MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

RESEARCH AND DEVELOPMENT - FINAL PROJECT REPORT

NF0403 - MISCANTHUS AGRONOMY (FOR FUEL AND INDUSTRIAL USES)

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ANNEX I

Technology Transfer:

The findings of this research programme have been reported widely in the scientific literature, commercial literature, popular press and conferences. Also, specific technology transfer days were held at ADAS Arthur Rickwood in February 1996 and March 1998, during which the key research was presented and field demonstration of planting and harvesting undertaken, to an audience of farmers, scientists and policy makers. The programme has also been reviewed by MAFF (5 June, 1998) and reviewed independently by Dr Keith Brent, on behalf of MAFF. Numerous site visits have been hosted for individuals in both public and private sector. The research has featured in radio articles and has fed into other research (e.g. taxonomic investigations of Miscanthus; activities of South West Industrial Crops Group).

A considerable number of research papers have been written (Annex II).The work that has been reported here has also featured in the final reports for the European Miscanthus Productivity Network, alongside a considerable quantity of European research findings.

Further work:

There are some key areas that warrant further research effort:

1. The continuation of existing experiments in order to identify yield profile and crop longevity into the 'middle term' of the required crop lifetime.
2. A significant research effort into understanding the processes that influence rhizome establishment is needed, and from that work recommendations for the most appropriate planting methods developed.
3. The relationship between yield and water availability; and the development of varieties with even lower moisture requirements.
4. The suitability of lowland ex-grassland for Miscanthus cropping, and the likely yield profile on such sites.
5. Further taxonomic studies with the genus in order to identify cold tolerant strains, high yielding strains and possible high pest and disease resistance.
6. Studies to improve harvesting efficiency and storage/transport losses, and investigation of November harvesting options;
7. Development of techniques for the production of a dried chip material;
8. Investigation of the feasibility of Miscanthus as a litter material
9. As advances are made in the husbandry and exploitation of the crop, so the economics of Miscanthus production will become better refined. It is essential, therefore, that this economic modelling assessment is repeated regularly.

Annex II

Research papers produced from NF0403:

- Bullard, M. J., Nixon, P. M. I., and Heath, M. C. (1997). Quantifying the yield of Miscanthus x giganteus in the UK. Aspects of Applied Biology, Biomass and Energy Crops, 49, 199-206.
- Bullard, M. J., and Kilpatrick, J. B. (1997). The productivity of Miscanthus sacchariflorus at seven sites in the UK. Aspects of Applied Biology, Biomass and Energy Crops, 49, 207-214.
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- Bullard, M.J. (1995) Perennial energy crops - experimental challenge and Compromise. In Field Experiment and Data Capture Handling. Aspects of Applied Biology, Churchill College, Cambridge 11-13 December 1995.
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- Bullard, M.J., Heath, M.C., Nixon, P.M.I., Speller, C.S. and Kilpatrick, J.B. (1994). The comparative physiology of Miscanthus sinensis, Triticum aestivum and Zea mays grown under UK conditions. Proceedings of Alternative Oilseed and Fibre Crops for Cool and Wet Regions of Europe. COST 814 Workshop, Wageningen. 7-8 April 1994, 176-180.
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- Bullard, M.J., and Kilpatrick, J.B. (1994). Energy from Elephant Grass. MAFF Bulletin, May 1994 pp 6-7.

- Heath, M. C., Bullard, M.J., Kilpatrick, J.K. & Speller, C.S. (1994). A comparison of the production and economics of biomass crops for use in agricultural or set-aside land. Aspects of Applied Biology 39, Arable farming under CAP Reform (ed Clarke, Lane, Mitchell, Ramans & Ryan) 505-515.
- Kilpatrick, J. B., Heath, M. C., Speller, C. S., Nixon, P. M. I., Bullard, M. J., Spink, J. G. & Cromack, H. T. H. (1994) Establishment, growth and dry matter yield of Miscanthus Sacchariflorus over two years under UK conditions. Proceeds of Alternative Oilseed and Fibre Crops for Cool and Wet Regions of Europe. COST 814 Workshop, Wageningen. 7-8 April 1994, 181-185.
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ANNEX 3

PRODUCTION ECONOMICS AND MARKET ASSESSMENT FOR MISCANTHUS

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Contents:

Summary:

1. Miscanthus is a genus of perennial sub-tropical grasses, that has received much research attention during the last ten years as a potential non-food crop in the UK, combining high biomass yields with low input requirements. This report provides a comprehensive analysis of the costs of production of this novel crop. It examines the likely markets for the crop and corresponding price of delivered material, and thus compares the profitability of a hypothetical Miscanthus enterprise with arable rotations, grassland and short rotation coppice (SRC). The necessity and impact of financial support are discussed.

2. The foremost market for Miscanthus will be that of energy generation, for which the baled product will be appropriate. The UK is committed to 10% (7,000 GWe) of its energy generation coming from renewables by 2010. If just 5% (350 MWe) were produced from Miscanthus, this would require c. 2 million tonnes of feedstock annually, or approximately 110,000 ha of crop. Thus, the scale of the market could be significant, and there are no technical barriers to its use. Even with the guarantee of a supply contract under the Non-Fossil Fuel Obligation (NFFO), growing Miscanthus for energy is a relatively high risk undertaking. In this market, it is anticipated that, at best, an ex-farm price of £40 odt^{-1} is attainable.

3. The cost of production (1999 prices) of one baled, oven dried tonne (odt) of Miscanthus, ex-farm, is calculated to be £46 in the absence of any support, and that of chipped Miscanthus to be £53. At these costs, Miscanthus could not be grown commercially. However, Miscanthus is currently supported (via set-aside payments), and will compete against alternative enterprises that are also supported. It is advocated that support for Miscanthus is continued in order that the environmental benefits of the crop, and the risk of the enterprise, are considered. Inclusion of current set-aside payments reduces the cost of production to £22 odt^{-1} and £26 odt^{-1}, for baled and chipped Miscanthus, respectively. The most cost-sensitive elements of Miscanthus production are yield and harvesting costs. Propagule price, a one-off payment, has very little impact over the lifetime of the crop.

4. If totally unsupported, Miscanthus performs similarly to coppice, and is not a viable option for the farmer. With the inclusion of set-aside support, Miscanthus produces slightly better margins than coppice (£286 ha^{-1} yr^{-1} compared with £255). Parity with arable cropping could be achieved with AAPS set-aside payments (£252 ha^{-1}), plus a one-off planting grant of £1,050 ha^{-1}, or alternatively annual support of £350 ha^{-1}.

5. Economically, Miscanthus would be better grown on ex-grassland, with support. However, whilst Miscanthus yields on arable land are reasonably well quantified, there is no evidence for viable yields on ex-grassland, particularly at altitude. Thus, Miscanthus as an ex-grassland enterprise remains speculative.

6. In order for Miscanthus to attain penetration in the renewables market by 2005 (through uptake in NFFO 6), a network of demonstration farms should be established which enable:
    - whole-farm yields to be verified;
    - whole-farm economics to be assessed;
    - technology transfer to promote the crop.

7. More speculative markets exist, notably paper pulp, medium density fibreboard, animal bedding and plant growth media. 26 million tonnes of plant fibres are used industrially in the UK. This figure excludes agricultural feeds, agricultural bedding and textiles. In 1993, the UK production of industrial plant material was 3.3Mt with an additional 4.1Mt from recycled paper. The import bill that year was c. £5 billion, with exports only totalling £1.3 billion. There is, consequently, a large import substitution market for appropriate crops with appropriate properties that can be produced economically in the UK. No long term security of supply could be guaranteed for these markets and they are consequently high risk. The scope for these markets to develop is limited by logistic problems or through lack of technical demonstration.

8. Pulp and medium density fibreboard (MDF) markets could offer very good or very poor returns due to the volatility of world market prices. Also, the processing capacity of existing plants in the UK is huge, they are unwieldy and the conservatism of the producer makes it unlikely that a shift from wood based products to Miscanthus would take place. Also, they are located in remote parts of the UK and consequently transport distances would be prohibitively high. However, more local initiatives are beginning to appear and might offer long term (say 10 years hence) opportunity.

9. Limited research indicates that Miscanthus might have value as a peat replacement in soiless growth media. The market is significant (perhaps as much as 35,000 odt yr^{-1}), and could be supplied by unsupported cropping. However, more needs to be known about the technical feasibility of the crop in this market. The animal bedding market is purely speculative. Insufficient evidence of the value of Miscanthus exists. However, if appropriate, margins to the farmer could be very attractive.

10. Production of this report has identified a number of key areas where further production-based research is needed if we are to get a better estimate of Miscanthus economics. These include:

    - Evaluation of Miscanthus yields on ex-grassland;
    - Harvesting efficiency and storage/transport losses;
    - Plant breeding for improved yield;
    - Low cost establishment techniques;
    - Low cost planting techniques;
    - Techniques for the production of a dried chip material;
    - Feasibility of Miscanthus as a litter material.
    - Evaluation of Miscanthus growing media.

11. To summarise, if Miscanthus is to be encouraged in a market where it sells at £40 odt^{-1}, then either:

a) significantly higher yields and efficiency gains during the harvesting phase; or

b) significant additional grants and equalising payments, will be needed.

At produce values greater than £50 odt^{-1} Miscanthus begins to become an attractive alternative to annual crops, in the absence of support, although even higher values may be needed to overcome mistrust of long term crops. Whilst Miscanthus must still be considered a pre-commercial crop, it does appear to have significant potential as an energy species within the next five years, so long as it receives support. More speculative markets offer viability of cropping in the absence of support, but the immediate feasibility of these markets is currently limited by technological or wider market issues.

12. As advances are made in the husbandry and exploitation of the crop, so the economics of Miscanthus production will become better refined. It is essential, therefore, that this economic modelling exercise is repeated regularly.

Glossary of terms

AAPS	Arable Area Payment Scheme
AEV	The Annual Equivalent Value represents an average annual value in current money terms which sums to the NPV (each annual value is discounted to present money).
BEC	Break-even cost - The break-even cost, is the price, in current money, that would be needed to offset all the costs of production amortised across the lifetime of the crop, taking into account successive yields discounted at 8% as the base case.
CEC	Commission of the European Community
EU	European Union
Gross margin	The gross margin in the difference between the market value of produce and the variable annual costs of producing that produce.
GJ	Giga-joule (one million joules)
kWh	Kilo-Watt hour
MJ	Mega-joule (one thousand joules)
MW	Mega-watt
MWe	Mega-watt electrical capacity
MDF	Medium Density Fibreboard
Net margin	The margin over costs excluding land rent
NPV	Net Present Value represents the sum of values in each year over the 20 years of planting, discounted to the present.
NFFO	Non-Fossil Fuel Obligation
odt	Oven dry tonne

1. INTRODUCTION

1.1 What is an energy crop?

An energy crop is a plant species that is grown specifically to be harvested and subsequently used as a feedstock for thermo-chemical processes to produce energy. Any plant species has the potential to be an energy crop. The principle underlying energy generation from crops is that the plant, during photosynthesis, captures the radiant energy incident upon it and stores this energy as fixed carbon (sugars, oils or ligno-cellulose). The process of combustion releases this stored energy into a form that can be used (heat or electricity).

1.2 Why grow energy crops?

There are two principal answers to this question; one agricultural, the other environmental. There is surplus agricultural land available in the UK and Europe; currently, 10% of arable land must be set-aside from food production under Common Agricultural Policy regulations (Agenda 2000). Some non-food crops (including energy crops) are eligible to be grown on set-aside land, and may, therefore, provide added value to the farmer if the economics are attractive. The market for energy crops is developing now in response to the need for atmospheric CO_2 abatement. The UK government identifies biomass-derived energy as one of the main ways that it can achieve its obligations under the Kyoto Climate Change Agreement (DTI, 1999a). Under this agreement, 10% of the UK's primary energy is generated from renewables by 2010, in order that we reduce anthropogenic CO_2 output by 12.5% relative to 1990 levels.

Much activity has been focused on the development of relatively high yielding, low-maintenance perennial plant species as energy crops, and the first short rotation coppice-powered stations are now being built[1]. Existing and imminent biomass generation capacity in the UK is less than 100 MW. In order to meet the UKs 10% generation target, a total of 7,000 MWe must be generated from all renewable sources. Across the EC, a target of 10,000 MWe from biomass crops is in place (EC, 1999).

We are now in a situation in the UK where large-scale production of coppice is attracting significant financial support from government on a localised basis, and with this support it is becoming a viable economic alternative to annual cropping for farmers. Coppice does, however, need support. Yields are not particularly high, and current predicted gross margins to farmers are sufficiently low to necessitate as much as £1,000 ha^{-1} of grant aid in the first year (in addition to set-aside payments) in order to stimulate uptake (Anon., 1998). Other species, still at developmental stage, are demonstrating higher yields than coppice and thus potentially greater acceptability. Principal amongst these is the Asian perennial C4 grass Miscanthus. However, high yield is not sufficient to guarantee viability. The crop must be able to provide an economic return to the farmer, at the prices likely in the unsupported marketplace.

[1] Four power stations are under construction. The station closest to commissioning is being built by ARBRE Ltd. An 8 MW station at Eggborough, North Yorkshire. Border Biofuels are constructing a 20 MW biomass-fired station near Carlisle, Cumbria. Ambient Energy are building two, 5.5 MWe power stations, one at Eye, Suffolk, and the other at Crickdale, Wiltshire. At least 8,000 ha of new short rotation coppice will eb established for these stations.

The value of Miscanthus may not be exclusive to energy generation. Its use as a feedstock in various fibre markets has been advocated, and in many cases technical feasibility has been demonstrated. How close these uses are to market reality is reviewed in this document. This report summarises our current expectations of costs of Miscanthus production, likely markets and products for the harvested material. It compares enterprise prices and consequently the viability of the species at present.

1.3 Growing Miscanthus

Miscanthus is a genus of tropical and sub-tropical perennial grasses. As low temperature-tolerant C4 plants, with the proven capability for high radiation use efficiencies and growth, they have received considerable research interest during the 1990s as a potential energy crop.

The growth pattern of these grasses in northern Europe is relatively simple. Following planting of rhizomes (or tissue-cultured plants) during late April and May, multiple shoots appear once daytime temperatures exceed approximately 10°C. Growth during May, June and July is extremely rapid, producing cane like stems which may reach 3-4m in height. Once full light interception is achieved, the lower layers of leaves begin to senesce, whilst shoot growth continues through August and September and even into October. Full senescence occurs following the first frosts of the autumn. During the end of the growing season, nutrients are re-mobilised from stems and leaves to the rhizomes. The standing stems gradually dry throughout the winter, until by February/ March time the crop is ready for harvest.

The crop can be harvested either by cutting/conditioning, swathing and then baling the stems or by chipping using a forage harvester. The early spring, between harvest and initiation of re-growth, is the ideal time for weed control. New shoots appear in March-May, when an accumulated temperature of 200-400°C has been reached. Thus, an annual cycle of biomass harvest is achieved with this crop. The forms of Miscanthus grown for biomass seldom flower due to their daylength requirement. Many other species, however, notably varieties of M. sinensis, do readily flower in the UK.

On current evidence (Beale & Long, 1995; Bullard, Heath & Nixon, 1995; Bullard, Nixon & Heath, 1997), it appears that the crop is an ideal energy crop due to:

1. efficient C4 photosynthesis during summer periods when moisture is not limiting, producing extremely high amounts of ligno-cellulosic biomass;
2. extremely efficient use of nutrients;
3. high resistance to pests, diseases or grazing mammals;
4. very high water use efficiency;
5. ease of handling at all stages, making it acceptable to farmers.

However, certain concerns are still apparent with this crop, in particular:

1. Insufficient cold tolerance to withstand springtime frosts which destroy the crop canopy;
2. We do not yet have sufficient evidence that high yields will be maintained for the 15-20 yr long-term yield profile required from perennial energy crops;
3. High moisture content on harvest (30-50%) may necessitate pre-drying before combustion and will make transport more costly;

Experimental material grown in the UK (and indeed continental Europe) is of unimproved genetic origin, principally of two species; M. sacchariflorus and M. x giganteus. A considerable diversity of genetic material is held at the National Collection at ADAS Arthur Rickwood, and this has been the subject of detailed taxonomic study (Hodkinson, Renvoize & Chase, 1997). Consequently, all evidence on which this economic analysis is based has been derived from genetically unimproved material. As a consequence, there is still considerable potential for improved yield in Miscanthus.

1.4 Land use and production/productivity zones

A significant research effort has been invested in determining the likely yield potential of Miscanthus in England (Bullard, Heath & Nixon, 1995; Bullard, Nixon & Heath, 1997; Bullard & Kilpatrick, 1997). Whilst after 7 year's experimentation, crop growth models are not sufficiently advanced to identify zones or soils of high yield capacity to any significant resolution (i.e. individual field scale ± 3 t ha^{-1}), we can, for the purposes of this review, make a few generalised statements.

It is unlikely that yields from established crops on any uncontaminated arable land (grades I-III) south of a line drawn from the Severn to the Wash will be less than 12 t ha^{-1} yr^{-1}. Many, can be expected to produce 18 t ha^{-1} in most years. These assertions are made on the basis that significant pest and disease problems are not encountered, that adequate levels of nutrients are supplied to the crop and that severe spring frosts and summer droughts are not experienced. In the case of the last caveat, we now have evidence that the long-term yield potential of Miscanthus is not reduced by a drought period. ADAS results from project NF0403 indicate that many sites both south and north of this line will provide yields well in excess of 18 t ha^{-1} yr^{-1}. It is anticipated that these conservative figures will be revised upwards as progress with the selection and breeding of more suitable varieties takes place. Judicious selection of land, on a site-by-site basis, should result in reliable yields in excess of 18 t ha^{-1} yr^{-1}. However, it must also be accepted that most sites and soils which are conducive to very high Miscanthus yields are more likely to be cropped with the highest value cash crops; and this will not necessarily be Miscanthus.

Miscanthus may also be suited to soils coming out of permanent grassland production, although soils, and therefore yields, will be more variable. There is no evidence yet to support yield predictions on restored grassland.

Use of landfill & derelict land - across the EU, 1.4% of land is classified as derelict and unsuitable for food production (Walsh, 1997). Particularly for the energy generation market, it may be expedient to make use of this land. Here, areas will require a period of bio-remediation and soil stabilisation that might form a suitable niche for a perennial crop such as Miscanthus. Lower overheads and rental prices on these lands will reduce the unit cost of production. However, crop yields may well be lower on contaminated soils. Further experimentation is required to identify whether the revenue lost due to the yield penalty on such sites is likely to exceed the value of the saving on fixed farming costs.

Additional revenue generation from disposal of wastes on the crop - application of sewage and other liquid wastes (for example from the brewing industry, glass making industry) may have the double benefit of providing nutrients and additional moisture to the crop whilst at the same time commanding a small income to the farmer/landowner for the regular disposal of these wastes. These avenues of cost reduction might only sensibly be prosecuted in areas adjacent to the producer of the waste, and as such, these special cases are not factored in to the break-even cost analysis in the following sections. Opportunities for the development of Miscanthus on long-term sewage disposal land, owned by Water Utilities, should not be overlooked, particularly in view of the increasing requirement to dispose of sewage on land rather than at sea. Miscanthus undoubtedly has a role in bio-remediation, derelict land improvement and waste utilisation, but disposal agencies and growers must be mindful that Miscanthus grown on contaminated soil may be unacceptable as a fuel, both from the ash disposal view point and from possible emission problems (Bullard, Christian and Wilkins, 1996).

Environmental aspects - a recent ADAS review (Spink & Britt, 1998) identified Miscanthus to be one of the most environmentally benign alternatives to permanent set-aside (Annex 1). The following economic analyses do not consider environmental aspects directly, although they must of course present an important consideration when evaluating the merits of different enterprises

1.5 Previous studies on the economics of Miscanthus production

There have been a number of previous studies that address aspects of the economics of production of Miscanthus. Each has used a different approach to cost analysis. Whilst some studies have been superseded by more recent research, they all contain useful data and their key observations are reported here.

Rutherford & Bell (1992)

In the first review of economics for the UK, break-even costs per tonne were calculated for a crop lifetime of 15 years, with costs discounted at 8% per annum. Individual propagules were predicted to cost £0.25, but harvesting operations (under contract) only cost £200 ha^{-1}. No provision for on-farm storage or handling, or subsidies, was made. On this basis, with a yield of 20 odt ha^{-1} yr^{-1}, a break-even cost per tonne (ex-field) of £36 odt^{-1} was calculated. Rutherford & Bell (1992) asserted that, based on its energy content, the price that Miscanthus might attain was likely to be in the region £21.6 - £26.2 odt^{-1}. Consequently, Miscanthus was not considered economic at that stage. Rutherford & Bell (1992) considered that the major consideration needed to be the reduction in establishment costs.

Chisholm, (1994). Towards a UK research strategy for alternative crops

This document reviewed the potential of a very wide range of crops for a number of markets, including energy, paper and building materials. It assessed the potential of Miscanthus for the energy market to be very high, although at the time it was considered a very expensive crop to establish. Miscanthus was not considered appropriate for any markets other than energy.

Allen, Brown, Hunter, Boyd & Palmer (1996)

Transport and supply logistics of Biomass Fuels: supply chain options for biomass fuels

Allen et al., (1996)

Produced a detailed analysis of production and transport costs, which considered two systems for Miscanthus production:

1. Cut & chop;
2. Cut & bale.

Option 2 was considered to be the more expensive production option, with harvesting operations costing £7 t^{-1} and £11 t^{-1} for 1) and 2), respectively. However, once transportation to the factory had been considered, option 1 was 20% more expensive due to differences in the bulk densities of the two materials. Their study assumed that the harvested material was stored on-farm for 6 months, and that moderate harvesting, storage and transport losses of biomass occurred. They calculated the supplied cost of Miscanthus to be £54 - £66 odt^{-1}; greater than that for forest fuel, coppice or straw.

Huisman, Venturi & Molenaar, 1997. Costs of supply chains of Miscanthus giganteus.

This Dutch study compared the unit costs required for Miscanthus under a number of scenarios, including eight different harvesting systems undertaken either by the farmer, or by a notional specialist company who undertook to plant and harvest the material for their own industrial uses. Individual operation costs were defined using standard texts. Cost of production included transportation to the factory gate and an element for farmer profit. As a consequence, the price per tonne of Miscanthus feedstock was estimated to be high. Where operations were conducted by the farmer there was very little difference in the cost of Miscanthus for those harvesting scenarios which are common to the current review. Miscanthus cost approximately £90 odt^{-1}. If operations were conducted by a specialist company then economies of scale and utilisation of equipment dropped costs, Miscanthus cost between £82 (self-propelled chopper) and £88 odt^{-1} (self-propelled baler).

Sanders and Bruce (1997). The financial viability of UK grown fibre crops for the panel products industry.

Analysing the cost of 12 crop feedstocks, specifically for the panel products industry, these authors used a whole-farm crop model in order to calculate 'net gross margin'. The net gross margin was defined as the sum of the crop gross margins less rotational penalties, timeliness penalties and machinery and labour costs. The model assumed that Miscanthus receiving set-aside payments, at a yield of 12 odt ha^{-1}, would be harvested in a chipped form and delivered following drying under ambient conditions. Of the nine annual and perennial crops compared, the delivered break-even cost of Miscanthus, at £155 odt^{-1}, was by far the highest. This estimate was distorted, principally by a very high assumed propagule costs (£7,500 ha^{-1}). When the model was re-run for propagule costs of £500 ha^{-1}, then the delivered break even cost was reduced to £45 odt^{-1}. It was concluded that insufficient information was available on key operations such as planting costs and drying costs, for a more accurate assessment of true cost to be made.

Venturi, Gigler and Huisman (1999) Economical and technical comparison between herbaceous (Miscanthus x giganteus) and woody energy crops (Salix viminalis).

The most recent study, this compared willow and Miscanthus costs of production from net margins (i.e. land charges were excluded) under four scenarios. For baled Miscanthus the net margin was £26 odt^{-1} (assuming a conversion rate of £0.65 $€^{-1}$). The cost for chopped Miscanthus was £25 odt^{-1}. Chipped and whole stem willow cutting costs were £33 odt^{-1} and £23 odt^{-1}, respectively.

1.6 Current support for Miscanthus

Miscanthus is currently (September 1999) an eligible crop for set-aside. Under Agenda 2000 reform it has been agreed that up to 100% of Arable Area Payment Scheme (AAPS) registered land can be set-down to Miscanthus and receive set-aside payments. The 1999 rate for set aside was £306 ha^{-1}, but it is anticipated that this figure will drop to £252 in 2000. At the time of writing this report, no planting grants were available for Miscanthus.

1.7 Purpose and structure of the current review

Alongside the economic studies conducted to date, a significant research programme since 1991 has undertaken to identify the yield potential and agronomic suitability of Miscanthus to the UK and also identify its value as a fuel source and feedstock for other end uses. We are now at a stage, particularly with the adoption of coppice as a commercial crop, where we need to reassess Miscanthus economics. The current review incorporates the most appropriate methodologies and comparative data from previous studies in order to determine the comparative costs of production of Miscanthus, its likely value in the range of markets which it suits, and consequently its suitability and long-term prospects in these markets. To be of maximum comparative value to MAFF, methodologies are integrated with those of Brown & Walsh (1998), in order that Miscanthus can be directly compared with current thinking on coppice.

The review is structured in the following manner.

- The First section summarises the current predicted costs of establishing Miscanthus and the costs associated with annual husbandry and harvesting of the crop. A productive economic lifetime of 19 years is assumed.
- Section 2 presents calculated costs over the entire lifetime of the crop, and shows which are the most important factors that can influence that price.
- Section 3 identifies the point (profit) at which farmers will realistically consider switching from other arable crops/grassland to Miscanthus.
- This report then presents, in section 4, the economics of Miscanthus on the basis of individual markets, in order of medium term viability; thus, the most likely market is presented first. The markets investigated are, in order:
    1. Energy;
    2. Fibre (composite materials and paper pulp);
    3. Building materials (light natural sandwich materials)
    4. Animal bedding;
    5. Growing medium additives
    6. Insulation
    7. Densified Heating blocks

For each of these, a comparison with other arable crops is undertaken in order to identify the likelihood of farmers adopting Miscanthus against other crops.

1.8 Objectives of the review

- To identify and evaluate the full range of markets into which Miscanthus might enter as a viable crop.
- To provide a comprehensive analysis of costs of production of Miscanthus.
- To compare the likely commodity price of Miscanthus in a range of markets.
- To provide an appraisal of likely market size, value and assess the opportunity for import substitution.
- To identify niche cropping opportunities, with particular respect to land types and waste deposition.
- To assess the comparative position of Miscanthus by reference to UK average gross margins for selected examples of cereals and break crops.

2. COSTS OF PRODUCTION

2.1 Economic framework for calculating Miscanthus production costs and margins

The following techniques and assumptions are made, which are consistent with the methodology of Brown & Walsh (1998) and allow cross comparison with their analysis of short rotation coppice (SRC) profitability. A productive lifetime of 19 years is assumed throughout and costs of production are considered as the break-even cost (BEC) of producing 1 odt (oven dry tonne) of biomass at the farm gate[2]. This allows direct comparison between production costs and likely product values in the range of markets later identified in Section 4.

In order to identify the relative merits of a Miscanthus enterprise against other cropping systems, gross and net margins[3] are expressed in terms of net present value (NPV)[4] and annual equivalent value (AEV).[5] This is both consistent with Brown & Walsh's (1998) paper, and also (by assuming a price of £40 odt^{-1}) with the current industry perception of likely product price for energy. NPVs and AEVs have been re-calculated for other potential markets on the basis of the most likely product price. For all analyses, a standard discounted rate of 8% is used. For indicative purposes, the effects of reducing discounted rates to 3% and 5% are presented (Annex 4). The impact of increasing/decreasing product price in alternative markets is considered in a sensitivity analysis.

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[2] The break-even cost, is the price, in current money, that would be needed to offset all the costs of production amortised across the lifetime of the crop, taking into account successive yields discounted at 8% as the base case.

[3] The gross margin in the difference between the market value of produce and the variable annual costs of producing that produce. The net margin includes elements of fixed costs. A comparison between different enterprises is important as biomass cropping involves a great deal of contract work (classified as a variable cost), which tends to lower the gross margin relative to other enterprises less reliant on contract work.

[4] NPV represents the sum of values in each year over the 20 years of planting, discounted to the present.

[5] The AEV represents an average annual value in current money terms which sums to the NPV (each annual value is discounted to present money).

Predicting the costs of Miscanthus production requires the use of techniques which discount future prices and costs against today's money value in the same manner as would be approached with SRC. However, Miscanthus does offer a more regular cash flow with annual harvesting, and lower establishment and crop maintenance costs. Costs of production can be split between one-off establishment costs in year one, and annual maintenance and harvesting operations in each subsequent year.

2.2 Establishment costs for Miscanthus

As a pre-commercial crop, the price of the starting propagules is one of the most difficult variables to quantify. Experimental Miscanthus crops have previously been established at a unit price of as much as £0.6 per propagule, when material has been purchased, in small quantities, direct from a nursery or tissue-culture facility. However, the vegetative productive capacity of the Miscanthus rhizome should allow for a significant reduction in this cost. It is anticipated that a unit price of £0.05 per propagule is feasible where field scale propagation of rhizomes is undertaken. In this scenario, Miscanthus lines will be raised by the breeder in multiplication beds. A mature rhizome can be split to produce 30 to 100 viable daughter rhizomes after two years. Thus, mature rhizomes are lifted, split, collected, graded and sold on to the farmer (Bullard, 1996; Huisman and Kortleve, 1994). The £0.05 unit price includes costs of cold storage of rhizomes prior to delivery to the farmer, deliver costs, plant breeder's rights and profit margin. A plant density of 10,000 plants ha^{-1} is considered the optimum density from a biological view-point (Bullard & Kilpatrick, 1997), although to compensate for current planting system inadequacies, a density of 20,000 plants ha^{-1} is used in this report (Annex 2). Other costs during this phase are land preparation, planting and agro-chemical inputs to control weeds. These costs are summarised in Table 1. A 'standard' cultivation is assumed (ploughing and disk harrow) followed by contract planting using a ridger and semi-automatic potato planter.

Table 1. Cost of establishing one hectare of Miscanthus

Activity	Cost (£ ha^{-1})
rhizome costs (£0.05 @ 20,000 plants/ha)	1000
Cultivation	75
Fertiliser	48
Herbicides	80
Contract planting	117
Insecticides/fungicides	0
TOTAL	1320

2.3 Annual maintenance

Evidence from multi-site field trials in the UK during the last six years indicates that annual husbandry after the first season will be minimal. Primary requirements will be for one broad-spectrum, translocated, herbicide application during spring to control grass weeds, and a moderate nitrogen fertiliser application. Although a low level of insect damage (primarily lepidoptera larvae) and some stem basal disease activity has been noted at some sites, chemical control is not considered economic at this stage. Annual husbandry costs are shown in Table 2.

Table 2. Annual husbandry costs for one hectare of Miscanthus

Activity	Cost (£ ha^{-1})
Cultivation	0
Fertiliser	37
Herbicides	32
Fencing	0
Insecticides/fungicides	0
TOTAL	69

2.4 Harvesting operation

The most effective method for harvesting Miscanthus has been demonstrated at ADAS Arthur Rickwood. Harvest should be timed between mid-February and late March to minimise crop moisture content (Bullard, 1996). The optimal harvest system comprises initial cutting as base level with simultaneous conditioning (as it passes through the mower) of the stem to allow easier baling and more rapid drying. Swathing for 6 weeks has been noted to reduce stem moisture content from 45% to c. 20% (authors' personal observations). After cutting and conditioning /swathing, a Hesston-type square baler is used to produce 1.2 m x 1.4 m x 2.2 m bales, with a bulk density of 240 kg m^{-3} and which weigh 0.9 t (authors' personal observations). These are easily moved, stacked and transported.

The harvesting operation is the most expensive annual operation due to the high yield of material to be baled and its high moisture content. Thus, a standing crop of 18 odt ha^{-1}, baled at 20% moisture content, will weigh 21.6 t and will require 24 bales. Equally, the bales will probably require on-farm storage prior to transportation to the factory. A detailed description of the derivation of harvesting costs is presented in Annex 2, but summarised here.

Table 3. Cost of harvesting one hectare of Miscanthus, assuming 30t of fresh biomass standing, and subsequently storing for 6 months.

Activity	Cost (£ ha^{-1})
Mower conditioner	25
Baling	120
Carting and stacking & loading	24
Storage costs	34
TOTAL	203

It is anticipated that the yield of material arriving at the factory is 80% of standing yield due to losses of leaf material during harvesting, and further storage and transport losses. However, further work is required in order to verify this.

An alternative method of harvesting for some niche uses of Miscanthus may be to cut and chip the material in one operation using a forage maize harvester. This has been demonstrated at ADAS Arthur Rickwood and is likely to carry a comparable cost per hectare (Table 4). However, losses of biomass during harvesting, storage and transport are anticipated to be higher, at 30-40%, due mainly to microbial degradation during storage (Huisman & Kortleve, 1994; D. Bartlett, unpublished). Also, transport costs per tonne will also increase because of the lower bulk density of the harvested material.

Table 4. Cost of alternative method of harvesting one hectare of Miscanthus, assuming 30t of fresh biomass standing, and subsequently storing for 6 months.

Activity	Cost (£ ha^{-1})
Contract forage harvesting, carting & stacking	125
Storage costs	86
TOTAL	211

If the chipped material requires forced-air drying, the cost of this additional operation is £0.44 for every percentage point dried. For example, to take the moisture content from 40% to 10% would cost £13.32 odt^{-1}.

2.5 Productive lifetime and yield profile

For the purposes of baseline cost modelling, a productive life-span of 19 years has been assumed (c.f. Brown and Walsh, 1998). This is four years more than the duration of a NFFO contract. Costs of production, and gross and net margins, are particularly insensitive to crop longevity in the base-case scenario, due to low start-up costs and high annual harvesting costs.

Standing yields of between 12 and 24 odt ha^{-1} have been reported with experimental Miscanthus crops. For the purposes of this exercise, the median harvested yield of 18 odt ha^{-1} is used, with a 20% reduction in biomass (due to processing losses) assumed to occur before sale of the material (i.e. 14.4 odt ha^{-1} arrive at the factory gate). No harvest is expected in year 1.

2.6 Fixed costs

Fixed costs are set at £117 ha^{-1} yr^{-1}, the level used by Brown & Walsh (1998) in their study of SRC production costs. Labour costs and machinery maintenance are included but rental value of land is excluded. This figure is significantly lower than other published equivalent costs for arable situations (e.g. £335 - £495; Nix, 1999).

2.7 Farm-gate production costs for Miscanthus

Annualised break-even costs of production were calculated both in the presence and absence of set-aside payments. Detailed methodologies are presented in Annex 3. In the absence of any form of support, and assuming a harvested yield of 18 odt ha^{-1} and using the assumptions detailed above, the break even cost (BEC) of production of baled Miscanthus is £46 odt^{-1}. The cost of delivering one tonne of chopped Miscanthus is £53, and chopped and dried Miscanthus is estimated to be £66. These figures decrease to £22, £26 and £44 respectively, when current set-aside support is included. The derivation of these figures for baled miscanthus are shown in Annex 4.

Where the crop is not supported, the principal contributors to the cost of Miscanthus production in the baled scenario are yield and the cost of harvesting. This is sensitive in turn to the scale of operation, biomass dry matter content, and bulk density of bales and harvester efficiency. Significant improvements should be attainable. When supported, break-even cost is relatively insensitive to improvements in yield because of the high additional costs of baling and storage. If unit baling costs are reduced by 30%, significant reductions in the cost of production can be seen when harvested yields are now increased.

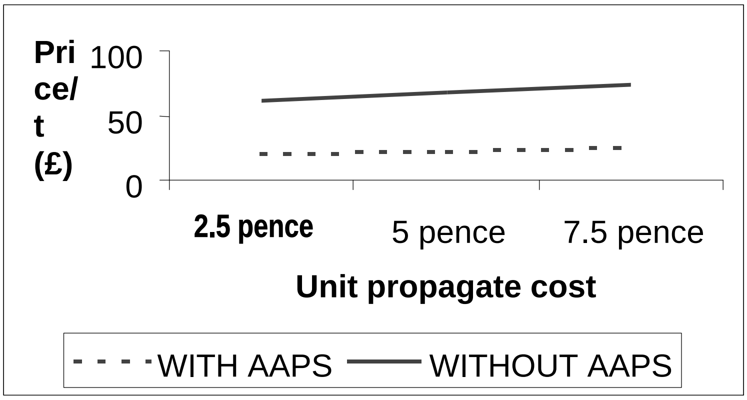
2.8 Sensitivity of Miscanthus production costs

For supported Miscanthus, production costs are seen to be surprisingly insensitive to variation in yield or crop moisture content. Doubling yield decreases the break-even cost requirement to £20 odt^{-1}. This relative insensitivity is because the unit costs of harvesting and storage, which is linked to yield, are high. Indeed, reducing harvesting costs is the most rapid way of reducing production costs; a reduction in baling costs from £5 to £3 per bale will reduce the break-even cost by £9. The other characters measured (crop longevity, harvesting costs, and propagule cost) do, however, exert a significant effect on commodity price (fig. 1). In the absence of support payments, yield does become the most important determinant of break-even price.

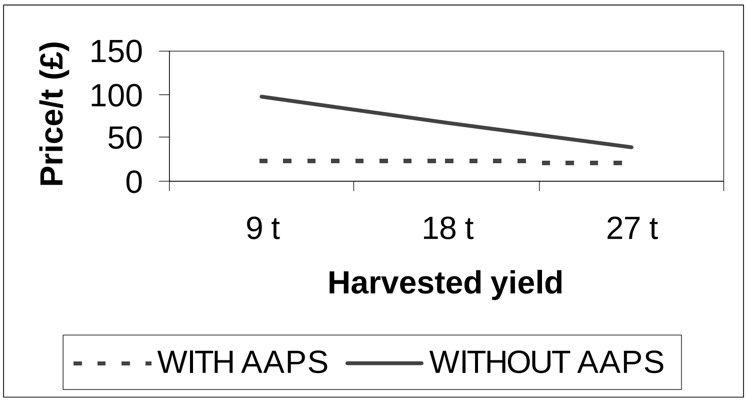
Figure 1

Sensitivity analyses for Miscanthus production. Effect on break-even price of varying individual price parameters from base case scenario. In each graph the central of the three variables represents the base case scenario option. Effect of inclusion of Arable Area Payment Scheme (AAPS) grants included.

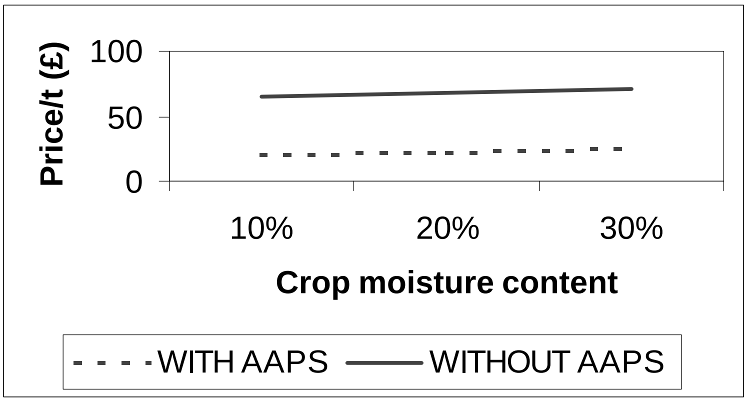
a) Propagate costs (pence per piece) varied.



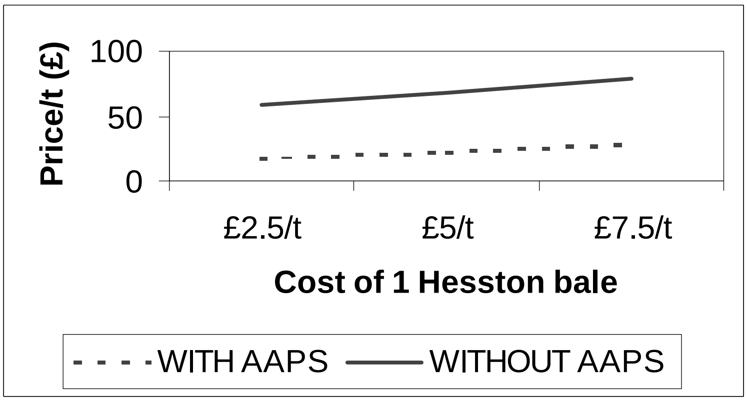
b) Harvested yield (odt ha^{-1}) varied.



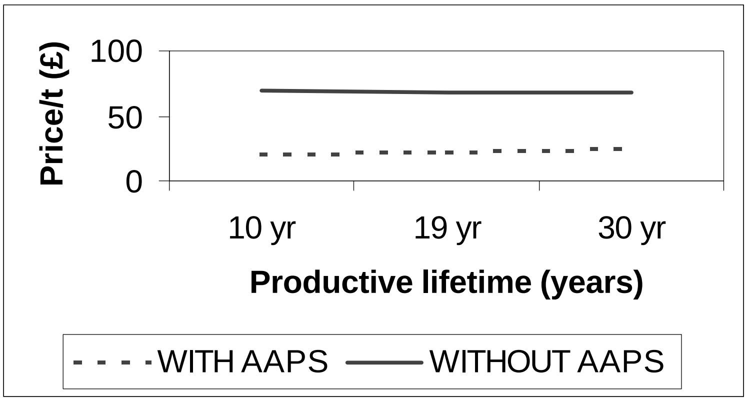
c) Harvest moisture content (%) varied.



d) The unit cost of producing one Hesston bale varied.



e) Productive crop lifetime varied.



2.9 Transport costs

For this review, it is assumed that bales of Miscanthus are collected at the farm gate by the processor and that the transport costs are borne by the processor. However, it is appropriate to identify the likely magnitude of these transport costs because this will influence market price of the product. This can be done for both baled and chopped Miscanthus. The following scenario presents transport costs, per tonne, to a power station requiring 200,000 t of biomass annually which is situated 40 km from the site of crop production. A bulk density similar to the best achieved at ADAS Arthur Rickwood during observational studies, 240 kg m^{-3}, is used for the baled scenario. A bulk density of 70 kg m^{-3} is used for the chopped material (D. Bartlett, unpublished).

Table 5. Transport cost breakdown for Miscanthus (a full breakdown of calculations is presented in Annex 7).

	Transport costs (£ odt^{-1} transported)	
Round trip distance (km)	Baled	Chopped
40	5.08	9.73
80	5.44	10.94
160	6.14	13.36

These figures for baled Miscanthus are better than those expected for baled straw. In neither scenario is the weight:volume ratio of the lorry maximised. Assumptions have been made regarding the bulk density of the chopped and baled Miscanthus. Further validatory work is required on harvesting systems that may lead to improvements on the bulk density of the material and thus reduce transport costs (see Annex 7 for sensitivity analysis).

The costs of production alone are meaningless. The likely price of the product must be considered if we are to make any assumptions on the likelihood of Miscanthus being grown in the UK. For the crop to be economically viable, the price attainable must be greater than the cost of production. This is considered in the next section.

3. THE PROFITABILITY OF MISCANTHUS

This section identifies the net margins (on an annualised equivalent basis) to farmers growing Miscanthus for a number of hypothetical markets, and compares the new enterprise with other annual and perennial cropping systems. Thus, a comparative evaluation of the Miscanthus enterprise is given.

3.1 Relative enterprise profitability

Table 6. presents the comparative net margins for a number of farming enterprises, under receipt of current area payments. Product value at the farm gate is set at £40 odt^{-1} for both Miscanthus and coppice. This is consistent with other current analyses. Alternative product values of £50 & £60 odt^{-1} are presented for Miscanthus, in order to identify the point at which crops receiving AAPS payments only, become profitable.

Table 6 shows quite clearly that current estimates of production costs render baled Miscanthus at a sale price of £40 odt^{-1} less attractive than other arable alternatives. A price of £50 odt^{-1} would be needed to achieve produce parity with a typical cereal/ break-crop rotation. Large scale production of Miscanthus would increase margins, but would also increase the exposure of the enterprise, as it would require significant capital costs to establish. Where chopped or chopped and dried Miscanthus is required, a much greater product value would be needed to confer economic viability on the crop. Specific niche markets for such treated materials are discussed in detail in section 4.3. It can be seen that chopped Miscanthus would produce better returns at the farm gate. However, these figures do not take transport costs into consideration. A processor is unlikely to pay a similar cost because transport costs for chopped material are approximately double that of baled material (Table 5).

Simple parity with other enterprises may not be sufficient to ensure that Miscanthus is grown. The high inherent risk of the venture, the perennial nature of the crop and potential opportunity costs from other enterprises suggest a figure closer to £60 t^{-1} may be needed to convince most arable farmers of the merits of Miscanthus.

Table 6. Indicative net margins (AEVs for Miscanthus, coppice and farm forestry) allowing comparison of relative profitability of contrasting enterprises[6].

Crop	Yield ($odt\ ha^{-1}$)	Product value (£ odt^{-1})	Net Margin (£ ha^{-1})	Reference
Baled Miscanthus	18	40	243	Current study
(50 ha planted)	18	50	375	“
	18	60	507	“
				“
Baled Miscanthus	18	40	291	“
(100 ha planted)	18	50	422	“
	18	60	554	“
				“
Chopped Miscanthus	18	40	272	“
	18	50	404	“
	18	60	535	“
				“
Chopped and dried	18	40	-51	“
Miscanthus	18	50	81	“
	18	60	212	“
SRC	12	40	259	Brown & Walsh (1998)
SRC	12	40	466	Spink & Britt (1998)
Broad-leaved farm forestry[7]			372	Spink & Britt (1998)
‘Arable rotation’[8]			349	Brown & Walsh (1998)
Grassland			57	Brown & Walsh (1998)

[6] All crops receive current AAPS payments.
[7] Including £400 ha^{-1} Farm Woodland Grant Scheme payment
[8] rotation of wheat, beans (or set-aside), wheat, barley, oilseed rape. Following Agenda 2000 proposals in their current form, this figure would drop to £290.

3.2 Support payments and comparative profitability

We have seen in previous sections that Miscanthus is not a viable crop in the absence of support, when other crops are receiving support. Indeed, even if Miscanthus were to receive similar support payments, it could not currently compete with many enterprises. Thus, we now consider the magnitude of additional support that would be needed to render Miscanthus a competitive enterprise.

The argument for additional support is complex, but is strongly influenced by the need of the UK to meet a 10% level of energy production capacity from renewables by 2010. Thus, additional support would acknowledge the lower environmental pollution caused by biomass energy generation and the need to pump prime the farming sector by compensating for the higher risks associated with a new enterprise. The need for support in groundbreaking agricultural ventures has been presented to the House of Lord's Select Committee on Non-Food Crops by ADAS (Bullard, 1999).

There are a number of possible support scenarios:

1. AAPS or annual support payment only, at current AAPS rate (£306 ha^{-1});
2. AAPS at Agenda 2000 rate (£252 ha^{-1});
3. One-off establishment grant payments are made so that Miscanthus receives the same Farm Woodland Grant Scheme[9] payment as SRC;
4. establishment grants of £1,000 are received, which emulate SRC payments in North Yorkshire (ARBRE);
5. 3) or 4) with additional annual support payments equivalent to AAPS;
6. 3) or 4) but with annual support set at Agenda 2000[10] levels;
7. No support

The effect of each of these levels of support payment is shown in Table 7. For comparison, the effect of Agenda 2000 on 'average' cereal margins is included for reference. Miscanthus production could be more profitable than grassland. However, soils under grassland vary far more than those under arable crops, so site selection will be crucial to the success of any enterprise. Certainly at this stage it is anticipated that Miscanthus will mainly be grown on arable land. This contrasts with long-term expectations of coppice, in which a significant area will be grown on ex-grassland. The feasibility of Miscanthus production on grassland should be investigated. Particular attention should be given to the potential grass ley pests of Miscanthus (Nixon, 1997) and their potential impact on yield and viability. If 18 odt ha^{-1} could be achieved on restored grassland, then Miscanthus would be a viable alternative.

To summarise, if Miscanthus is to be encouraged in a market where it sells at £40 odt^{-1}, then either:

a) significantly higher yields and efficiency gains during the harvesting phase; or

b) significant additional grants and equalising payments, will be needed.

At produce values greater than £50 odt^{-1} Miscanthus begins to become an attractive alternative to annual crops, in the absence of support, although even higher values may be needed to overcome mistrust of long term crops. The likelihood that the Miscanthus product will be worth £40 odt^{-1} or more is considered in the next section.

[9] Farm Woodland Grant Scheme payments; £400 or £600 ha^{-1}.
[10] Agenda 2000 stipulates that set-aside support will drop to £252 ha^{-1}

Table 7. The influence of varying levels of support on the break-even cost of production of Miscanthus, with SRC, general arable and general grassland as reference crops

	Miscanthus									SRC[11]		Arable		grassland	
												1998/9	2000+	1998/9	2000+
AAPS support[12]	306	306	306	252	252	252	0	0	0	0	252				
Planting grants	0	600	1000	0	600	1000	600	1000	0	0	1000				
Subsidy t^{-1} feedstock[13]	17	19	20	15	17	18	2	3	0	0	33				
BEC[14]	22	17	14	26	21	18	51	48	46	--	--	--	-	-	-
Net margin	243	301	340	189	247	286	-5	34	-63	-94	255	349	290	57	75

[11] Assumes conversion from arable land. Tables 4a and 8 from Brown and Walsh (1998).
[12] Arable Area Payment Scheme
[13] Represents an annual equivalent subsidy that is the product of the total payments received for the crop over its lifetime divided by the tonnage of fuel yielded throughout the 19 year lifetime of the crop.
[14] Break-Even Cost of producing one oven dried tonne, ex-farm.

4. MARKETS FOR MISCANTHUS

This section outlines the potential markets for Miscanthus, and comments on the scale and likelihood of the market. Market sectors are designated as either 'probable', 'possible' or 'speculative'. Probable markets combine technical feasibility, size, likelihood of support and positive farmer economics. Possible markets demonstrate technical feasibility and magnitude, but currently present market or logistics problems. Speculative markets include those where theoretical feasibility has not been translated into technical demonstration, where the market may be small or fragmented and where, as a consequence, it is more difficult to make firm assumptions on product value and profitability to the farmer.

4.1 Miscanthus for energy (probable market)

Miscanthus was first considered as a crop to produce feedstock for the renewable energy market. The UK is committed to 10% primary energy generation (c. 7,000 MWe) from renewables by 2010 (DTI, 1999a). Currently, the plan is to achieve this using a range of renewables technologies and many biomass conversion systems including gasification, pyrolysis and combustion of agricultural and forestry wastes and also by growing energy crops. UK government is stimulating the development of biomass energy generation through the Non-fossil Fuel Obligation. Under this scheme, premium prices for national grid electricity production are paid where generation has come from renewables. For example, the electricity pool price is currently 2.67 pence kWh^{-1}, compared with an average NFFO-4 contract price of 3.46 pence kWh^{-1} (DTI, 1998). Contracts are awarded on a competitive basis, and parity with the electricity 'pool' price is the long term objective. Parity with the electricity pool price has already been achieved in the case wind power.

There have been many rounds of NFFO contract awards (NFFO 5 contracts were recently awarded) and a number of coppice burning stations have received consent under NFFO-3 and NFFO-4. The viability of these power plants is dependant upon a secure supply of biomass. In order to stimulate the supply-side (i.e. feedstock production), MAFF has investigated the stimulation of up to 125,000 ha of coppice on both arable land and ex-grassland (Brown and Walsh, 1998). This would be sufficient, assuming an average annual yield of 12 odt ha^{-1}, to produce 1.5 Mt of biomass with an energetic value of 25.5 GJ, or approximately 150 MWe capacity (at 30% conversion efficiency). Thus significant market stimulation is in place, or should soon be in place.

The thermo-chemical conversion efficiencies of Miscanthus should be similar to coppice, and whilst the energy density of dry Miscanthus is slightly less than that of coppice, the projected higher yields, ease of handling and low disease and pest control requirements should render it a suitable alternative. The ability to produce a high density bale with Miscanthus will also ensure that it will be easier to handle, store and process.

The costs of production for a perennial energy crop such as coppice or Miscanthus will be to some extent underwritten by supply security contracts with the energy generator. These should guarantee produce sale for 15 years; the bulk of the productive lifetime of the crop. Thus, the inherent risk of undertaking perennial cropping for the energy market, is relatively low.

It is anticipated by British BioGen (the trade association for UKs biomass energy generation industry) that coppice will command an ex-farm price of £40 odt^{-1}. This may be optimistic. The price is high if the energy equivalent value of coppice is compared with coal or oil (Annex 5). This price also assumes that the coppice is to be supplied to a NFFO power station which can pay a higher market price due to receiving a preferential electricity supply price. Lower prices for biomass will be paid where there is no NFFO contract, or where the power purchaser takes responsibility for harvest and storage of the material (e.g. ARBRE power station in North Yorkshire, Farmer's Weekly, 30 October, 1998).

As seen in previous sections, coppice production is currently uneconomic to the farmer, unless he receives significant start-up grant aid and annual equalising payments. Coppice is being planted commercially, but with the support of either one-off planting grants, or Farm Woodland Grant Scheme payments. Miscanthus has the same requirements. The delivered price for unsupported Miscanthus would currently not be below £50 odt^{-1}, and the ex-farm cost would be £46 odt^{-1}. Thus, for Miscanthus to compete directly with coppice and arable rotations in this market, at a price of £40 odt^{-1}, additional annual support payments would be needed.

Table 8 presents a comparison of support requirements for Miscanthus to achieve parity with other arable enterprises. Parity with arable cropping could be achieved with AAPS set-aside payments (£252 ha^{-1}), plus a one-off planting grant of £1,050 ha^{-1} or alternatively annual support of £350 ha^{-1}. Hypothetically, to match the profitability of supported coppice under project ARBRE, Miscanthus would require a planting grant of £935 ha^{-1} plus annual support of £252 ha^{-1}, thus it would be a slightly less expensive enterprise than coppice (which receives up to £1,000 as an initial grant). These levels of support are not unprecedented; fibre hemp currently receives annual support of £506 ha^{-1}.

Thus, for the energy market, Miscanthus production on a large scale, receiving subsidy equal to that of coppice, is equally profitable and comparable to the net margins achieved in current arable rotation systems.

Miscanthus will have similar thermo-chemical properties to cereal straw, and therefore that the two feed-stocks could be burnt within the same system, either simultaneously or sequentially. As an agricultural 'waste', cereal straw will cost significantly less than Miscanthus. However, seasonality of supply and annual variability of demand from other, more lucrative markets render security of supply questions for straw in all but the densest cereal growing areas. Thus, Miscanthus may find a niche, by 'topping up' cereal straw burning power stations, such as the one under construction at Sutton, Ely.[15]

[15] EPR (Ely) Ltd, are constructing a 36MWe power station, which will receive c. 200,000 t of straw annually.

Table 8. Planting grants and annual support payment needs for Miscanthus to achieve parity with arable cropping rotations and coppice.

	Planting grant ($£ ha^{-1}$)	Annual support ($£ ha^{-1}$)	AEV[1] ($£ ha^{-1}$)
Unsupported comparisons			
Arable rotation[2]			290
Grassland[2]			75
Coppice (no subsidies)	0	0	-94
Miscanthus (no subsidies)	0	0	-63
Coppice (subsidised)[2]	786	367	349
ARBRE/Agenda 2000 support level[3]			
Coppice[4]	1000	252	255
Miscanthus	1000	252	286
Support required to achieve parity with Arable AEV[1]			
Miscanthus	0	350	290
	1050	252	290
Coppice	0	384	290
	1618	252	290
Support required by Miscanthus to achieve the same AEV[1] as supported coppice			
Miscanthus	935	252	255

[1]Annual Equivalent Value, excluding all land charges
[2]Example used by Brown & Walsh (1998)
[3]Current establishment grant paid to farmers in N Yorkshire for supply of coppice to the ARBRE power station. Represents the current highest support for energy crops.
[4]Calculated using modified figures from Brown & Walsh, 1998

4.2 Miscanthus for paper pulp and medium density fibreboard (possible markets)

Twenty six million tonnes of plant materials are used industrially in the UK (Robson & Hague, 1993). This figure excludes agricultural feeds, agricultural bedding and textiles. In 1993, the UK production of industrial plant material was 3.3Mt with an additional 4.1Mt from recycled paper. The import bill that year was c. £5 billion, with exports only totalling £1.3 billion (McDougall et al., 1993). More recent figures indicate that the gap between production and demand has not closed in the intervening 4 years (Annex 6). There is, consequently, a large import substitution market for appropriate crops with appropriate properties that can be produced economically in the UK.

The industrial potential of fibre products from Miscanthus has been investigated thoroughly during the last three years in MAFF-funded collaborative research programmes which have involved ADAS (NF0203, NF0303). Research with Miscanthus has been summarised by Hague (1997) and the generic potential of fibre crops has been discussed by Bolton (1995). Like most biomass crops, the fibre in the harvested material may offer increased value to the grower in a range of alternative markets. Miscanthus has short fibres (c. 2 mm), and the major fibre markets that offer potential for Miscanthus are paper pulp and medium density fibreboard (MDF). MDF consists of plant fibres bonded with resins which are thermally treated to produce panel products. The UK market is expanding at a rate of 10% per year, and there may be an environmental premium for non-tree sources of MDF. For both MDF and pulp sectors, a large speculative market is possible, although logistics and market competition render them somewhat less viable than Miscanthus for energy.

The principal constraints to growing Miscanthus for pulp are a) volatility of produce value (due to market fluctuations), b) volatility of produce value due to variable quality and c) the absence of large scale processing facilities in the UK. The main constraint for MDF production is the distance between the potential Miscanthus cropping areas and the existing MDF plants in the north west of the UK. Demonstration of economic Miscanthus production in Wales and the north west would enhance the opportunities for Miscanthus entering these markets. Market size for both products could be measured in millions of tonnes, all other factors being equal.

For both markets, Miscanthus could be presented in both baled and chopped form. Bales would require additional factory investment (e.g. hammer mills) for comminution of feedstock, but would benefit from lower transport costs. Conversely, chopped Miscanthus would be an appropriate feedstock, although farm losses would be greater and high transportation costs restrict viability.

MDF production facilities are centred on the north west of England and in Wales. Given that Miscanthus production is expected to be limited, at least initially, to southern and midland regions, haulage distances (round trips) will be at least 250 km. Thus extrapolating data from Table 5, minimum transport costs would be £8.26 odt^{-1} for bales and £16.08 odt^{-1} for chopped Miscanthus.

Semi-chemical pulping plants are needed to produce high quality pulp from Miscanthus (Hague, 1997). Not only do these not exist currently in the UK, but also conventional plant requires in excess of 1M tonnes of feedstock annually. Alternative regional systems, such as ‘Mini-mills’ are under development (S Redstone, pers. comm.), however, and these could dramatically cut costs of transport and also reduce the quantity of Miscanthus required.

Current delivered prices for soft woods, for both paper and MDF mills, are in the region of £30 - £60 depending on market fluctuations. Consequently, only heavily supported Miscanthus, with low unit costs of production, would approach feasibility (Table 9) unless the market was sustaining high prices perhaps due to environmental constraints.

Table 9.
The relative prices required to cover production and transport costs for Miscanthus destined for hypothetical MDF and pulp mills.

	Cost (£ odt^{-1})	
	Baled Miscanthus (base case)	Chopped Miscanthus (base case)
Production	22	26
Transport	8	16
10% profit	4	4
Price	34	46

To summarise, technically Miscanthus could be used successfully in both paper and MDF markets but economically such operations are not currently feasible. Both require very large quantities of feedstock. Suitable pulping facilities in the UK are not currently in place, and economic production of MDF from Miscanthus would require co-location of crop and industrial processing plant; this is not likely with current crop 'varieties' in the short to medium-term.

The markets into which the product would be destined demonstrate significant price volatility. Miscanthus production for these markets would be viable only if harvesting costs were dramatically less than the current base-case forecast, or if they received additional grant aid.

The further development of regional and local small scale pulping facilities would improve the viability of Miscanthus as a feedstock, but this is unlikely to occur in the foreseeable future (J Hague, pers. comm.). Further details on market size for pulp and MDF products is given in Annex 6.

4.3 Light natural sandwich (LNS) materials (speculative market)

Light natural sandwich materials comprise wood-based horizontal layers, between which are bonded hollow, vertically aligned plant stalks, which confer rigidity and strength to the product. They are being developed commercially (Wilhelm-Klauditz-Institute and Tubas Bauer Co.) and EC-funded research (FAIR5-CT97-3784; K-U Schwarz, pers. comm.) is identifying the most appropriate crop species to use as the 'filling'. Miscanthus is one of the crops under study.

It is anticipated that LNS materials would replace current market products that are based predominantly on PVC, polyurethane or aluminium. Thus, the LNS would confer environmental acceptability if energy inputs into construction of the material could be kept low. LNS from Miscanthus has been produced on a bench scale, but problems with variation in stem quality, with identifying suitable adhesives and with embedding the stems in a suitable foam matrix are hampering scaling up. Of those crops tested, Miscanthus looks the most promising.

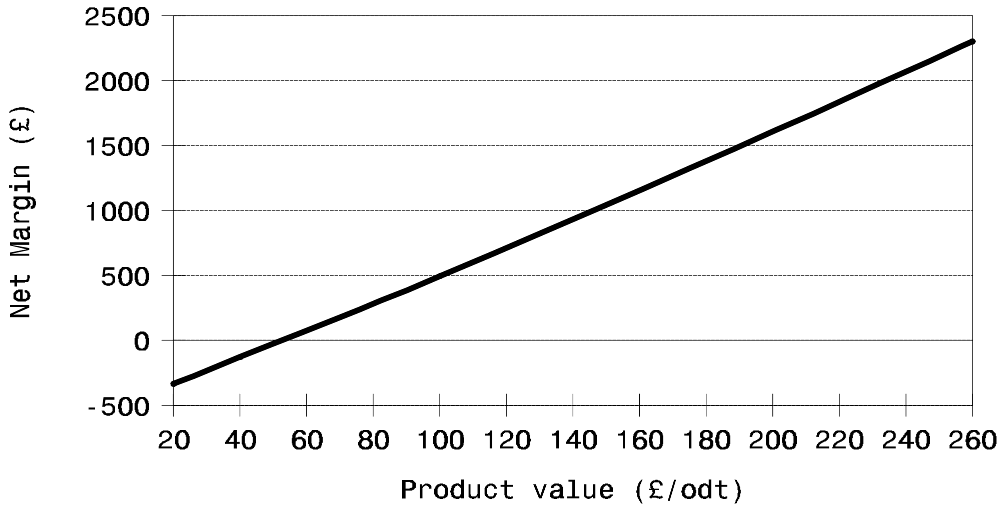
There is little published evidence to quantify the scale of the potential market or the production costs for producing the material from Miscanthus. It is unlikely that either chopped or baled Miscanthus would be suitable for the production of LNS materials and that specialised harvesting machinery would be used. This will inflate the production costs of this material. However, it has been stated (Walsh. 1997) that LNS from Miscanthus would cost only one third of a similar material made from plastics (€175-350 m^{-3} compared with €1,500 m^{-3}). More information is needed before an estimation of the feasibility of UK-grown Miscanthus this market can be assessed.

4.4 Miscanthus for animal bedding/litter (speculative market)

Currently this must be considered a speculative market. The scale of the markets for animal bedding is large (> 4Mt yr^{-1}; Annex 6). Product value is estimated to lie within a very large range (£10 - £350 t^{-1}) depending on the specific target market, the absorptive properties of the Miscanthus bedding, frequency of replacement and propensity of the bedding to produce fungal spores. Research is needed to identify the quality and value, if any, of Miscanthus to these markets.

Hypothetically, to produce Miscanthus for animal bedding the crop must be direct chopped and immediately dried, possibly using on-farm grain dryers. Alternatively, dried bales could be passed through a hammer mill to produce chips of the correct dimensions. The dry chopped material is then bagged using specialist equipment. The result of these extra costs (forced air drying £13.32, additional handling and labour £10 odt^{-1}, capital cost of packing machinery £400 ha^{-1}, variable costs £2.40 odt^{-1}, Annex 6), is that break-even costs of production, for a crop receiving set-aside payments only, increases from £22 odt^{-1} to £63 odt^{-1}. Thus, depending on the quality of the product, Miscanthus bedding could be prohibitively expensive to produce, or an extremely lucrative enterprise (Figure 2). Before more comment can be made, basic research on the absorptive properties of chopped Miscanthus must be undertaken.

Figure 2.
Sensitivity of net margin to product sale value in animal bedding market.



4.5 Miscanthus as a growing medium additive and soil improver (speculative market)

MacCárthaigh, Sturm & Schmugler (1997), working in Germany, have reported that Miscanthus may function as a growing medium additive, replacing sphagnum peat substrate. Only preliminary work has been reported, indicating that substitution of up to 40% of sphagnum peat base resulted in no significant yield reduction in test plant species. They suggest also that 100% Miscanthus growing media (i.e. peat-free compost) might be possible to develop.

Figures relating to the total growth media market size are difficult to obtain for the UK. However, informed estimates suggest that the total annual market for amateur growers and councils was 3.52 million m^3 in 1997 (Anon., 1999), 64% of which was peat. Peat-free growth media occupy a niche of c. 100,000 m^3 (P Wallace, pers. comm.).

On the basis of these figures, there is a potential annual market of 1.25 million m^3 into which Miscanthus could be substituted. If Miscanthus were included as a 40% blend in the entire annual market, then 500,000 m^3 would be needed. With a bulk density of 70 kg m^3 (Bartlett, unpublished), we can calculate that 35,000 odt yr^{-1} would be required to satisfy this market (i.e. 2,778 ha, grown under the base-case scenario).

The cost of producing 1 t of chipped Miscanthus in the absence of subsidy is £53. With £11 transport cost added for an 80 km deliver round trip, the cost of producing this product is still within the margin needed for it to compete with alternatives, that sell for approximately £100 t^{-1} (P Wallace, pers. comm.). If it were technically feasibly to produce growth media products from Miscanthus, the products should command an ‘environmental’ premium price. Thus, Miscanthus may be viable as a growth media additive. However much work is needed to identify the suitability of the material for each individual market. The cost assessment here assumes that there is no need for composting or nutrient additions. These assumptions should be validated.

The value of Miscanthus as a general compost and large-scale soil amendment is currently under investigation in Devon, in an Objective 5b project (J Perryman, Pers. comm.). No data are yet available.

4.6 Insulation (speculative market)

Whilst some plant materials are used as a substitute to fibreglass and other man-made fibres in lagging products, there is a prerequisite of long fibre length which suggests that Miscanthus will not be viable.

There is already some commercial use of short plant fibre, recycled paper etc. as loose fill insulation. There is an opportunity to use Miscanthus in these situations (as an alternative to loose filled polystyrene). However, low value cereal straws predominate in this market. Further research would be needed to determine any thermal or acoustic benefits from using Miscanthus.

4.7 Densified Heating Blocks and Fuel Pellets for domestic markets (speculative market)

Densified heating logs, produced principally from soft and hard wood and wood waste, occupy a niche market of approximately £50M yr^{-1} in the UK. There are markets for household fire and boiler use as an alternative to coal, and possibly as a barbecue fuel as an alternative to charcoal. Densified sawdust logs command a wholesale price of £80 –100 t^{-1} and a retail price of c.£200 t^{-1}. The likely value of Miscanthus entering such production systems is unlikely to exceed £50 t^{-1} as it will be competing with a plentiful waste; sawdust. If Miscanthus heating blocks and fuel pellets are found to have better thermal properties than sawdust-derived logs, then this price may increase. Research is needed to determine this. Straw has been assessed as a suitable product for these heating logs, but the high silica content in cereal straw leaves a molten silica lump in the fire grate which has to be disposed of and hinders complete combustion. The silica content of Miscanthus, although lower than straw, may render it unsuitable for this market.

5. DISCUSSION, CONCLUSION AND FORWARD LOOK

This report has presented detailed analysis of the costs of production of Miscanthus and the likely annualised margins that would result. Unlike previous studies, yield and the cost of harvesting, rather than establishment costs, have been shown to be the key determinants of profitability. However, most of the costs associated with this phase of production are assumed - very little work on harvesting efficiency, bulk density or harvesting and storage losses has been undertaken. The work that has been undertaken is incomplete. Thus, an immediate research priority is to determine accurately the work rates and logistics of the harvesting operation in the UK.

The most likely market for Miscanthus is energy. Biomass crops will be necessary, covering relatively large areas, in order for the UK government to fulfil its Kyoto targets. Perennial biomass crops, including Miscanthus, require additional measures to ensure that long-term raw material supplies are secure. Without this, such crops will fail; that much is clear from the analysis above. Although some additional measures are currently in place, they are insufficient to stimulate the necessary grower interest because of the risks associated with committing land to perennial crops for 15 years.

The constraints of NFFO structures mean that biomass purchasers will be unable to pay the true value of their biomass. Additional direct support payments are necessary. These will a) offset high start-up costs, b) reflect the true environmental benefit of these species, c) acknowledge that growing perennial crops reduces the growers options for subsequent opportunities, and d) compensate for the lower yields achieved by early adopters who will be unable to benefit from new, significantly higher yielding varieties. These payments may take a number of forms:

- The high start up costs should be covered by a first year establishment grant (as is currently the case with ARBRE).

- The environmental and social benefits of biomass cropping should allow the farmer to offset these against any carbon, fertiliser or pesticide taxes imposed on his other farming activities.

- The long term nature of the cropping could be reflected by tax reduction on sales, or direct contributions where the growers, who would otherwise leave farming, choose to take the receipts as part of their pension. In some areas of the community this approach to support may help to maintain populations in rural areas.

- Whilst annual support for alternative enterprises continues, so should Miscanthus remain eligible for such payments.

It is clear from the preceding section that neither Miscanthus nor coppice are viable without support whilst they compete against crops that are supported. Whilst Miscanthus may be slightly more viable than coppice, it can only be produced profitably with significant support. To attain the equivalent net margin to a typical arable enterprise, Miscanthus would require either a) a one off planting grant of £1,050 ha^{-1} plus AAPS payments annually, or b) equalising annual payments of £350 annually.

Like coppice, Miscanthus would provide feedstock, and require major husbandry operations, at a quiet time in the farming calender (March), thus spreading the labour workload on farm, bringing financial benefits. The indirect economic advantages of seasonality have not been considered in the current study.

As an energy crop, Miscanthus is still a developmental species, with no credible large scale commercial production in place in the UK. However, the author is aware that there is now considerable commercial interest in developing the crop in the immediate future, should the right support measures be put in place. The crop does have significant potential in the UK. Applied strategic research is still essential to bridge the remaining gaps for the commercial uptake to become reality. Key areas that will support the full exploitation of Miscanthus in the energy market are:

- Evaluation of the establishment and yield of Miscanthus on ex-grassland;
- Harvesting efficiency and storage/transport losses;
- Plant breeding for improved yield and low temperature leaf expansion;
- The development of low cost establishment techniques, including low cost planting techniques;

The lack of a nation-wide support mechanism is the single greatest impediment to uptake of Miscanthus and coppice. As noted above, there is a requirement of fiscal stimulation to encourage high risk perennial cropping and which provides financial acknowledgement of the environmental benefits of carbon neutral energy systems. However, a number of other constraints exist:

- The magnitude of feasible energy conversion systems is not consistent with centralised, national grid energy generation. This can be addressed through the stimulation of small scale embedded systems running at a local scale. This would simultaneously reduce transport requirements and CO_2 generation through transport fuel use.

- There is insufficient technology transfer of options for biomass energy generation, and the most advanced specialist crops (short rotation willow and poplar coppice) have only recently entered breeding programmes specifically for increased biomass production. This needs to be expanded and take in other, potentially higher yielding species such as Miscanthus and other perennial grasses. Equally significant advances in the agronomy of perennial systems should produce significant yield increases which in turn will improve the economics of biomass systems.

- Many attempts to build biomass burning power stations have faltered at planning consent stage, often through misconceptions of environmental impact. Clearer governmental guidelines on environmental impact (positive and negative) should be made available to planning authorities.

In order for Miscanthus to attain penetration in the renewables market by 2005 (through uptake in NFFO 6), a network of demonstration farms should be established which enable:

a) whole-farm yields to be verified;

b) whole-farm economics to be assessed;

c) technology transfer to promote the crop.

Other markets offer the potential of viable cropping in the absence of support, but they are impeded by other factors. Of the other possible uses for Miscanthus, it is technically a viable feed stock for chemical pulp mills or for the production of speciality paper and MDF. But such pulp mills do not exist in the UK nor is there any likelihood on one being built in the foreseeable future. Research into the viability of Miscanthus as a light natural sandwich (LNS) material and as insulation, is ongoing. Miscanthus is not a viable feed stock for woven and non-woven textiles, or for geotextiles. Research validation of Miscanthus as a litter product, and as an additive to growth media, is urgently required. Quality of end product will determine marketable value and consequently sale price. This should be linked with technology transfer to ensure that the full market potential of the crop is exploited as quickly as possible.

Opportunities for minimising costs of production exist for all uses, by growing Miscanthus on landfill sites, and disposing of liquid wastes on the crop during growth. These opportunities should be further investigated. Animal bedding offers an opportunity to grow, harvest, package and market the product from the farm, thus maximising profit to the farmer.

This review has necessitated the identification and quantification of various factors involved in the economics of Miscanthus production and related issues in the UK. These include production costs, net and gross margins and profitability, and have been illustrated by example calculations given in tables. However, building on this review, a framework can be developed to examine such economics using not only fixed variables but those which undergo systematic and stochastic/random change which naturally reflect the real world. Although this has been attempted, by way of relatively crude examples illustrating sensitivity analysis in Figure 1, such a framework could form the basis of a powerful modelling tool for economic prediction and hence could be a useful policy or planning/decision-making tool. Future work would be the development of the system-framework to meet specified objectives that could be translated into a suitable spreadsheet or database such as Excel or ACCESS97, with its attendant programming features such as visual Basic. The use of Monte Carlo methods and/or other modelling techniques would enable economic outputs to have not only deterministic value but would also be accompanied by confidence intervals for each economic scenario and of course economic prediction based on real cost factors present or anticipated in the near future. The initial modelling approach, would be to keep things as uncomplicated as possible and to use Microsoft software which is a recognised industry standard. Results using this model could be evaluated against actual costs/economic outcome and the utility of the modelling tool assessed.

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ANNEX 1

THE COMPARATIVE ENVIRONMENTAL AND ECONOMIC RANKINGS OF CROPS[16]							
Crop	Net Margin	Flora and fauna	Soil protection	Pesticides in water	Nitrates in water	Total environmental (4 - 20)	Total (5 - 25)
Wheat	4	1	2	1	4	8	12
Barley	3	1	3	1	4	9	12
Oats	4	1	3	2	4	10	14
Winter high erucic acid rape	2	1	3	2	4	10	12
Spring HEAR	2	2	3	2	4	11	13
Winter oilseed rape	2	1	3	2	4	10	12
Spring oilseed rape	2	2	3	2	4	11	13
Linseed	1	2	2	3	4	11	12
Dual purpose linseed	3	2	2	3	4	11	14
Flax	4	2	2	3	4	11	15
Hemp	3	2	2	5	4	13	16
Winter evening primrose	4	1	3	1	4	9	13
Spring evening primrose	5	2	3	3	4	12	17
Borage	5	2	3	4	4	13	18
Sugar beet	1	1	1	2	4	8	9
Potatoes	2	1	1	2	3	7	9
Short rotation coppice	4	3	2	1	4	10	14
Miscanthus	5	2	4	3	5	14	19
Broadleaved forestry	5	5	5	5	5	20	25
Conifer forestry	4	4	3	5	5	17	21
Natural regeneration	3	3	3	3	3	12	15
Sown grass covers	2	3	5	5	5	18	20

[16] After Spink & Britt (1998). Key indicators compared with natural regeneration set-aside and scored on a 1 to 5 scale, where 1 is significantly worse, 3 equal to and 5 significantly better than natural regeneration.

Annex 2

Principal assumptions for Miscanthus break-even cost calculations (net margin's NPVs and AEVs)

Cost category	Timscale	Value
Productive lifetime, years		19
Rotation cycle, years		1
Set-aside grant		£306
Other grants		£0
Planting rate (plants per hectare)		20,000
Cost of rhizome pieces, per plant		5 pence
Fencing costs		£0
Yield (odt at harvest)	year 1	0odt ha^{-1}
	year 2	10 odt ha^{-1}
	year 3 onwards	18 odt ha^{-1}
Land preparation costs	cultivation	£75.5
	Planting & rolling	£116.5
Fertiliser	year 1	£48
	year 2 onwards	£27
Herbicides	year 1	£80
	year 2 onwards	£32
Harvesting costs	cutting (ha^{-1})	£25
	baling (per 0.9t bale)	£5
	carting/storage (/t)	£7
Harvest & storage losses (%)		20%
moisture content at harvest (%)		25%
Storage duration (months)		6 months
Loading lorry (£/bale)		£1
Decommissioning costs	year 19	£255.5
Discount rate		8%

Detailed description of the derivation of Miscanthus production costs.

Baseline costs of land preparation and crop establishment for Miscanthus

Regardless of end market, there are a number of operations in the process of establishing a Miscanthus crop and these can be categorised according to current best practice. Likely costs of individual actions are detailed.

Site preparation

The provision of a good quality 'seed bed' is essential to the establishment process for Miscanthus. A suitable seedbed will optimise soil-plant contact and consequent moisture and nutrient supply. Site preparation will not deviate from the methodology employed for the establishment of any spring-sown annual, although greater provision may be needed to ensure good sub-soil structure before the crop is planted. However, there will be tremendous farm to farm variation in the operations required. The average farmer costs for site preparation, which includes sub-soiling, ploughing and disc harrowing, is estimated to be £75 ha^{-1}.

Propagule costs

Current experiments establish Miscanthus at densities of between 10,000 and 40,000 plants ha^{-1}. The most appropriate density is not definitively established across a wide range of soils, but on current evidence will be closer to 10,000 plants ha^{-1} (Bullard et al., 1997). However, current lack of experience with establishment techniques, plus the anticipated poor quality of most of the soils into which the Miscanthus will be planted, indicates that a more appropriate planting density will be 20,000 plants ha^{-1}, with the expectation of 50% establishment. Clearly, experimentation in order to improve establishment is of paramount importance.

The most cost effective method of crop propagation would probably be through seeding. However, currently available ‘varieties’ do not set viable seed. Also, seed collected from Japan & Korea (NF0404) exhibits protracted germination and slow emergence even under controlled conditions. Therefore, it is very unlikely that seed will be sufficiently vigorous to establish successfully in a seedbed. Two alternatives, establishment from micro- or macro-propagation are currently used. At present, establishment of micro-propagated material (small plantlets produced via tissue culture) has proven to be very expensive and the plants are vulnerable to desiccation during springtime. Establishment of small scale trials using hand-lifted rhizome sections is no cheaper. However, fields of mature Miscanthus can act as a low cost propagule production system. Using a V-form plough to lift rhizome masses, a rotavator/bed maker to split the rhizomes, and then harvesting the split rhizome sections with a bulb harvester or stone picker, can yield sufficient material from 1 ha after two years for re-planting 30 ha, and can reduce the cost of material to as little as £0.02 (Huisman & Kortleve, 1994). Certainly variations on this method have been employed successfully at ADAS and throughout the EC Miscanthus Productivity Network (Walsh, 1997).

For the purpose of this exercise, it is assumed that a Miscanthus producer buys tissue cultured plants and grows them in the field for two years before ‘harvesting’ the rhizomes and selling on to farmers. A price per propagule of £0.05 has then been used in the base case analysis, on the following basis:

Table A2.1. Derivation of Miscanthus propagule costs

OPERATION	COST (£ ha^{-1} harvested)	
Original cost to producers for 1 ha plantation (20,000 plants)	6,000[17]	
24 months' fixed costs	234	
Land preparation	75	
24 months husbandry costs, including planting	380	
Harvesting & removing canes, 2 years	275	
Harvesting rhizomes		
Ploughing	65	
Rotavating	55	
Stone picking + carting (contractor rates)	160	
Grading and packing	1,000	
Cold storage, handling and transport		1,800
(1) Cost sub-total	10,044	
(2) Profit [(1) * 25%]	2,011	
(3) Ex farm transport costs	250	
Unit price, assuming 300,000 harvested per hectare [(1)+(2)+(3)/300,000]		0.04

Adding an additional 25% to cover plant breeder's rights (PBR)[18] produces a unit price of £0.05. This is taken as the supply price in this study. This means that propagule costs are set at £1000 ha^{-1} amortised across the 19 year lifetime of the crop.

[17] figure based on recent quote, provided by a European tissue culture specialist, based on a 100,000 plant order

[18] There is no PBR associated with Miscanthus currently, yet it is inevitable if improved, higher yielding varieties are to be entered into the market. Thus the current model anticipates a price increase for projects established in 5 years time.

Establishment costs

Rapid, accurate mechanical planting methods remain a leading challenge with Miscanthus, principally because of the range of shape and size of planting material that is produced from the original splitting operation. The most cost effective method presently appears to use a potato ridger and semi-automatic potato planter (Huisman and Kortleve, 1994). Certainly, even if specialist contractors are used, this 1 in 20 year operation is compensated for by lower fixed costs in the subsequent 19 years. The figure used in this work is based on Nix (1999) for use of a contract potato planter (£116) and includes an element for rhizome handling as well as planting.

A major research task is to assess existing planting machinery and modify as necessary. Time of planting, depth of planting and the interaction of soil type and structure are all poorly understood. The percentage emergence of the crop will improve if a more uniform planting depth and seed bed conditions can be achieved. A Danish company has developed a specialised Miscanthus planter, but is has yet to be demonstrated in the UK. Recent attempts at low cost establishment have involved simply spreading the rhizomes on the soil surface with a slurry applicator and ploughing-in. This method could potentially reduce establishment cost by 70%, but is not technically proven.

Fertilisers

Seven years' research with Miscanthus has provided basic information on the nutrient requirements of Miscanthus. Evidence suggests that no more than 130 kg ha^{-1} crop N are required for optimal growth (crop canopy development). In most cases a significant proportion of this will be provided by the soil. Off-take figures of 7 kg t^{-1} N, 10 kg t^{-1} K and negligible offtake of P are quoted (Christian, Bullard & Wilkins, 1996). The model does not relate predicted yield with fertiliser requirements (based on off take figures), because soil supply will vary more from site to site than offtake. Accordingly, a hypothetical (average) is used assuming an annual, post establishment application of 80 kg N, 10 kg P and 60 kg K ha^{-1}. The fixed cost of application is £7.25. Variable costs for the fertiliser products themselves are £30. It may transpire that these levels are higher than actually required. Clearly, there will be great site to site variation in the fertiliser regime required. Additional application of micro-nutrients and lime are not considered as Miscanthus does not appear susceptible to any particular micro-nutrient deficiency, and can tolerate pH ranges of 5.5 – 8.0. It is also assumed that any field deficiencies would be corrected during general farm management and can therefore be considered a fixed cost.

Weed control

The importance of effective weed control during the establishment of Miscanthus is well known (Bullard et al., 1995). Specific herbicide requirements (or mechanical methods) will vary tremendously from site to site in the establishment year. For the purposes of this work it is assumed that first year herbicide applications consist of one pre-planting application of glyphosate (£25 ha^{-1}) plus two applications of bromoxynil + ioxynil (£20.50 ha^{-1} each). This gives a total product cost of £66 ha^{-1} in the first year. However, subsequent weed control should be achieved with annual March-time (post-harvest) applications of translocated herbicide. Variable costs in this model are set at one annual springtime application of glyphosate timed for post-harvest, pre crop-emergence (£25 ha^{-1} yr^{-1}).

Irrigation

Whilst there is increasing acknowledgement that Miscanthus has a high water demand despite a high water use efficiency, it will not be economically (or environmentally) feasible to use irrigation as a viable tool for increasing yield, regardless of the end market. Therefore, no allowance for irrigation is included in this model.

Harvesting

One of two harvesting techniques will be appropriate depending on the end use of the crop. Miscanthus for energy will be required to be baled. This can be achieved using existing farm machinery (e.g. mower conditioner followed by optional swathing and baling as a 2- or 3-phase operation), or in one operation using specially modified combine harvesters (e.g. the Claas developmental machine). The former option is likely to cause less trafficking damage than the heavier Claas machinery. For the purposes of this model, the former option is used on farm. Hesston-type baling costs will be very dependent upon the scale of the operation. A cropping area of 50 ha with 30 tonnes of biomass standing will cost £5 per bale, assuming a bulk density of 240 kg m^{-3}. These figures would produce 33 bales, and the price per bale includes costs for bale twine. Increasing the scale of production to 100 ha reduces baling costs by 40% (Figure 3).

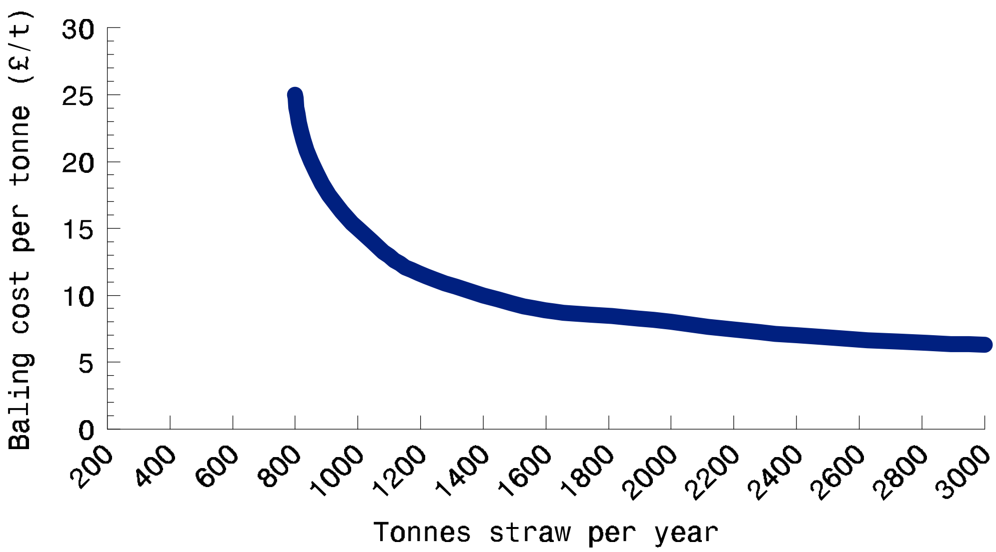


Figure 3. The relationship between baler utilisation and cost per tonne (Bull, 1986)

The base case model assumes that a standing crop of 18 odt ha^{-1} is cut at 40% moisture which then dries in the swath to 20% moisture; thus, 21.6 fresh tonnes are harvested. Cutting using a mower conditioner is assumed to cost £25. Baling at £5 $bale^{-1}$ costs a further £120 ha^{-1}. Carting bales to storage on hard standing costs £2 t^{-1}, and storage for 6 months costs £4 t^{-1} with a further £0.80 t^{-1} cost for providing plastic cover.

For alternative markets Miscanthus will be required to be provided in 2-5mm chips. This can be achieved to a high degree of accuracy (internal screens can produce a 2mm - 14mm range of chip size) using self-propelled forage harvesters (e.g. CLAAS Jaguar 690 forage harvester with standard Kemper header). Importantly, many of the markets which require chopped Miscanthus also require a product moisture content of c. 50% for maximal efficiency of product development (Hague, pers. comm.) - this is the moisture content frequently achieved in UK trials. A contractor's cost is assumed of £125 ha^{-1}, and this includes additional tractor/trailer activity taking chopped material to store. Storage costs for 6 months are assumed to be identical to the case above.

Yield and crop value.

These two characters will determine the revenue generated by a Miscanthus crop. The present MAFF funded screen of seven sites (NF0403), EU Network and ADAS Seedcorn physiological studies of Miscanthus are producing valuable data on the yields that can be expected throughout Europe. However, insufficient data are available to accurately predict yields in any situation; there are still likely to be regional and seasonal variations in yield, and as mentioned earlier, the productive life-span of the crop is still unclear. We anticipate that mean yields of 15-20 odt ha^{-1} should be achievable under most arable conditions. The average figure obtained from current experiments is 18 odt ha^{-1}, and this yield is used in the base-case scenario. For the purposes of sensitivity analyses, a band between 12 - 24 t ha^{-1} is used, with increments of 3 t ha^{-1} considered.

ANNEX 3

Analytical methods used
The economic analyses, for all scenarios, consider 'to the farm gate' production costs of Miscanthus production, and presents costs both in terms of break-even price (per tonne) and also hypothetical gross margins. Both are set in context against the equivalent figures for cereals and break crops grown on arable land.

Break-even cost (P) is calculated as:

$$P = \frac{\sum_{t=1}^{T} \frac{C}{(1+d)^t}}{\sum_{t=1}^{T} \frac{Y}{(1+d)^t}}$$

where T = duration of productive crop, t = sequential year of crop, Y = yield,

d = discounted rate (set variously at 3%, 5% and 8% p.a.) and C = costs (fixed and variable).

Net margins and Gross margins are presented as both Net Present Value (NPV) and Annualised Equivalent Value (AEV). Net margins are the preferred comparative figure used throughout the report.

Net Present Value is calculated as:

$$\Sigma((P.Y)-C).(1/(1+d)^t$$

Annual Equivalent Value is the 1999 margin that would accumulate the calculated NPV, assuming the constant discounting rate.

Break-even costs for production with AAPS at discount rates of 3%, 5% and 8% and without AAPS at 8% discount rate are presented below.

ANNEX 4

Comparative NPV, AEV and break-even cost at varying discount rates for baled miscanthus under the base-case scenario.

	8% discounted rate (base case scenario)				3% discounted rate				5% discounted rate			
	No support		AAPS support		No support		AAPS support		No support		AAPS support	
	Y1	*Y2+*	***Y1***	*Y2+*	***Y1***	*Y2+*	***Y1***	*Y2+*	***Y1***	*Y2+*	***Y1***	*Y2+*
Cost category												
Propagules	1000	0	1000	0	1000	0	1000	0	1000	0	1000	0
Cultivation	76	0	76	0	76	0	76	0	76	0	76	0
Planting	116	0	116	0	116	0	116	0	116	0	116	0
Fertiliser												
a) application	7	7	7	7	7	7	7	7	7	7	7	7
b) product cost	41	30	41	30	41	30	41	30	41	30	41	30
Herbicide												
a) application	14	7	14	7	14	7	14	7	14	7	14	7
b) product cost	66	25	66	25	66	25	66	25	66	25	66	25
Pesticide	0	0	0	0	0	0	0	0	0	0	0	0
Fungicide	0	0	0	0	0	0	0	0	0	0	0	0
Harvesting	0	145	0	145	0	145	0	145	0	145	0	145
Carting	0	24	0	24	0	24	0	24	0	24	0	24
Storage	0	34	0	34	0	34	0	34	0	34	0	34
Sub-total costs	1320	272	1320	272	1320	272	1320	272	1320	272	1320	272
Fixed costs	117	117	117	117	117	117	117	117	117	117	117	117
Support	0	0	306	306	0	0	306	306	0	0	306	306
Yield profile:												
Harvested yield	2	18	2	18	2	18	2	18	2	18	2	18
Loaded yield	1.6	14.4	1.6	14.4	1.6	14.4	1.6	14.4	1.6	14.4	1.6	14.4
Break even price (£ odt^{-1})	46		22		42		19		43		20	
Gross Margin AEV	42		360		122		557		97		471	
Gross Margin NPV	438		3736		1264		5778		1005		4888	
Net Margin AEV	-75		243		-45		391		-46		328	
Net Margin NPV	-775		2523		-462		4052		-480		3403	

ANNEX 5

Miscanthus for Energy Production (a detailed analysis of likely product value and market size).

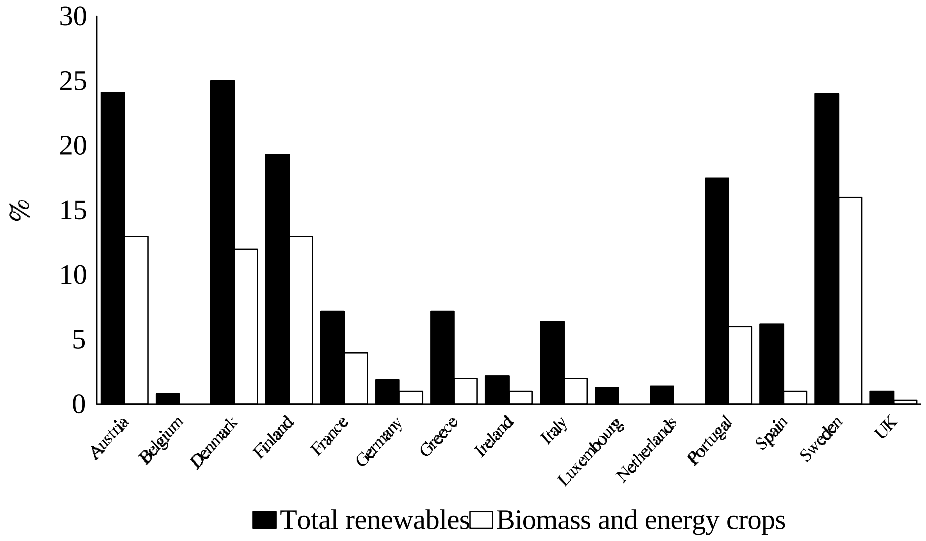
The nature and scale of the Market

The large or medium scale bioenergy market exists already in the UK and EU, yet it is heavily supported by the exchequer. To compete unsupported against fossil fuel requires a revised approach for comparing costs of production between fossil and non-fossil fuel sources. Various reports suggest that EU energy production can (and should) by 2010 contribute 7-18% of primary energy needs from renewables, with energy crops and wind power dominating the proportionate contribution of different technologies to this figure (EC, 1998). Indeed the EU has recently set an attainment target of 12% of energy generation from renewables. This may necessitate as much as 10% of the EU's total agricultural land area being put down to energy crops. The UK government has adopted a goal of 10% of total primary energy production to be generated from renewables by 2010 as their stated objective (DTI, 1999a). The current level of energy generation in the EU from renewables is c. 6%. The current share of renewables as a percentage of energy consumption for each of the EU15 is shown in Figure 4. As much as half of these are produced from biomass systems utilising agricultural and forestry wastes and crops grown specifically for energy. The EC aim is to double the share of renewables energy generation, to 12%, by 2010 (EC, 1998).

It is not possible to speculate in this report about the likelihood of carbon taxation or tax breaks on renewables, but the 'internalisation of externalities' will enhance the economic viability of crops that can probably already compete under certain conditions. A full review of the effect of market distortions caused by the omission of environmental costs in pricing fossil fuel energy has been produced by Hall (1997). The government's recently stated objective is to 'produce 10% of the UK's primary energy demand from renewables by 2010' (DTI, 1999a). Biomass is considered to be a significant contributor to this. Assuming that biomass will contribute one quarter of this likely 7,000 MW_e of new declared net capacity, we can make some general predictions of the scale of crop production required in the UK.

Figure 4

Energy generation from renewable sources (Eurostat data for 1994) and energy generation from biomass and energy crops (most recent available data) expressed as a percentage of total energy production[19].



1,250 MW_e using current conversion technology would require in the order of 8.5 M odt biomass yr^{-1}. Assuming mean yields of 15 odt ha^{-1} this would require 550,000 ha of agricultural land. This is equivalent to 16% of the cereal cropped land or 2-3% of total agricultural land in England & Wales. Furthermore it is approximately equal to the maximum area of set-aside seen in 1994.

Even at an uptake rate of 10%, 500 MW_e will require 3.4M odt, to supply an estimated 20-30 new power stations. These may develop to run on a range of fuel types including SRC, forestry waste, coal and annual agricultural wastes as well as potentially Miscanthus.

In the first move towards this, MAFF is investigating a target of 125,000 ha of coppice to be planted by 2006. Initial support has come in the manner of a £1,000 establishment grant payable to farmers within a 50 mile radius of the first coppice powered station under construction - Project ARBRE in North Yorkshire. This £1,000 includes the £400 or £600 Farm Woodland Grant Scheme payment for arable and grassland respectively. It is therefore credible to assume a similar level of additional intervention might be available to Miscanthus growers. Early evidence suggests that these grants are stimulating coppice uptake in North Yorkshire.

[19] Total renewables data from CEC (1996). Biomass and energy crops data from Scurlock & Hall (1994) except Austria (Hall, 1997). Data therefore represent a spread of years (1988-1996) and should be treated with some caution.

This market offers the greatest short-term potential simply because it is currently the politically favoured scale of renewable energy generation in the UK. Combustion technology (@25% efficiency) is currently available. A $5MW_e$ power station would require approximately 32,000 oven dry tonnes. In the above yielding scenarios, this would equate to 1,333 - 2,667 hectares of Miscanthus. GIS-based predictive systems for locating suitable areas and land are being developed to facilitate location of power stations, but the final viability of the system will relate to our ability to accurately predict Miscanthus yield.

Whilst cereal straw is sometimes plentiful (c. 12M t annually) demand and value is sporadic and consequently the value of this 'waste material' can fluctuate between £10-60 t^{-1}. The volatility of this market, together with the restrictiveness of secured supply contracts indicate that cereal straw will not be the extreme competitor once anticipated. Much of the straw available following harvest is immediately chopped and incorporated into the soil. Approximately half of the available harvested straw is used for animal bedding, whilst much of the remainder is so geographically dispersed that it could not contribute to an economically run power station of any significant size. With yields of 3-5 t ha^{-1} of straw, the area needed to produce sufficient for a large power station is large. In only the most intensive cereal areas would straw powered stations be viable. Consequently, the value of Miscanthus will not be tied to straw prices. Indeed, co-fired straw/Miscanthus power stations may be the most likely Miscanthus systems.

The potential of Miscanthus within the energy market

Miscanthus was initially investigated solely as a feedstock for the energy market. We know now that the crop can perform well under UK conditions, producing yields in excess of 18t ha^{-1}. Some yields may be as high as 25t/ha dry matter. There is no evidence to suggest that baled Miscanthus would not be at least as suitable as straw or coppice chips for combustion/gasification. Whilst transport costs may be high due to low bulk density and high moisture content, it is probable that it will be more cost effective to dry the product at the power station using waste heat rather than attempt in-field drying (Nellist, 1997). The energetic values of dry Miscanthus and dry coppice are almost identical (Alexander, 1995) and moisture contents generally slightly lower on harvest. We are currently predicting higher annual yields for Miscanthus than for coppice, thus the supply radius for a power station of any given size will be reduced. This in turn will reduce the transport costs (see Annex 7).

The value of Miscanthus in the energy market

This report assumes a value of £40 odt^{-1} for Miscanthus in the energy market. This is consistent with the value commonly assumed for coppice, based on assumptions from British BioGen. However, an investigation of the value of the crop, based on its energy yield, suggest that this figure may be optimistic.

It is not realistic to tie Miscanthus value to that of straw - a finite waste commodity. It is more realistic to tie biomass fuel price in with crude oil on an oil equivalency basis. The current price (12/8/99) for Brent Blend, which could be taken as a benchmark, is US$20.50 per US barrel at the oil field (c.f. 'to the farm gate'). During 1997-99, the range for a US barrel had fluctuated between US$25-US$10 per barrel (DTI, 1999b). Prices are generally higher in the winter and traditionally it is a very volatile world market; the price increases rapidly if there are problems in the Middle East. Prices during 1998 were very depressed at US$10-12 per barrel. For the purpose of this comparative study, an oil field price of US$20 is assumed.

One tonne of oven dry biomass has an energetic value equivalent to 400 kg of crude oil. A barrel of oil currently sells for a pre-delivery price of £12.40 (US$20). Therefore, we can estimate that on a purely substitutional basis, Miscanthus (or coppice) would have a market value of c. £31 odt^{-1}. The high capital cost of commissioning a biomass burner/gasifier, coupled with the present support systems emphasis on favouring low price bids (pressure under NFFO's to achieve parity in energy supply costs with respect to fossil fuels) indicates that the market price for the biomass may initially have to be significantly less. Certainly for co-firing in coal burning stations, a price of £30 odt^{-1} is more realistic, unless the co-generation is supported with grant aid.

ANNEX 6

Miscanthus for Fibres (an analysis of likely product value and market size).

THE SCALE OF THE MARKET

26 million tonnes of plant materials are used industrially in the UK (Robson & Hague, 1993). This figure excludes agricultural feeds, agricultural bedding and textiles. In 1993, the UK production of industrial plant material was 3.3Mt with an additional 4.1Mt from recycled paper. The import bill that year was c. £5 billion, with exports only totalling £1.3 billion (McDougall et al., 1993). More recent figures presented below indicate that the gap between production and demand has not closed in the intervening 4 years. There is, consequently, a large import substitution market for appropriate crops with appropriate properties that can be produced economically in the UK.

The industrial potential of fibre products from Miscanthus has been investigated thoroughly during the last three years in MAFF-funded collaborative research programmes which have involved ADAS (NF0203, NF0303). Research with Miscanthus has been summarised by Hague (1997) and the generic potential of fibre crops has been discussed by Bolton (1995). Potential markets can be split into six main areas:

1. woven and non-woven textiles;
2. pulp for paper and packaging;
3. composite materials (particle board, chipboard, wafer board, plyboard and MDF);
4. geotextiles;
5. Filters, sorbents and active surfaces;
6. Insulation.

The potential and value of Miscanthus in the fibres market

Woven and non-woven textiles, geotextiles

The relatively short ultimate fibres of Miscanthus (c. 2 mm) are not suited to woven textile or geotextile production, and research indicates that no viable markets exist in this area. In addition, the textile industry consumes a small proportion of the total tonnage of plant fibres used. (cotton, jute and flax involve only 1.2% of the total fibre production). While textile fibres command the highest prices of all plant fibres (cotton at c. £1,500 t^{-1}) the total land area involved in the production of textile fibres is small when seen in the global context.

Pulp for paper and packaging

6.6M t of pulp were used in the UK during 1996 for the production of paper and pulp products. Of this, 4.3M t came from recycled waste products, 1.6M t from imported pulp and 0.6M t from home-produced pulp. A further 4.9M t (43% of total market) of pulp products were imported (Tables 11-13).

World-wide, less than 10% of paper products are made from non-wood fibres and in the UK this figure is only 1%. However, it has been demonstrated that Miscanthus has qualities that render it a non-wood alternative with high potential (Hague, 1997). Indeed, chemically pulped Miscanthus produces high quality paper with similar properties to spruce and eucalyptus derived pulp. Whilst Miscanthus can be used as a blending component in lower grade pulp products (from semi-chemical and mechanical pulping), it is very unlikely that the quality and price of the raw material would make production economic. Table 14 indicates the proportion of pulp products currently produced using waste (i.e. recycled) pulp. It is highly unlikely that Miscanthus could directly compete on the basis of costs with any product market where recycled fibre is acceptable. Thus newspapers, sanitary products and to a lesser extent boxboards and case materials would not represent suitable end markets.

One caveat to this statement is necessary due to the recent provision of Producer Responsibility Obligations (Packaging Waste) regulations (PRO) which create recovery and recycling targets for all obligated companies within the packaging chain. Recovery includes waste to energy and recycling of cardboard and plastics. It is feasible that the inclusion of a renewable fibre source such as Miscanthus as a minor constituent to some of the products will enable companies to attain their recycling targets more readily. More information is required in this area and more technology transfer between scientists and potential end users is required.

High quality paper for books/graphics/writing paper would seem the most suitable sector to target; conveniently this is the largest individual market, demanding 4.1M t annually, and is also the sector that is reliant on chemically pulped product. Of this, 1.6M t is imported. Assuming a 50% yield of fibre for this pulp from Miscanthus, Complete substitution of wood pulp imports could be attained by growing 160,000 ha of Miscanthus (at a yield of 20 odt ha^{-1}). With a raw product price of £30 - £60 per tonne depending on market fluctuations, this would equate to £96 - £192 M with a farm income of £600 - £1,200 ha^{-1}.

There is some potential to market paper products from Miscanthus at an environmental premium. The concept of paper that has been produced without the need to cut down forests, may allow an 'eco-friendly' label to be applied to the product. However, there is a large caveat to the feasibility of using Miscanthus as a fibre source for the high quality paper pulp market. No large-scale chemical pulping mills exist in the UK nor are any likely to be built specifically for Miscanthus. Combined Miscanthus/straw mills might be a possibility, but would demand an extremely high level of investment; one which is unlikely given the very socio-politically volatile nature of international pulp markets. Alternatively, the BioRegional Development Group is attempting to get a Mini-Mill system running which would be a) portable, b) require lower volumes of feedstock and c) require only a fraction of the capital investment of a large processor and therefore might be appropriate for a developing market such as Miscanthus (S Redstone, pers. comm.).

Composite materials

Medium Density Fibre Board

MDF has been identified by research conducted on behalf of MAFF as the wood-based product most suited to substitution by Miscanthus (Hague, 1997). FAO statistics suggest that global demand for wood based products will double by 2010. Assuming no growth in plywood production (currently 50% of global production) there will be a concomitantly high increase in wafer board, particle board and MDF manufacturing. This demand must be met with raw material production increasing at a suitable rate. However, the relationship between supply and demand is fragile: During the last two years in South East Asia, too many new MDF-plants were put into operation. This development was so rapid that demand could not keep up with the new increased supply. This has led to a reduction of prices. If one had calculated 2 years ago a sales price of approx. \$US340 m^{-3} for MDF, the achieved price is only \$US200 - \$US220 m^{-3}. This situation will not change for the next 2 - 3 years; in the long-term, however, the increased demand for wood based panel products can be anticipated with a commensurate increase of the sale price for this product. 1.25M t of wood was used in domestic MDF production during 1993 (representing only 34% of UK demand). With an increasing perception that logging tree-plantations is environmentally unfriendly, there may well be a niche in the production of MDF from Miscanthus at a raw product purchase cost of £30-60 odt^{-1} (the equivalent soft wood supply cost). It is anticipated that 20% substitution of Miscanthus in MDF production systems might be attainable by producers (Hague, pers. comm.). MDF will have an approximate utilisation rate of 75%. Assuming that half of all MDF domestic production incorporates Miscanthus (@20%), this would equate to a requirement of c.200, 000 t of Miscanthus annually (8-16,000 ha).

Single layer particleboard

Troger, Wegener and Seemann (1998) report successful production of particle boards using Miscanthus, when bonded with PMDI (polymeric diphenylmethane-4, 4'-diisocyanate), but not with UF (urea formaldehyde), PF (phenol formaldehyde or MUPF (melamine urea phenol formaldehyde). However, Hague (1997), reporting MAFF-funded work, found that with all bonding systems the internal board strength with Miscanthus was too low to be considered a viable option. Consequently, the potential for Miscanthus in this market is not considered further.

Light natural sandwich (LNS) materials

Light natural sandwich materials (or wafer boards) are considered in the body of the report under section 4.6.

Insulation materials

These are considered in detail in the main body of the report (section 4.7)

The economics of Miscanthus production for fibre for paper & packaging
Break-even costs of production are increased by the need to include specialised harvesting equipment (e.g. forage harvesters). This would most likely be used on a contract-hire basis. Moisture content upon harvest is not a problem because a moisture content of 50% is actually desired in the manufacturing processes (J Hague, pers. comm.); however, transport costs for this material would double.

Miscanthus for animal bedding/litter products

Poultry litter

Considering broilers alone, the UK market potential for litter products based on Miscanthus is very large. In 1998 the UK produced 765,000,000 broilers. Working on a very broad average that 1 bird occupies $0.1m^2$ of a broiler unit, we can determine that the following area of litter and equivalent weight of Miscanthus would have been used in 1996, depending on the depth of product used:

Table A6.1

Estimates of likely Miscanthus feedstock required to supply UK broiler houses (based on 1998 figures).

	Depth of Miscanthus litter (cm)	
	10.0	2.5
Area of litter used nationally (km^2)	76.5	76.5
Equivalent weight of Miscanthus (Mt) required	4.4	1.1
Area of Miscanthus needed for supply, assuming an average yield of 18 t ha^{-1} harvested ('000 ha)	349.2[1]	87.3[1]

[1] This figure assumes that 30 & of standing crop is lost due to harvesting and transport inefficiencies

The depth of litter that would be required from Miscanthus is not known, because the absorbency characteristics of the crop have not been quantified. The principal requirements of litter for the broiler industry are absorbency combined with dust-freeness. Standard products are straw and wood shavings that are treated with microbial disinfectants. The degree to which the product is absorbent determines the depth of the litter. Broilers are usually grown on 46-day cycles and the litter is replaced after each cycle. Wood shavings are generally superior absorbents to straw, and can consequently be spread over a larger area.

Whilst no specific information is available on Miscanthus as a litter or absorbent product, it may have significant potential. The value of the product will be dependent on the quality of the alternative that it replaces. Subsequent to its use in a broiler system the litter could be burnt in an NFFO-linked power station.

Table A6.2. Potential Miscanthus litter product retail value. Given for a range of replaced products and litter depths.

Replaced product	Equivalent Miscanthus sale price odt^{-1}			
	2.5 cm deep	5 cm deep	7.5 cm deep	10 cm deep
straw	43.75	35.00	26.25	17.50
wood shavings	84.00	63.00	42.00	21.00
Crumbledown®	82.00	63.00	44.00	25.00

Whilst the figures are taken from publicity material gathered at the Royal Show in 1997, it must be said that the figures for straw are very low. Current agricultural statistics indicate that Hesston Baled straw is currently on sale for £10 –12 t^{-1}, thus profit margin following chipping must be very low!

Horse bedding

Horse bedding offers a smaller but potentially higher value market. Essentially an identical product to poultry litter. There is a total potential market of c. 1Mt annually, which is currently met with wood shavings and straw. There is a higher premium on dust free nature and anti-irritant properties (Table A6.3). Specific high value products such as hemp straw and decorticated hemp are also entering the top end of the market. The total value of the UK horse bedding market is c. £70M annually. Key characteristics of horse bedding are that the product should be absorbent and dust/spore free.

Table A6.3.

Current retail prices of horse bedding products

Product	Retail cost (£/t)[1]
Sawdust	166
Straw	55
Paper	132
hemp shiv	350[2]
Other[3]	263

[1] Costings provided by commercial bedding manufacturers.
[2] Costing of hemp chiv from Hemcore Ltd. or AUBIOSE UK Ltd.
[3] Other specialist dust free products.

On the basis of the above table, it is clear that Miscanthus will need to perform significantly better (in terms of animal health and absorbency) to make an economically justifiable crop. However, if product quality can approach that of paper or hemp shiv (Miscanthus and shiv look remarkably similar) then there is outstanding market opportunity for Miscanthus. This is reflected in the gross margins below.

Industry standard assessments are required, comparing Miscanthus with sawdust and other current products. Chipped Miscanthus needs to be fully evaluated in terms of animal health and husbandry characteristics.

Costs for producing animal bedding

Field chopped Miscanthus will be immediately dried using on farm grain drying facilities, reducing moisture content from 40% to 10%. This will incur a cost of £13.32 odt^{-1} (Bartlett, pers. comm.). Additional handling costs from grain dryer to packaging machine, packaging materials and depreciation on capital equipment purchases will be incurred. Against these costs, some savings from reduced field storage will be made. Specific modifications to the base case model for chipped material are:

Capital costs. Specialised packaging equipment and conveyor systems have been seen to 'bale' Miscanthus into 25 kg bags well. The capital cost of such a system (£20,000), spread as a depreciating asset against the 50 ha producing Miscanthus, is £400 ha^{-1}.

Drying costs. Use of existing grain drying facilities is assumed. Thus, the cost per tonne, of drying from 40% moisture to 10% moisture is set at £13.32.

Additional handling & labour costs. Additional handling will be required. Two workers will be needed to man the packaging line. Assuming it takes one hour to package one tonne, this will result in a labour cost of £10 t^{-1}.

Variable costs. Bags for 25 kg of Miscanthus are expected to cost £0.06 each, or £2.40/t.

The resultant break-even cost is £63.

Table A6.4.

Market data for fibre products in the UK

UK paper pulp consumption by product sector (1996)

Sector	tonnage (Mt)	% of total
Newsprint	2.2	19
Wrapping papers etc...	0.4	4
Graphics/high quality paper	4.1	35
Case materials	2.5	22
Sanitary (tissues etc...)	0.8	7
Folding boxboard	1.2	11
Others	0.3	2
TOTAL	11.5	100
of which...		
Imports	4.9	43
Home sales	6.6	57

Source: UK Paper Federation.

UK paper pulp production by product sector (1996)

Sector	tonnage (Mt)	% of total
Newsprint	1.0	16
Wrapping papers etc...	0.1	2
Graphics/high quality paper	1.8	29
Case materials	1.7	27
Sanitary (tissues etc...)	0.6	9
Folding boxboard	0.7	11
Others	0.3	6
TOTAL	6.2	100

Source: UK Paper Federation.

Fibrous and raw material use (%) in the domestic pulp market

Sector	1986	1996
Imported woodchip	40	27
Home produced pulp	11	10
Waste paper pulp	49	62
Other pulps and fibres	0	1

Source: UK Paper Federation.

Percentage use of waste products by product sector (1996)

Sector	
Newsprint	c. 90%
Wrapping papers etc...	c. 65%
Graphics/high quality paper	c. 10%
Case materials	100%
Sanitary (tissues etc...)	c. 85%
Folding boxboard	c. 75%
Others	c. 65%

Source: UK Paper Federation.

ANNEX 7

Transport costs - calculations and sensitivity analysis

For the purposes of this review, it is assumed that bales of Miscanthus are collected at the farm gate by the processor and that the transport costs are borne by the processor. However, it is appropriate to identify the likely magnitude of these transport costs. This can be done for both baled and chopped Miscanthus.

The following scenario presents transport costs, per tonne, to a power station requiring 200,000 t of biomass annually which is situated 40 km from the site of crop production. Miscanthus bulk density is set at 240 kg m^{-3}; thus a full load consists of 33, 0.9t bales and will weigh 29.6 t. This is significantly more than the equivalent load of cereal straw (c. 16 t). A bulk density of 70 kg m^{-3} is assumed for the chopped material (D Bartlett, unpublished), thus a full load will consist of 8.6t.

A. Mileage related costs:

	£/km
Fuel & lubricants	0.18
Tyres	0.02
Repairs	0.06
TOTAL	0.26

B. Annual costs for baled system:

Total annual mileage cost per lorry	£41,916
Total annual cost of lorry (time + mileage)	£94,718
Total cost of 10 lorries	£947,175
Cost of transporting 200,000t annually =	£4.73/t

C. Annual costs for chopped system:

Total annual mileage cost per lorry	£41,916
Total annual cost of lorry (time + mileage)	£94,718
Total cost of 18 lorries	£1,704,924
Cost of transporting 200,000t annually =	£8.52/t

Calculation for transportation of baled Miscanthus:

V + (d*m)/l

where, V = annual lorry cost/t, d = return distance of journey (km), m = related mileage costs (per km) and l = the load (odt).

Thus, for baled Miscanthus; 4.73 + (80 * 0.26)/29.5
and, for chopped Miscanthus 8.52 + (80 * 0.26)/8.6

Thus, we have the following transport costs for varying transport distances for Miscanthus to the factory gate:

	£ odt^{-1} transported	
Round trip distance (km)	Baled	Chopped
40	5.08	9.73
80	5.44	10.94
160	6.14	13.36

These figures compare favourably with those reported by Allen et al. (1996) although they show less sensitivity to transport distance:

	£ odt^{-1} transported	
Round trip distance (km)	Baled	Chopped
40	3.60	8.00
80	4.50	10.00
160	6.75	14.00