52% moisture content (which is an average for recently felled brash). A level of 35-45% seems to be a happy medium. This means that there needs to be approximately a 33% reduction of moisture content after felling prior to entering the plant.

There are a two ways of addressing this:

- Allowing the ambient air to dry out the brash naturally.
- Forcing air through a bed of chips to dry down to the agreed moisture content.

This trial uses the forced air method.

COST

The total cost of this project was £21,190, with the Department of Trade and Industry (DTI) contributing £10,595 and Kielder Forest Products Ltd the balance.

DURATION

12 months - June 2000 to June 2001

BACKGROUND

Over the last ten years, there has been much research into the general comminution of forest residues. We are now able to put the theory into practice (as the woodfuel in this project will be used in a gasification system to produce electricity). It is becoming very apparent that the quality of the woodfuel and the way it is handled are of paramount importance.

There is a misconception within the forestry and renewable industry that any type of woodchip can be used on a combustion system. If the woodchips are soiled, wet and out-of-specification, the converted electricity will be significantly less than if clean, dry and uniform woodchips are used. The actual woodfuel needed for these plants is high-quality woodfuel. The better the quality of the woodfuel used, the better the results will be. If the woodfuel is dirty (eg if it has been run over by forestry machines and is covered in soil), then the combustion system produces a higher percentage of ash, which reduces efficiency. If the woodfuel is wet, then the amount of energy needed to dry the woodfuel prior to the combustion reduces efficiency.

The management process for obtaining high-quality woodfuel starts with the wood in the clear felled areas. Prior to the very slow emergence of the woodfuel industry, the forest industry regarded the side branches and tops of the trees as waste products, which were generally used by the forwarders to stay on top of the ground. There is a certain amount of the brash still needed for forwarders to operate. There also is a very large amount of this material (which could be used for woodfuel) wasted in these mats. This process needs to be addressed in an agreed method of operation prior to any harvesting taking place. The brash must be regarded as a product (as is the case with round wood) and handled accordingly, so that the maximum amount of brash can be recovered from each site and converted into woodfuel. This not only fulfils the criteria of utilising renewable energy but also gives the forestry industry another useful product.

THE WORK PROGRAMME

The raw material used during this trial included prematurely felled Sitka Spruce trees, which were approximately 20 years old, and brash from a traditionally mechanically harvested site. The raw material was brought to the roadside by a forwarder and left in rows, but facing into the road and stacked up 3-4 meters high. This raw material was then chipped stored in a lay-bye and then loaded onto articulated tippers and transported to the drier. The trial included 20 similar batches passing through the drier, which totaled approximately 500 tonnes (reducing the moisture content down to 35%).

A tonnage was also set a side for smaller producers to introduce woodchips into the drying system.

The trees were hand felled and brought to the roadside with a forwarder, where they were stacked as roundwood is, up to a height of 3-4 meters. When chipping within the constraints of a forest, there may be a need (as there was in this case) to build a landing area both for the storage of chips and to allow the wagons to manoeuvre more easily. When the stockpile was large enough, a wagon was brought in to transport the chips to the drier; this initially caused a few problems (until the loading shovel operator and the wagon drivers worked out the best loading methods).

The chips were tipped onto a concrete apron in front of the drying building; this is useful, as it helps to keep the chips clean (away from muck, soil and dirt). With the use of a loading shovel, the chips were loaded onto the drier to a depth of 18 inches. Ambient air was then forced through the chips with the use of a Lister fan until the average moisture content was reduced to around 35%. The chips were then removed from the floor and stockpiled undercover.

The method used to dry the woodchips is a very simple method, which could be used on many farms (as most farmers already have the necessary equipment). One can actually see the woodchips change colour (as the air removes the moisture from the bottom of the layer and takes it further up the pile). This drying method would be ideally suited for farmers who grow coppice and want to add value to the product by reducing the moisture content. When handling larger volumes, there is the logistical problem of having enough space to handle the delivered woodfuel, drying, storage and subsequent loading (which also increases the cost dramatically). If the woodfuel is destined for a small heating unit, it is imperative to have a high-quality, uniform sample (as the combustion systems are very susceptible to fuel variation). This forced air on floor drying system can guarantee the moisture content falls to within a 5% variation, which is acceptable. The smaller units are capable of paying a small premium for drier fuel in comparison to the larger power stations.

There were regular samples taken to test the moisture content of the woodchips in each batch. It became apparent that the ambient air was removing the moisture from the woodchips nearest to the floor first. This drying process then worked its way up through the depth of woodchips. A number of samples were taken from varying depths; each batch was removed from the drying floor when the average moisture content was 35%.

See the full report for details on reduction and transportation, drying and storage buildings, air ducts, floor decking and drier specifications.

CONCLUSIONS

- As woodfuel is a low-value product, handle the product as few times as possible to keep costs down.
- To warrant forced-air drying, a premium price must be achieved. The funding is likely to be

channelled to the heating systems rather than for electricity production.

- Transport charges are a large percentage of total costs, so working within a maximum radius of the end user is essential for a viable operation.
- Top-quality, uniform, clean woodfuel must be produced at all times to ensure that a competitive, non-fossil fuel is produced.
- It is possible to reduce the moisture content from 52% to 35%. Moisture content should be kept as low as possible.
- Drying 1 tonne of woodchip from 52% to 35% requires approximately 237,600m^3 of air.
- Specification and moisture content requirements should be established before committing to supply.
- Checks should be made to ensure that there is sufficient inside storage for dry chips.

It is essential to remember that woodfuel (regardless of its destination) is a low-value product and, generally, the more it is handled, the more expensive it becomes.

There are two potential scenarios for managing woodfuel. The first scenario assumes that the Power Station produces renewable electricity at a very competitive rate. The fuel for this system must be managed and dried within the wood or at the roadside, utilising the natural air to reduce the moisture content. The raw material needs to be chipped and sent straight to the plant (as transferring to a drier would require additional handling and would add on so much cost that it would become unprofitable).

In the second scenario, the smaller units supplying heat for a school or a large country house need to have a very uniform fuel, not only for the combustion but also for the handling systems (which are also susceptible to blockages and bridging if the fuel quality deteriorates). Low-cost, on-floor drying systems will ensure higher standards of fuel quality. If the fuel is not of sufficiently high quality, there will be major problems with smaller units.

POTENTIAL FOR FUTURE DEVELOPMENT

Research and development should be concentrated on natural drying, as it will prove to be the norm in the years to come. The method should be kept simple, brash stockpile removed and covered, and chipped when required.

Research is needed into a comparison of the following two methods:

- Method 1: Remove green brash stockpile and cover, leave for six months.
- Method 2: Leave brash on clear felled areas for two months, remove, stockpile and cover.

A comparison of the reduction in the moisture content between the two methods will help to guide the industry into utilising the brash for energy production.

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Report Ref: B/W2/00640/REP Publication date: August 2001

DEVELOPMENT OF A SRC HARVESTING AND CHIPPING SYSTEM

Coppice Resources Ltd

OBJECTIVES

To build a direct short rotation coppice (SRC) harvester chipper that would be:

- front-mounted on an ordinary agricultural tractor
- capable of delivering wood chip to an ordinary agricultural trailer
- comprised as far as possible of existing agricultural technology
- capable of working in wet conditions on heavy and poorly drained soils
- capable of harvesting whilst in continuous forward motion
- capable of delivering wood chips in accordance with alternative specifications from generating customers.
- capable of feeding the SRC in a manner that could serve a bundler/baler as opposed to just a chipping drum.

SUMMARY

As the planting of SRC has expanded on the back of the development of a wood-fuelled power station at Eggborough, near Selby, North Yorkshire, the lack of a proven harvesting system has become a concern of potential growers.

Coppice Resources Ltd was awarded a DTI contract to build a harvester chipper that could be mounted on an ordinary agricultural tractor delivering wood chip to an agricultural trailer, and capable of working in poor ground conditions and delivering wood chip to alternative specifications. The method of gathering and feeding in the SRC was also to be compatible with feeding subsequent bundler/baling machines.

Considerable emphasis was put on achieving a complete gathering of the crop, a precise and even cut at a defined height and on causing minimal stool and soil damage.

COST

The total cost of this project was £64,870 with the Department of Trade and Industry (DTI) contributing £25,000 and Coppice Resources Ltd the balance.

DURATION

10 months - November 1999 to August 2000

BACKGROUND

Coppice Resources Ltd had assisted in UK trials of a prototype Swedish Salix Bender machine but had identified significant weaknesses in the concept of bundling and the design and engineering of the machine.

It became clear that in the early harvest years the production of wood chip from SRC would only sustain the power plant for part of the year and therefore a direct harvester chipper machine would satisfy the immediate needs whilst other methods were being developed. Coincidentally, in Northern Ireland a programme was operating to develop small- scale combined heat and power (CHP) plant supplied by SRC for which a direct harvester chipper machine would be sufficient.

Having investigated a number of machines that were being tried in the UK and abroad for harvesting SRC, the conclusion was reached that these adaptations from other agricultural uses did not produce harvesting or chipping of a sufficient standard.

THE WORK PROGRAMME

Coppice Resources designed and constructed a prototype harvester and trials were carried out in three principal locations near Retford, Nottinghamshire, Woolley near Barnsley and Brooke Hall Estate in Northern Ireland.

Early trials were carried out in light crops to determine the effectiveness of the harvester. The results from the trials could be used to modify the design and manufacture an efficient harvester to the required specifications.

RESULTS

By the end of the trials the machine was producing a good clean cut with little stool damage. There were minimal harvesting misses and the feeding system to the chipper chamber was effective with few losses.

There was good delivery of the chip to the trailer and soil damage was minimal, even through some very wet trials in Northern Ireland. Chip quality and work rate proved to be the major problems, which were not overcome during the project.

CONCLUSIONS

- The cutting system adopted produces a clean cut across the full width of the stool.
- The cutting system does minimal damage to the stools.
- As with many agricultural crops such as sugar beet, carrots and potatoes, precision planting of the crop is a major contributor to successful harvesting.
- When mounted on an agricultural tractor equipped with wide tyres the machine can harvest on waterlogged heavy soils without causing serious rutting even in very wet conditions.
- The feeding system developed is capable of collecting the cut rods and presenting them to the chipper without significant losses.
- The chipping system is not capable of matching the revised chip specification from ARBRE and Brooke Hall Estate.
- The machine effectively delivers the chip to the trailer without significant losses.

Figure 1 The tractor-mounted harvester

POTENTIAL FOR FUTURE DEVELOPMENT

During the course of the project new specifications for wood chip emerged from both Project ARBRE and Brooke Hall Estate indicating that a larger chip was required than had been originally anticipated and that dust and fines from shattered wood is likely to cause difficulties at the power plant. Further work is therefore required to achieve a chunk rather than a chip with the chunk remaining in the round and not shattering. There needs to be flexibility to meet different chip/chunk specifications.

Achieving this will involve attention to the specification of the drum itself and the presentation of the rods into it, whilst considerably improving the work rate of the machine, which is inadequate at present for other than trials and small sites.

The ease with which the wood fragments, even when freshly cut, causes concern as to the feasibility of achieving a chip of the desired specification from SRC which has been left to dry in bales or bundles. Such dry material fed into the harvester drum simply disintegrated. Investigations should be made into the feasibility of storing the chunks rather than bales or bundles.

It was also noted that the harvested chip did not compact in the trailers, giving a low weight to volume ratio and consequently high transport costs.

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Report Ref. B/U1/00589/REP Publication date: September 2001

FOREST RESIDUE BALING DUE DILIGENCE ASSESSMENT, PROVING AND TRANSPORT TRIALS

Forestry Contracting Association

OBJECTIVES

- To provide an independent report on the technical and financial acceptability of forest residue compression to meet the requirements of financial and technical due diligence.
- The specific objectives were:
- To establish the availability of a cost effective baling technology, suitable for use with forest residues, by consultation with researchers, designers and manufacturers.
- To source a baler suitable for operation in the UK environment utilising the baling technology identified above.
- Engineering modifications to provide an integral baler and transport vehicle for UK operations.
- Identify a range of forest sites at a number of distances from a NFFO contract site containing different quantities of available residues.
- Conduct long term tests on the baler thereby establishing and quantifying its performance, reliability and ability to perform within forest harvesting systems, and to determine the production costs.
- Carry out sufficient trials to establish the logistics of, and effective cost of, delivered residues in bale form, using both road and rail networks from and to a number of different locations.
- Carry out further trials to build on existing data regarding bale storage and drying.

SUMMARY

Transport is known to be the most significant cost element to wood fuel supply cost, with the cost of comminution being the most variable depending on the method chosen. It has been shown in previous studies that wood fuel compaction in the form of compression can significantly increase the net load capability of the transport systems currently available, thereby leading to significant reductions in transport costs.

Previous compression trials conducted in the UK concentrated on the Bala Press Residue compression Baler. Although significant compression of the residues was achieved to allow full utilisation of the transport element, the size and shape of the bales required existing extraction and transport equipment to be modified. The low productivity of the Bala Press and the high cost of the tying material meant the system was not economically

viable, and the scope for significant productivity improvements did not seem to be easily attainable. Since these harvesting trials there has been a significant move towards central comminution in Sweden, with further compression equipment being developed. To enable compressed residue material to be delivered to the Carlisle Bio-energy plant at an economic cost there had to be a compression machine, offering increased productivity with the ability for the product to use existing extraction and transport equipment. The compression machine and its carrier had to offer flexibility for their introduction into existing shortwood and whole tree harvesting systems.

The study identified the Fiberpac residue compression machine as suitable for use under UK conditions. The Fiberpac machine was trialled for a period of approximately six months to gain information on productivity, reliability and production costs.

COST

The total cost of this project was £363,500 with the Department of Trade and Industry (DTI) contributing £166,750 and UK industry the balance.

DURATION

21 months: July 1998 - March 2000

BACKGROUND

Border Biofuels and their associated partners have secured interests in six of the projects awarded under the 1997 round of the Non Fossil Fuel Obligation (NFFO) and Scottish Renewables Order (SRO). The consortium are now progressing plans to implement the first phase of their development programme which will enable the creation of a market for about 350,000 green tonnes of wood fuel.

All of the projects will be fuelled using forest residues until such time as coppice fuel can compete for a market share. This is unlikely to happen in the short term but will almost certainly form part of the fuel product mix in the medium to long term.

Transport is known to be the most significant cost element to wood fuel supply cost with the cost of comminution being the most variable depending on the method chosen. It has been shown in the previous studies that wood fuel compaction in the form of baling can significantly increase the net load capability of the transport systems currently available, thereby leading to significant reductions in delivery costs.

There are alternative methods of increasing net vehicle weight such as hauling comminuted wood fuel (processed either at stump or at clear-fell roadside). These methods depend on cost effective inforest processing, which has also been shown to be too expensive and impractical in most UK forest situations, and is not likely to contribute greatly to wood fuel supplies.

The consortium now needs to establish key parameters for baling and transportation of such material using both the road and rail networks. Baling has been shown to provide a near cost-competitive solution to residue compaction and carries with it a number of inherent advantages:

1. Simplicity of handling
2. Simple methods for establishing quantities
3. Good in-forest storage capability
4. Efficiencies from centralised comminution.

The work to date on forest residue baling in the UK has demonstrated that whilst the concept is sound, and the equipment reliable the costs of baling are too high.

Design improvements are feasible, and necessary, to bring down the costs of baling. Bale wrapping systems and the material used require modification. The planned use of the baler to feed the Border Biofuels plants is quite different from the conditions under which it was tested and demonstrated. Developments are required to reduce the costs of baling while integrating this process with current forestry operations. Additional extensive road and rail transport trials are required to establish the cost and effectiveness of each transport method. Preliminary trials of storage would indicate the wood fuel in bale form dries significantly more quickly during the storage period; additional trial information on bale storage is necessary to determine optimal storage times.

The proposed baler developments are based on earlier trial results, which concluded that terrain baling was not a viable operation and that the speed of baling residues collected at the forest landing should be increased. The remounting of the baler on a rigid lorry, rather than the high cost forwarder base, requires investigation and engineering modifications.

Initial investigation of resource sites would indicate that transport by rail in addition to road could offer a reduction in costs. Both road and rail transport, including the possible modification to transport vehicles, required investigation.

THE WORK PROGRAMME

The following activities and programme of work was developed:

- Establish the availability of cost effective baling technology. By direct contact with researchers, contacts through the International Energy Agency (IEA) and visits to European manufacturers, the most acceptable technology and manufacturer for UK conditions would be identified.
- To source a baler suitable for operation in the UK environment using the baling technology identified above.
- Carry out engineering modifications to provide an integral baler and transport vehicle for UK operations. The chosen carrier unit has to be adapted for use in UK conditions – any structural or necessary hydraulic modifications will be carried out.
- Identify residue sites, quantities and travel distances. The sites of the proposed generation plant and tonnage demands are to be calculated. Potential residue supply sites will be identified in a series of radii from the generation plants in relation to road and rail supply lines. Supply options will be studied that optimise supply quantities, transport systems and total delivered wood fuel cost.
- Conduct long-term tests on the baler to establish and quantify performance, reliability and ability to perform and to determine the costs of production. Carry out compression trials in forest residues on a range of sites with harvesting systems adapted to allow collection of residues with minimal disruption to the roundwood harvesting system but allowing minimal contamination of the wood fuel element. The baling/ compression trials will

take place over 13 working weeks on existing harvesting sites which are being worked by BSW Harvesting.

The compression unit will move from site to site to identify working methods and the logistics of operating commercial wood fuel harvesting, integrated into existing roundwood harvesting operations. It was proposed that the trial length would involve some 500 machine hours of compression in actual in-forest operations involving some 5,000 bales.

- Carry out trials to establish the logistics and cost of baled residues delivered by road and rail networks. It was proposed to carry out an initial series of trials of road and rail transport of forest residues in co-operation with private road hauliers and specialist rail freight companies.
- Carry out trials on bale storage and drying. There is considerable potential in the drying and storage of wood fuel in compressed form. The opportunity to store prior to comminution minimises dry matter losses, and ventilation through the bale/compressed bundle encourages quicker and more even drying. It was proposed to carry out a storage and drying trial of bales/compressed bundles. The aim being to monitor moisture content and dry matter losses in compressed residues, stored in the open in a series of combinations, and moisture content at time of baling.

RESULTS AND CONCLUSIONS

The Fiberpac residue compression machine after investigation offered the potential to be introduced into existing harvesting operations. The size and shape of the Fiberlog offers the opportunity to utilise existing extraction and transport equipment.

Residue sites and quantities within an 80km transport distance of Carlisle Bio-Energy plant were identified. A total of 265,205 green tonnes per annum was available. This quantity had constraints applied both by Forest Enterprise, dependent on terrain and soil type, and by BSW Harvesting (contracted fuel suppliers for Carlisle Bio-energy plant) dependent on the transport distance and local area manager knowledge.

Productivity of the Fiberpac used in an integrated harvesting system ranged from 11.9-14.6 green tonnes per productive machine hour (GT/PMH), an average of 13.3GT/PMH. This gave an average production cost of £7.32 per GT. The second pass residue harvesting systems were developed, with productivity ranging from 2.5-11.7GT/PMH. Production costs ranged from £24.14-£27.79 per GT. The second pass residue harvesting systems also incurred the additional cost of extraction of the Fiberlog to roadside, a cost of £2.92 per GT. At these levels of productivity the second pass residue harvesting systems are uneconomic. Of the second pass residue-harvesting systems the ‘long tops and mat minimisation’ method, dependent on an increase in productivity, offered both the potential for cost effective harvesting linked to minimal ground disturbance and maximum retrievable wood fuel yield with minimal contamination.

Transport by both road and rail were investigated with haulage by an articulated timber lorry being the only system to offer 100% load utilisation. The rigid timber lorry with drag trailer, due to the length of the Fiberlogs did not obtain a full payload. The restrictions on height and the length of the OTA rail wagons did not allow full load utilisation to be reached. With 100% utilisation of the transport equipment total delivered wood fuel costs ranged from £15.07-£43.14 per GT. The lower cost range was to be found by using the integrated harvesting system in transport zone 1. Total delivered wood fuel cost, at £43.14 per GT is uneconomic.

A proportion of the Fiberlogs were sampled at the time of compression to ascertain moisture content, calorific value and presence of foreign material. A proportion of Fiberlogs were also weighed and placed in stacks that minimised required ground area (to simulate a commercial situation) and stacked in a pattern to ensure drying of the wood fuel material. A proportion of the stacks were covered to monitor the effect on the drying of the material. These stacks are to be re-weighed after a period of nine and 12 months to monitor moisture content change, calorific value and dry matter losses.

POTENTIAL FOR FUTURE DEVELOPMENT

With any wood fuel harvesting system there has to be planning at the timber harvesting stage to allow minimal wood fuel contamination, minimal ground disturbance and to ensure the material is presented in a way to allow the compression machine to obtain high levels of productivity. The integrated harvesting system offered the lowest production cost, without alteration of the cable crane harvesting system, with adaptation of the whole tree system there is significant scope to further reduce costs.

The second pass residue-harvesting systems, at the levels of productivity obtained within the trial, were uneconomic. The adaptation of the shortwood harvesting systems for second pass residue harvesting gave positive results with no productivity loss on the shortwood harvesting equipment.

The low productivity of the Fiberpac was due mainly to technical reasons with the cutting mechanism. With improvements in productivity the second pass residue harvesting 'long tops and mat minimisation' method offered the greatest scope to be introduced into existing shortwood harvesting systems, it gave minimal ground disturbance, minimal wood fuel contamination with maximum retrievable wood fuel yield.

There has to be planning at the timber harvesting stage for the introduction of a wood fuel harvesting system. This will allow ease of implementation for the compression machinery and to allow full utilisation of the transport equipment. Proper planning will also minimise the effect on the environment and will allow minimal contamination of the wood fuel. Storage will also be a major issue to ensure minimal dry matter losses and maximise calorific value of the fuel. Considerable on going work by Swedish researchers of Fiberlog storage needs to be linked to the current trials.

Planning and correct implementation of all elements within the wood fuel supply chain will aid in reducing total delivered wood fuel costs.

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Report Ref: B/W1/00642/REP (URN 01/1515) Publication date: December 2001

SUREFIRE WOOD FUEL HARVESTER DEVELOPMENT PROJECT

Econergy Limited

OBJECTIVES

- To provide a route to market for the products of currently undermanaged woodland, thus bringing this woodland back into production.
- To design and develop a versatile, highly mobile and relatively low-cost woodfuel harvesting unit by assembling tried and tested components in a novel manner.
- To make a novel and significant contribution to the availability of wood- fuel harvesting capacity in the UK with excellent scope for replication.
- To bridge the current wide gap in capacity between the tree-surgeon type chipper and large-scale forestry machinery.
- To achieve a far greater degree of chipper mobility and versatility than has hitherto been possible, enabling:
- the accessing of smaller, scattered, often undermanaged woodland
- the provision of realistically priced chipper capacity to scattered and assorted projects, enabling start-up without crippling capital costs
- the development of others sources of woodfuel, such as single-stem poplar, SRC sticks etc.
- To provide a capability to produce high quality chips at a realistic price to dispersed projects before they achieve critical mass or financial close: ie breaking the *chicken-and-egg* conundrum.
- To realise the above objectives by achieving one year of commercial operation (not funded by the DTI programme).

SUMMARY

The majority of current biomass electricity generation capacity and a substantial part of that now under development is clustered in East Anglia, perhaps because of the existence of an established fuel supplier in the region.

While energy crop resources will be needed and are under development substantial supplies from this source are 5 to 10 years off.

The majority of woodland in East Anglia is still in private hands; 27,000ha of it is undermanaged and thus represents a potential fuel source. 80% of these woodland blocks are under 10ha, the average size being 3.1ha.

Examining the resource data for East Anglia indicates that exploiting this type of material will be critical to upscaling the wood fuel supply: the earlier resource studies indicated that this was the main untapped potential.

Accessing this resource also has potential to greatly improve the economics of small woodland management, boosting rural economies and jobs and improving the economic and ecological value of woodlands.

Available chipping machines were unsuited to accessing this resource; handfed type machines having neither the capacity nor the productivity required; large trailer-mounted machines being unable to access the sites and uneconomic to run for small sites and dedicated forestry machines unable to travel between sites independently and thus also uneconomic.

In order to access this untapped woodfuel resource Econergy has developed a prototype mobile woodfuel chipping machine, the 'Surefire Woodfuel Harvester'.

COST

The total cost of this project was £235,652 with the Department of Trade and Industry (DTI) contributing £60,188 and EAGGF and Econergy Ltd the balance.

DURATION

21 months - November 1999 to July 2001

BACKGROUND

After many years of promulgation, there is now a commercial market for woodfuel in the UK. This has arisen from the commissioning of NFFO-3 (and to some extent NFFO-2) projects. There is every indication that the demand will rise rapidly as projects with NFFO-4 contracts come on-line. Furthermore, in many areas of the UK development of heating networks and corresponding *Energy Service Companies* (ESCOs) are underway. These too will demand woodfuel on an increasing scale.

There are a number of projects, either operational (e.g. Fibrowatt plant at Eye Airfield, the Fibro group 38MW_e plant at Croxton near Thetford, EPR's plants at Ely) or under/awaiting construction (eg EPR Corby, Project Arbre, Eye and Cricklade) that will require fuel resourced from forestry operations.

Many of these projects are located in or near East Anglia, and all except Cricklade will take fuel from that region. While the Forest Enterprise holding of Thetford Forest is an obvious resource, there are a number of similar and larger forest blocks in the UK.

This begs the question: why are such a high proportion of projects connected with East Anglia? The existence of an established wood chipping and supply contractor in the area was undoubtedly a major factor in the location of these projects. That contractor had to make a *very* speculative investment in order to be available prior to projects commissioning, and indeed prior to these reaching financial close. It is significant that forestry contractors in other areas are showing little real interest in woodfuel operations in the absence of an established market, resulting in the classic *chicken-and-egg* situation that has bedevilled biomass energy for some time.

THE WORK PROGRAMME

In order to access untapped woodfuel resource Econergy developed a prototype mobile woodfuel chipping machine.

A specification was produced for the harvester and then a detailed design was drawn up. The prototype unit was constructed and a testing programme carried out. The specification included:

1. High speed on/off-road rolling chassis
2. Hydrostatic transmission for field use
3. Chipper of at least 30mm/12" capacity with sliver reduction measures
4. Crane to feed chipper
5. Felling-head (single/multitree)/grapple to fit crane
6. High-performance hydraulic system for fast, accurate working
7. Winch for skidding inaccessible timber to within crane reach on steep and/or wet sites.

RESULTS AND CONCLUSIONS

The Surefire Woodfuel Harvester was constructed over a period of about nine months based on; a Unimog U2150 with full agricultural specification and high-speed 'N16' PTO and fitted with a hydrostatic drive; a modified Erjo 7/45 340mm diameter capacity chipper; a Parker/Linde based high performance hydraulics and control system and a Kronos loading crane and grab.

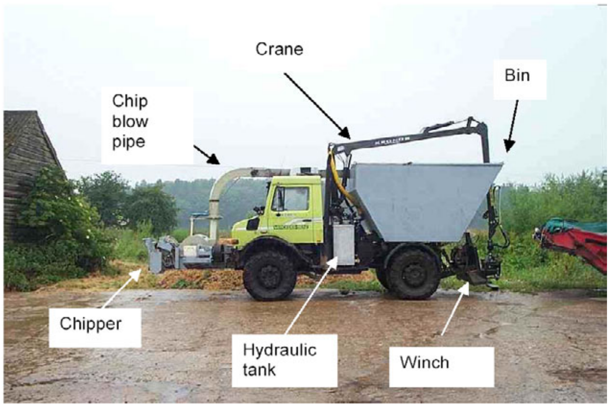

Figure 1 the finished machine prior to final painting

Numerous components from crane mounts to the high-tip chip bin system to the chipper transmission were custom-made by specialist suppliers and in the Econergy workshop.

The testing programme was performed in several stages:

1. The chipper and chipper driveline
2. The hydraulic system and crane
3. The hydrostatic ground-drive
4. The bin tipping system
5. The whole machine.

The Surefire Woodfuel harvester has now been thoroughly tested under field conditions and has performed well. Econergy is undertaking further work to address the presentation of material for chipping machines, which is critical to productivity; to integrate woodfuel harvesting into conventional forestry operations; and to reduce costs and risk in the onward logistics chain.

There is now a British designed and built chip harvester in operation and capable of replication. Furthermore, the capacity to design, develop, build and test such machines has now been demonstrated. Links between UK and continental companies have been forged, and networks of subcontractors and suppliers established.

A number of points requiring modification have been identified, and these will be dealt with as-and-when the machine returns to the workshop for overhaul.

POTENTIAL FOR FUTURE DEVELOPMENT

The introduction of a high performance chipper into fuel supply operations inevitably exposes other system constraints, both up- and downstream. Some of these were anticipated, and some were not:

- The need to present felled timber in a way that facilitates feeding of the chipper. It is likely that felling will be carried out as a first pass some time before chipping to provide both low-cost fuel buffering and drying in the round. Presentation is a particular cause of difficulty where trees are motor-manually (chainsaw) felled. Multi-stem hardwoods, which abound in lowland woods, cannot be felled reliably by currently available forestry harvesters. This is due to damage to the chainsaw mechanism that results when working in this type of crop – a crop utterly different from the softwood for which these machines are designed. If this issue is successfully addressed it will go a long way towards achieving the target costs for forest woodfuel. Thus there is an urgent need to:
    - o examine existing felling technologies, especially those unfamiliar in the UK, along with suitable base units and cranes
    - o conduct a development exercise, wherever possible using proven components, in order to produce a mechanized harvester suitable for a wide range of UK broadleaved crops.
- High production chippers require a high performance logistics system to prevent the loss of their performance benefits. While this fact is known both from Danish experience and from previous UK work, the particular situation in lowland woods in the UK requires a novel chip shuttling solution. Successfully addressing this issue could reduce chipping costs to one third to one half of what they would be without such equipment.
- Onward logistics, such as dispatch to the power plant is capable of streamlining to minimise cost.

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Report Ref: B/W2/00716/REP (URN 02/1535) Publication date: December 2002

IDENTIFICATION AND CHARACTERISATION OF FACTORS AFFECTING LOSSES IN THE LARGE-SCALE, NON-VENTILATED BULK STORAGE OF WOOD CHIPS AND DEVELOPMENT OF BEST STORAGE PRACTICES

First Renewables Ltd (with ADAS Consulting Ltd)

OBJECTIVES

- To determine and characterise factors affecting losses in the large-scale non-ventilated bulk storage of wood chips and to develop best storage practices which can be implemented on a commercial scale.

SUMMARY

Two wood chip piles were constructed, one pile with willow chip and a second with wood chips from broadleaf forestry residues. Temperature changes and spore measure-ments were taken during storage and samples were removed periodically from various depths within the piles to investigate chemical changes. A computer model was constructed to try to understand heat and air flows within the piles.

It was concluded that natural air drying can reduce wood chip moisture content to acceptable levels without unacceptable chip degradation, but only in the core of a pile where the chips are insulated from the effects of the weather by the surface layer above.

Best storage practices were developed and these are set out and discussed in greater detail in the final report (referenced above).

COST

The total cost of this project was £36,280, with the Department of Trade and Industry (DTI) contributing £18,140, and First Renewables Ltd the balance.

DURATION

19 months – February 2001 to August 2002

BACKGROUND

Literature regarding the commercial storage of wood chip is limited. Research has been conducted for other wood handling industries eg wood pulp and paper production, but in many cases this work is irrelevant to the large scale storage of wood chip for the biomass industry. ARBRE Energy Limited has built the UK's first biomass power generation plant in North Yorkshire. The fuel used is a mixture of forestry residue (derived from woodland management practices eg thinning) and energy crops such as willow Short Rotation Coppice (SRC).

SRC is harvested during the winter months on a three-yearly rotation and is often not immediately required at the power station. Therefore, the wood chip must be stored on the farmer's land or at a storage site close to the plant for an indefinite period. Similarly, the forestry material will be stockpiled at the edge of the forest until it is required at the station. However, it is hoped that this delay will allow the natural air-drying of the wood. The fuel entering the plant must be below a moisture content of 30% in order to maintain generation efficiencies. Another important fuel specification is the particle size; the ideal wood chip is greater than 3mm and less than 30mm. Wood chip degradation (dry matter losses) must be minimised if the energy crop/fuel is to remain economically viable.

Previously, ARBRE has constructed large piles of forestry material with a trapezoid cross-section. The chips were compacted on delivery using heavy machinery. The purpose of compaction was to reduce air flow and minimise aerobic degradation processes, although this approach was not without its problems. In older piles the temperatures rose and fires started, highlighting the necessity of establishing best storage practices.

Figure 1. Aerial views of the SRC and forestry residue piles at the Northern Straw storage site (forestry residue pile on the left and the SRC pile on the right)

THE WORK PROGRAMME

Two wood chip piles were established at a storage site near Great Heck in North Yorkshire. One pile was constructed with willow chip and the second with wood chips from broadleaf forestry residues. Thermo-couples were buried in the piles to measure temperature changes during storage. Samples were taken periodically from various depths within the piles to investigate chemical changes. Spore measurements were made to asses the health risk of exposure to partly degraded wood chips. A computer model was constructed to try to understand heat and air flows within the piles.

Figure 2. Interim sampling - using a teleporter to make a vertical face in the forestry residue pile

RESULTS

Weather information was obtained from a local met station to assess the influence of ambient conditions on the piles.

Moisture content measurements revealed that the top layers in each pile (0.1m and 0.5m deep in the SRC and forestry residue piles respectively) were predominately wetter than the core layers (1.5-3.0m deep) throughout the duration of the trial. After 50 days in storage the core layers dried, reaching a static moisture content of approximately 30%. The moisture content of the piles correlates tentatively with the average monthly rainfall.

The ash content analysis did not show any trends relating the ash content to the chip depth. The ash content of the SRC pile remained constant at approximately 1-2%. The levels in the forestry residue pile fluctuated dramatically, most likely because of random scatter in the measurements.

No clear trends were found when the calorific value of the piles was assessed in relation to wood chip depth. It was noted that the surface layer of the pile had a lower calorific value than the core layer, a finding that was common to both piles.

Thermocouple temperature measurements were grouped together to identify trends relating to particular areas of the piles. The core and surface layers were analysed together. It was discovered that the SRC pile behaved as one thermal mass throughout the duration of the storage period. The core temperature of the forestry residue pile was higher than the surface temperature throughout the trial. There was no trend between the centreline temperature and the wood chip depth in either the SRC or the forestry residue pile. When the ambient temperature was subtracted from the results it showed that overall both piles reached an excess temperature of around 50°C before a decline to 10°C.

No relationship was found between the number of days in storage and the particle size in either the SRC or the forestry residue piles. The global average amount of fines was 5.0% in the forestry pile and 1.0% in the SRC pile.

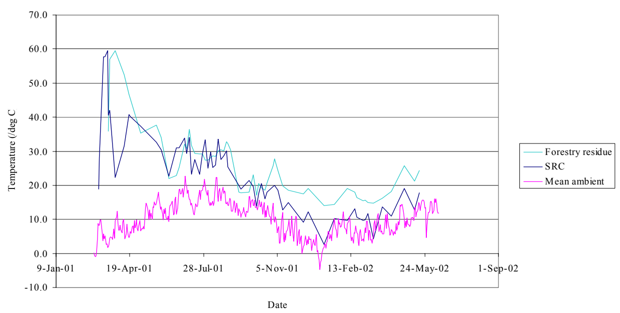

Figure 3. Pile mean temperature against time

The water-soluble carbohydrate content (WSC) in the SRC pile was erratic at the start of the trial before declining to a level below 0.5% for the remainder of the trial. It appeared that the liberation and deployment of water-soluble carbohydrate was uniform throughout the pile. In the forestry residue pile two peaks were seen at 75 and 225 days into the storage period. The average content was 1.25%. No differences between content and depth were found.

Lactic acid levels showed signs of early fermentation activity, but sample variability indicated the heterogeneity of in-stack conditions. The lactic acid content of the SRC pile remained constant at less than 800mg/kg after an initial fluctuation at the start of the trial. The lactic acid content in the forestry residue pile followed a different pattern as two peaks were seen at 15 and 117 days into the storage period. The average content was also less than 800mg/kg.

The spore measurements (focusing upon the indicator species, Thermophilic actinomycetes and Aspergillus fumigatus) revealed that no change in spore levels occurred during the pile disturbance created artificially at the end of the storage period to mimic chip handling operations. Levels recorded (194 colony-forming units/m^3) were well within the current Health and Safety guidelines.

The bulk density of the wood chip was measured at the start and end of the storage period. The difference between the two was 28.76 oven-dried kilograms per metre cubed (odkg/m^3) in the SRC pile and 17.89odkg/m^3 in the forestry pile.

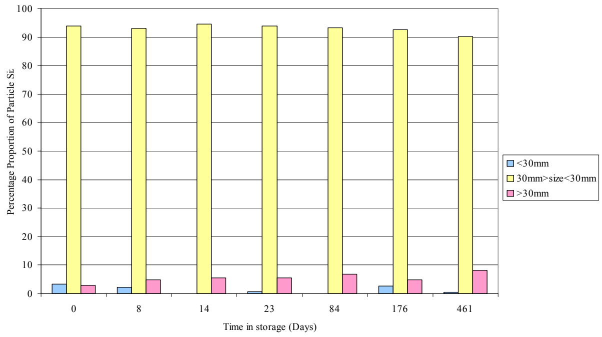

Figure 4. Particle size distribution of SRC wood chip against time

It was found that the near infra-red reflectance spectroscopy (NIRS) analyses provided a good correlation between wet chemistry and dry matter, lignin and cellulose content. This technique has the potential to be used for the prediction of wood chip degradation in store and rapid assessment of fuel quality and type on arrival at plant.

CONCLUSIONS AND RECOMMENDATIONS

- Natural air drying can reduce wood chip moisture content to acceptable levels without unacceptable chip degradation, but only in the core of a pile where the chips are insulated from the effects of the weather by the surface layer above.
- Chips should be piled loose, rather than being compacted, in order to maximise convective heat loss and related moisture loss, and reduce risk of spontaneous combustion.
- Harvesting and chipping should be optimised to provide a chip with as uniform a chip size as possible and with the minimum of fines in order to give a low resistance to air flow. The chip size should be as large as is possible given the constraints of the handling equipment at the plant.
- Piles could be built higher than the piles in this study to increase the core:surface ratio. However piles should not be built so high that there is a danger of temperatures reaching levels at which spontaneous combustion may occur. Based on this work, and literature, a 10m pile height would seem reasonable if machinery allows.
- Alternative pile shapes, which increase the core:surface ratio, should be considered. CFD modelling may give an insight into whether alternative shapes will still allow adequate air flow.
- Covering materials that will shed a large proportion of rainfall while still allowing plenty of air movement should be investigated.
- Careful scheduling of material removal from store can minimise the amount of dry matter loss.
- No evidence of a significant health risk arising from exposure to wood dust or fungal spores during routine operations was found. However, based on experience in Sweden, precautions should be taken in handling wood chip that has been in store to minimise exposure.

Report Ref: B/W1/00753/REP (URN 03/1193) Publication date: June 2003

DEVELOPMENT OF A PROTOTYPE SPECIALIST SHUTTLE VEHICLE FOR CHIPPED WOODFUEL

Econergy Limited

OBJECTIVES

The central aim of the project was to develop a specialist chip shuttle vehicle that combines, as far as is possible, the following characteristics:

- Designed for ease of chip transfer from chipper unit to shuttle and on into haulage units, including suitable high-tip capability, to obtain maximum utilisation from both chipper and shuttle unit.
- Good on- and off-road performance (the former will much reduce the cost of moving the shuttle between harvesting sites) and high maneuverability for operation in woodland.
- Good payload capacity with low ground pressure operation.

SUMMARY

High capacity dedicated woodfuel harvesters, such as those now operating and under development, are extremely capital-intensive (costing up to £300,000 per machine). They need to operate, therefore, at the highest possible productivity in order to produce woodfuel at a viable cost. One way to achieve high productivity is to ensure that the harvester does not spend time 'shuttling' out of the forest or field to offload its wood chip to a haulage unit or storage area some distance away.

A prototype chip shuttle vehicle was designed and built based upon a fully air-suspended Lanc-Trac crop sprayer air-braked chassis. It was fitted with a custom-designed and built high/low tip chip bin complete with hydraulic side flaps and high-speed augers to assist chip loading for the chip harvester.

COST

The total cost of this project was £120,200 with the Department of Trade and Industry (DTI) contributing £60,100 and Econergy Limited the balance.

DURATION

18 months - November 2001 to April 2003

BACKGROUND

Demand for woodfuel is set to rise substantially over the next decade as NFFO projects come on line, new electricity projects are developed with Renewables Obligation support and markets for biomass heat and CHP take off commercially. However, there is currently very little dedicated woodfuel supply infrastructure in the UK. A number of forestry and energy crop harvesters designed for UK conditions are under development with DTI support, including the forestry woodchip harvester which Econergy has successfully built and operated for over a year (Ref: B/W1/00642/REP, URN 01/1515). However, the woodfuel supply chain involves not just the chipping itself, but also the associated logistics, and one element that has not been addressed in a substantive fashion hitherto is the movement of wood chips within a harvesting site.

High capacity dedicated woodfuel harvesters, such as those now operating and under development, are extremely capital-intensive (costing up to £300,000 per machine). They need to operate, therefore, at the highest possible productivity in order to produce woodfuel at a viable cost.

Time spent 'shuttling' out of the forest or field to offload its wood chip to a haulage unit or storage area some distance away is effectively dead time for the harvester and can have a devastating impact on productivity. For example, it is difficult to provide an integral chip bin of greater than 9-12m^3 on a front-feed chipper of the type suited to plantation softwood thinning. The speed of the harvester over the ground is restricted also by the terrain and, in many instances, by the speed of the machine itself.

As a response to this, a sensible approach is to use a 'chip shuttle' to take fuel from the harvester out of the field/woodland to the storage area or haulage unit.

While there is a range of agricultural machinery which might service this need, such as tractors and grain trailers, they are not well suited to the task. While chip shuttle vehicles are in use in other EU countries (and are regarded as an essential operational component in many circumstances) they tend to be one-off adaptations of other machines, neither designed for UK circumstances nor available for 'off the shelf' purchase.

Econergy therefore proposed to develop a prototype specialist shuttle vehicle designed specifically for woodfuel supply work under UK conditions and ideally suited to working with harvesting machines already developed with support from the DTI programme.

THE WORK PROGRAMME

At first a project profile and shuttle vehicle specification was produced. A design study was then carried out in order to produce an outline design for the vehicle. The parts for the vehicle were procured and the prototype was constructed.

Initial proving trials were held, before complete field trials took place. The trials were carried out at Saldons Farm in Worcestershire. The shuttle was operated over two days of chipping alongside Econergy's *Surefire* prototype woodfuel harvester to shuttle chip from the chipping site into a barn store on the farm.

Figure 1 Completed chip shuttle, showing high tip bin mechanism in action

CONCLUSIONS

The field trails provided proof of concept for the shuttle design in that the shuttle allowed the chipper near-continuous running at the chipping site rather than having to spend time shuttling chip back to the barn store several time per hour.

The shuttle had the additional advantage of being able to tip directly into the barn store, unlike the chipper itself, which can operate in high tip mode only and requires some 7m clearance to tip.

Figure 2 Low level tipping in the fuel storage barn

Depending on the working system, it is estimated that the shuttle will improve chipper productivity by between 25% (from stack to local store) and 150% (from terrain chipping to distant store). It is estimated that this productivity improvement will reduce the overall cost of woodfuel production in suitable working conditions by perhaps 45% (before storage, loading and transport to end user). This translates into a total woodfuel cost reduction of perhaps up to 20%.

Based on the initial trials it is estimated that the use of the shuttle will reduce overall woodfuel production costs for sites where the (one-way) shuttle distance is between 500m and perhaps 6km.

It is expected that the chipper/shuttle combination will work particularly well on forestry terrain chipping sites, where the raw material cost is significantly reduced by whole tree/long top chipping with no extraction cost.

POTENTIAL FOR FUTURE DEVELOPMENT

Econergy plans to run further field trials, beyond the scope of this project, which will establish in more detail the impact of the shuttle on woodfuel production costs for a range of working systems, including terrain chipping of whole tree thinning and long tops with shuttling to a distant chip store.

dti

Report Ref: B/W2/00759/REP Publication date: July 2003

SRC WOODCHIP STRUCTURE IN DIRECT HARVESTER CHIPPER MACHINERY

Coppice Resources Ltd

OBJECTIVES

- To transfer the technology developed with the tractor-mounted SRC Harvester Chipper onto a larger power unit in the form of a forage harvester.
- To meet the chip specification for effective use in gasification projects whilst maintaining the ability to produce chip specifications for other uses.

SUMMARY

With DTI support, Coppice Resources Ltd successfully constructed a tractor-mounted direct harvester chipper in 1999/2000 (ref. B/W2/00640/REP). The cutting head and feeding mechanism were particularly successful and the machine proved itself capable of harvesting field-scale SRC crops (28.33ha being harvested in 2000).

The additional benefit of the head being capable of 'bolting on' to an existing forage harvester extends the annual usage and thus improves the economic performance of the machinery. The longer usage period and a lowering of the cost per harvested tonne of material also improves the economics of the crop.

The cutting head developed for the tractor-mounted harvester has been successfully scaled up and mounted on the Claas forage harvester platform. Reducing the number of blades in the drum, slowing down the feed rollers, and in static tests altering the feed roller angles, have helped to achieve a more consistent product. However, the ideal chip specification for gasification has proved to be a harder task to achieve. There still remains too high a proportion of out-of-specification material and so further work involving a major redesign and reconstruction of the whole feed system of the head and drum of the harvester will be needed.

COST

The total cost of this project was £130,150 with the Department of Trade and Industry (DTI) contributing £53,931 and Coppice Resources Ltd the balance.

DURATION

19 months - January 2002 to July 2003.

BACKGROUND

In mainstream agriculture the harvesting of specialist crops has become a contractor or farmer group based operation. This is a requirement to meet economics of low-cost harvesting per tonne of product and to allow rapid harvesting of larger areas of crop within growing seasons. In crops such as maize and grass silage the industry has developed to where the majority of crops is harvested by specialist contracting teams using large horsepower forage harvesters. It is this model that the development of the SRC system is based upon, thus leading to the construction of a larger-size harvesting head.

Gasification projects at Project Arbre in Yorkshire and Brooke Hall Estate in Northern Ireland have both participated in previous harvester trials. During the course of the trials it became apparent that the small chip produced by the machine was not ideal for gasification. The machine was shattering the SRC rods producing a flake-shaped chip and a proportion of fine material. This chip would flow with difficulty through a fuel feed system and would be hard to gasify as it would have a tendency to burn.

The successful operation of the harvester chipper has helped promote the idea that larger areas of crop might be harvested in this way through the winter months, especially if it can be demonstrated that the crop can be stored and naturally dried in large clamps of chipped material.

There is therefore the need for a harvester chipper that can handle larger acreages than the previous machine, can produce a chunk not a chip, and can vary the specification of the chunks to meet different power plant requirements.

THE WORK PROGRAMME

Initially, research into the harvester and its head investigated what was available and could be used. A design process was followed to produce a specification for the harvester. A prototype unit was then constructed that could be used for carrying out trials.

The harvesting system was subjected to a series of field trials and subsequent modifications over a period of three months during the winter of 2002-3. It began with simple operating trials to test the principles and the construction of the machine and continued through to work rate and output testing.

Figure 1 The cutting head mounted on a Claas forage harvester

RESULTS AND CONCLUSIONS

- The cutting head developed for the tractor-mounted harvester has been successfully scaled up and mounted on the Claas forage harvester platform.
- The quality of cut has not been compromised and the manoeuvrability of the larger machine is such that it can access the same areas as the tractor-mounted machine.
- The better balance and larger tyres have reduced ground pressure so that the machine can actually operate in more adverse conditions than the original.
- The output of chipped material has been raised to a level whereby, with a more consistent operating pattern, the machine can be developed to a commercially viable harvester for SRC crops.

- Slowing feed roller speeds has resulted in a longer chip/chunk.
- Removing blades from the drum has also resulted in a longer chip/chunk.
- Consistent feeding of SRC has resulted in a more consistent chip/chunk size and structure.
- SRC that has been fed at an acute angle to the drum results in a chunk of SRC that retains itself in the round and does not shatter along its length.
- The harvester can produce a range of chips from 4-5mm through to 30mm lengths with minimal alterations.

POTENTIAL FOR FUTURE DEVELOPMENT

- Issues have been identified with regard to the amount and size of support and transport machinery required to keep pace with the machine when it is operating at maximum output. These require further investigation as to the most efficient solution.
- The power drive system for the head is fragile when faced with crop that has been allowed to grow beyond normal commercial harvesting cycles. A system of clutches or a change to hydraulic drive from the belt-driven system will alleviate this.
- Auto-contour ground tracking of the cutting head requires further attention. The gross weight of the cutting head compared with grass/maize attachments is too much for the current hydraulic system.
- The cutting head saw blades can be blunted if ground contact is made. The auto-contour system will assist in stopping this happen but a jig for regular sharpening, or a different material for the blades, requires investigation.
- The proportion of SRC that is cut at the correct angle needs to be increased in order to increase output of the correct specification. This involves redesigning and rebuilding the whole feed and drum cutting system on the harvester and head.
- To maximise output volume and quality a new bespoke chipping drum needs to be built and an investigation carried out of variable drive speed.
- Consideration should also be given to the plane of the chipping drum in relation to the direction of travel of the crop.

dti

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DENSIFICATION OF CHIPPER-HARVESTED SRC USING ON-FARM MACHINERY

Coppice Resources Ltd

OBJECTIVES

Research

- To identify 'standard' SRC fuel for energy generation.
- To identify suitable standard on-farm densification/baling machinery.
- Trials
- To produce freshly harvested fuel with a SRC chipper harvester.
- To process SRC fuel through on-farm densification/baling machinery.
- To assess 'bales' produced for density and handling characteristics.
- To assess bales produced for long-term storage of up to 15 months.
- To asses bales for heating value.
- Economics
- To assess the individual cost of densifying SRC fuel.
- To assess impact on the cost of transport systems.
- To integrate the costs to show the joined- up fuel supply system economics.
- To identify future development areas to reduce further the cost of delivered SRC fuel.

SUMMARY

SRC and wood chip is by nature a material low in density. This causes logistical issues and additional cost implications when transporting any distance. Wood chip is also quite difficult to handle and store in bulk – requiring larger storage volumes and large- capacity handling machinery – compared with a tightly packed bale. Some end users are able to accept material in baled form only, such as the EPRL power station at Ely that mainly operates on large Hesston-type straw bales.

Therefore, the objective of the project was to solve these problems and to do so by utilising existing on-farm technology and machinery. This has the added implication of minimising capital and operating cost by using technology that farmers are capable of operating and in many cases own already. With a low-value bulk product such as raw wood fuel this is valuable in maintaining an economic margin for the grower at an affordable price for the generator.

The trials were carried out in two stages using differing lengths of chip but always focused on material that

can be produced from a standard SRC harvester. The machinery used was all of standard farm type and had no modifications. It proved impossible, however, to create a bale owing to factors related to the design of the machinery and also the structure of the wood. In some cases part bales were formed and in others failure occurred at the material intake level. No one machine or combination of machines gave a result that was acceptable.

It does not appear from this work that standard farm machinery can be used to bale SRC chip. Extensive modifications, or the importing of technology from waste and forestry industries, may produce a densified bale of SRC but the cost and operating implications make this currently unviable.

COST

The total cost of this project was £29,046 with the Department of Trade and Industry (DTI) contributing £8,500 and Coppice Resources Ltd the balance.

DURATION

19 months - February 2002 to August 2003

BACKGROUND

With DTI support, Coppice Resources Ltd successfully constructed a tractor-mounted direct harvester chipper in 1999/2000. The cutting head and feeding mechanism were particularly successful and the machine proved itself capable of harvesting field-scale SRC crops (28.33ha being harvested in 2000). During this period it became apparent that ideas of harvesting and bundling SRC were potentially very costly, with associated difficulties in handling, transporting and chipping the bundles.

Upon examination of the chipped output of the harvester it became apparent that SRC as a chip is a low-density material. When transported in bulk containers the cost to transport fuel any distance was large. Allied to a low financial value for the chipped material, this became a potential limiting factor in SRC fuel systems.

To overcome this it is necessary to increase the density of chipped material. To be as economically viable as possible the material needs to be densified prior to any transportation taking place and so the farm site at point of harvest was identified as the ideal place.

With the site of densification identified, the issue of achieving this at as low a cost as possible was addressed. The use of existing on-farm machinery to create a 'bale' of SRC chip would appear to be the cheapest way of adding density. A series of machines was considered both individually and as a sequence of operations to achieve this.

Contacts with developers of SRC-fuelled energy generation systems both on the large and small scale have highlighted that an increase in SRC chip density with its reduction in transportation cost would make a significant difference to the economic viability of their projects.

THE WORK PROGRAMME

Research into the types of balers that are available was carried out. There are three main types:

- small square balers
- large (Hesston-type) square balers
- round balers.

One machine from each type of baler was selected for work in the trials.

An economic model was created for the baling process. However, this had to use several estimations because the results from the trials were poor.

Research was carried out into how other industries achieve densification and whether these technologies would be of any use.

RESULTS AND CONCLUSIONS

This set of trials demonstrated that it was not possible to create a bale of compressed SRC chip using existing mainstream farm baling equipment. Through the two sets of trials the three options on bale size were tested. Within each category the major technology types were tried, again with no positive result. There was also variation in the chip size tested in order to see if a smaller/larger chip would bind together to form a dense bale of material. There was no difference in the effectiveness of the machinery on either size grade and so it was concluded that the physical characteristics of the material – stem length, lignin content, compressibility/ expandability - make it unsuitable for compresseing and baling.

POTENTIAL FOR FUTURE DEVELOPMENT

In light of the above, it is concluded that baling of SRC chip as a means of increasing density to reduce transport cost is not possible using farm machinery. It is also not practicable to import technology from other industries to achieve compaction at present. It is recommended that unless there is a technological breakthrough in machinery no further work be carried out at present.

dti

Report Ref: B/W2/00710/REP Publication date: August 2003

STORAGE OF FOREST RESIDUES IN COMPRESSED 'FIBERLOGS'

Forestry Contracting Association

OBJECTIVE

- To monitor the change in composition of compressed residue logs during storage over a period of 18 months.

SUMMARY

The movement towards central comminution has led to the development in Sweden of the Fiberpac residue compression machine that creates compressed residue logs (Fiberlogs). Depending on the species, moisture content of material at the time of compression and the density of the Fiberlogs, concern has arisen in the UK, Sweden and Denmark that during storage the material can decompose resulting in a significant decrease in the net energy value.

An 18-month storage trial of 360 compressed residue bundles was carried out in North East Scotland. Results from the trial indicate that six months storage is the ideal to allow moisture content loss, minimal dry matter loss and to enable an increase in energy value per log. To obtain these results the recommendation is for stacking that ensures air flow between the Fiberlogs, and for the stacks to be covered on the top only to prevent rainfall entering the stacks from above.

COST

The total cost of this project was £97,539 with the Department of Trade and Industry (DTI) contributing £24,386 and industry the balance.

DURATION

21 months - May 2001 to January 2003

BACKGROUND

Transport is known to be the most significant cost element in forest residue supply. Previous studies have shown (report B/U1/00589/REP, project B/U1/00549/24) that forest residue wood fuel compaction in the form of compression systems can significantly increase the net load capability of forest residue transport systems.

A previous study on the storage of compressed residue and short rotation coppice bales gave favourable results with minimal dry matter losses and high moisture content loss and net energy gain over an 18-month period.

The movement towards central comminution has led to the development of the Fiberpac residue compression machine. This system offers increased productivity owing to the continuous flow process of the machine, a low-cost tying system for the Fiberlogs and the ability to utilise existing transport and extraction vehicles. Concern has arisen that during storage the material can decompose resulting in a significant decrease in the net energy value.

THE WORK PROGRAMME

The storage trial was concerned with the compression of Sitka spruce and Lodgepole pine forest residue with different initial moisture contents, transporting to a central storage area and storing for a period of approximately 18 months. During this period the Fiberlogs were monitored to assess Fiberlog weight change, moisture content change, net energy value and dry matter losses.

The residue material was sourced locally from Buchan Forest District within an 8km catchment area of the storage site. Residue material used was both air dry ie that had been felled 3-12 months prior to compression and material that was fresh ie that had been felled 1-5 days prior to compression. The compression of air dry and fresh material was to assess the effects of the different materials on the productivity of the compression machinery, the Fiberlog density and the effects of storage.

All forest sites had been harvested with the conventional short wood system. On the storage site two different types of stack were utilised. Conventional stacks are those where the Fiberlogs are laid parallel to each other and they interlock - the same as stacking of conventional roundwood. Criss-cross stacks are formed with Fiberlogs laid on the ground parallel to each other with an approximate distance of 0.5m between each log; the next Fiberlogs are laid on top at right angles to the layer below, again with a space of approximately 0.5m between each log. Each criss-cross stack was three layers high with six Fiberlogs on each layer, a total of 18 Fiberlogs per stack. Twenty stacks were formed of which 8.5 stacks were covered with a woven plastic sheet. Thermocouples were placed in 15 of the stacks to measure the internal temperature.

Fiberlogs were weighed at the time of stack erection and at two points during the trial and at trial completion. All weights were recorded and samples taken for moisture content analysis using the standard oven method.

RESULTS AND CONCLUSIONS

- The intention of the criss-cross stack type was to let the air pass through the stack to aid in drying the Fiberlogs; the results from the trial showed this to be successful.
- After six months of storage the distinction between the materials' initial status (air dry or fresh) at the time of compression was obvious. However, after 18 months storage there was little difference.
- Fiberlogs composed of Sitka spruce fresh material had the highest density. The high density and moisture content resulted in a lower energy value per Fiberlog at the time of storage. However, after six months storage and the associated moisture content loss they had a higher energy value. There was no relationship between density and weight, moisture content and dry matter losses.
- Weight lost at the first re-weigh was higher on covered stacks in a range from 70-145kg/fiberlog. After 15 months of storage the covered stacks were still losing

weight in a range from 5 to 50kg/fiberlog. The uncovered stacks had regained weight in the range of 6 to 56kg/fiberlog.

- Biological/ dry matter losses in covered stacks were less than in uncovered stacks.
- There was no difference in stack temperature whether the stacks were covered or uncovered and throughout the trial period internal stack temperature reflected the ambient temperature.
- Higher operational losses were sustained on Lodgepole pine stacks because of their material characteristics resulting in less well-formed Fiberlogs.
- The highest energy value per Fiberlog was obtained after six months storage, which was 5.62GJ.
- The moisture content of fresh material decreases more quickly than that of material that is air dry at the time of compression.
- Residues with a moisture content of 25 – 30% at the time of compression should not be stored as they have reached the wood saturation point ie where their moisture content is dependent on the current temperature and relative humidity of the air. With a relatively high humidity of over 85% for the period of the storage trial, once the material reaches the fibre saturation point the material moisture content will not decrease any further. At this moisture content range under climatic conditions of high relative humidity, storage is not required.
- As storage is only one element of the supply chain Sitka spruce is preferred because of a higher compression machine productivity coupled with the ability of the Sitka Fiberlogs to withstand increased handling.
- The lowest moisture content figures were achieved after six months of storage. At this time the moisture content in some of the stacks was as low as 20%. Calorific value increases when the moisture content decreases. At the time of reweighing, after six months, the low moisture content, combined with the low weight loss in the stacks (ie weight loss attributable to moisture content loss, not biological/dry matter losses) resulted in a high energy value. After the six-month period, owing to the fibre saturation point of the wood being reached, coupled with wet climatic conditions, the moisture content increased with total stack weight decreasing through biological losses. This resulted in a low calorific value and greater dry matter losses at the end of the 18-month storage period.
- The overall results of the trial show that with the climatic factors experienced at the storage site the optimum period of storage would be 5-6 months, using covered stacks of fresh Sitka spruce material in a criss-cross stack formation.