IENICA

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OPPORTUNITIES FOR INDUSTRIAL CROP PRODUCTION IN IRELAND

Summary

Interest in non-food crop production has been stimulated by restrictions on the output of most food crop and animal enterprises, and a consequential reduction in on-farm employment. The production of fuel crops would also contribute to the abatement of greenhouse gas emissions, which will be a major concern in Ireland over the next ten years.

Unlike most other EU countries, Irish agriculture is dominated by grass-animal enterprises, with less than 10% of agricultural land devoted to arable crops. The set-aside area is therefore relatively small and mainly in grassland.

The non-food crop options chosen for review as having most relevance in Ireland include the following:

1. Oil crops for fuel production.
2. Production of sugar, starch or ligno-cellulosic crops for ethanol production.
3. Crop production for heat and/or electricity.
4. Crop production for processed board use.

In all the biomass-energy systems reviewed, raw material procurement is the predominant cost component. To produce energy at a cost approaching that of conventional mineral fuels, stable supplies of low-cost raw materials are essential. These are most likely to be residues or wastes for which competing uses are either low-value or non-existent. In the immediate future the most likely material in this category is waste vegetable oil. An industry based on these materials could be established, but would require de-excising to make it viable.

While the technologies for energy production from crops are improving rapidly, the costs remain uncompetitive with mineral fuels. In the absence of subsidy to reflect their environmental benefits and employment potential, little development in energy crop production can be expected.

Grass is of particular interest in Ireland. Ethanol production from grass by conventional technology is not viable, but two other options should be kept under review: conversion of hemicellulose sugars to ethanol, or extraction of xylose for industrial use.

Of the non-energy industrial crop uses, the most promising appears to be hemp for fibre or insulating board production. Its high yield, low dry matter and ease of establishment would be useful advantages. Demand will be dependant on the rate of expansion of the fibre board industry in relation to the availability of forest thinnings and saw-milling wastes.

OPPORTUNITIES FOR INDUSTRIAL CROP PRODUCTION IN IRELAND

Table of contents

OPPORTUNITIES FOR INDUSTRIAL CROP PRODUCTION IN IRELAND

Current situation

1.1 Introduction

Restrictions on the volume of production of most food crop and animal enterprises have led to an increasing interest among farmers in non-food crop production. In the early nineties when unemployment rates in Ireland were high, non-food crops were seen as a means of generating additional rural activity and employment and helping to maintain the production capacity of agriculture. The production of fuel crops could also contribute to the abatement of greenhouse gas emissions, which will be a major concern in Ireland over the next ten years.

1.2 Current land use

Of the 7 Mha area of Ireland, 72% (5 Mha) is devoted to agriculture and forestry. In 1999, 11% of this area (0.6 Mha) was in forestry, leaving 4.4 Mha in agriculture. This area was devoted predominantly to grass (83% or 3.7 Mha) for milk, beef and mutton production. Arable crops were produced on less than 0.4 Mha, the main crops being cereals (0.3 Mha), sugar beet (34,000 ha), potatoes (18,000 ha), silage maize (8,000 ha), linseed (8,000 ha), and oilseed and protein crops (5000 ha). Apart from an increase in the area under forestry, no other major changes in this land use pattern are envisaged in the near future. Virtually all agricultural production is for food or animal feed purposes, with no industrial use at this time.

The area breakdown between cereal crops in recent years is shown in Table 1. Spring barley and winter wheat predominate.

Table 1: Areas of various cereal crops, 1996-8

Year	1996	1997	1998
Cereal		Area grown (ha x 1000)	
Winter wheat	67.2	70.2	65.5
Spring wheat	18.5	23.7	18.4
Winter barley	40.9	41.1	39.0
Spring barley	140.5	148.6	151.7
Winter oats	12.5	11.2	12.1
Spring oats	8.4	9.4	7.3
Other cereals	5.5	5.6	6.6

Total area	293.5	309.9	300.6

Source: Department of Agriculture, Food and Forestry.

Cereal yields over the past three years have been as in Table 2. Yields of winter wheat have been among the highest in Europe. In 1998 the average yield of sugar-beet was 45 t/ha, and of potatoes 31 t/ha.

Table 2: Cereal yields, 1996-8

Year	1996	1997	1998
Cereal		Average yield (t/ha)	
Winter wheat	9.4	8.0	8.1
Spring wheat	7.5	6.8	7.4
Winter barley	8.0	7.0	6.4
Spring barley	6.4	5.4	5.5
Winter oats	7.6	7.4	6.9
Spring oats	6.1	5.2	5.7

Source: Department of Agriculture, Food and Forestry

1.3 Arable set-aside

The main spur to the search for industrial uses for crops in Ireland has been the desire to find alternative uses for set-aside land, with a view to sustaining output and employment on arable farms. However, the availability of set-aside land in sufficient quantities for a substantial non-food industry has always been uncertain.

The total area of set-aside increased to 36,600 ha in 1994, but had halved by 1997 (Table 3). While it increased again to 30,000 ha in 1999, the equalisation of the set-aside requirement for rotational and permanent set-aside in 1996 led to a sharp increase in the proportion of permanent set-aside. The present breakdown between permanent and rotational is not recorded, but it is estimated to be about two-thirds permanent. Most of this is in grassland, and is unlikely to be readily available for non-food crop production.

Within the remaining set-aside pool (currently about 10,000 ha), farmers with very small areas of set-aside, or with a high proportion of sugar-beet, or growing continuous winter wheat, may have reservations about growing industrial crops on their set-aside. Frequent changes in set-aside requirements and regulations have also generated uncertainty about future supplies of crops from set-aside to support a non-food industry.

To date, the use of set-aside land for non-food crop production has been confined to very small areas of oil-seed rape and wheat, which were exported for industrial use.

Table 3: Set-aside areas in Ireland

Year	Set-aside area (ha x 1000)		
	Rotational	Non-rotational	Total
1994	22.9	13.7	36.6
1995	19.1	13.1	32.2
1996			25.2
1997			18.4
1998			20.2
1999			30.4

Source: Department of Agriculture, Food and Forestry

1.4 Work-force employment

There has been a rapid increase in work-force employment levels in Ireland in recent years. Unemployment has fallen from 12.1% in 1995 to 5.6% in 1999, in a period when the total labour force grew from about 1.6M to 1.8M (Table 4). Labour availability is now seen as a production constraint on many farms, and this has somewhat reduced interest in alternative uses for set-aside land.

Table 4: Average annual unemployment rate 1995-9

Year	1995	1996	1997	1998	1999
Unemployment rate (%)	12.1	11.5	9.8	7.4	5.6

Source: Central Statistics Office

1.5 Potential industrial uses

The most promising large-scale industrial uses for crops in Ireland at present are as follows:

1.5.1 Energy crops: In addition to maintaining output and employment, energy production from biomass crops, by-products or residues would have two other significant benefits:

> *(i) Enhancement of environment:* As renewable energy sources which re-cycle most of the carbon released on combustion, biomass crops could contribute to a reduction of CO_2 emissions. Perennial biomass crops could increase the reservoir of carbon stored in soil and plant. Liquid bio-fuels could also contribute to a reduction of urban air pollution caused by vehicle emissions.

> *(ii) Indigenous fuel supply:* While the proportion of total Irish energy needs that could be supplied from biomass in the medium-term future is small, native renewable energy supply could provide some security in crises as well as improving the trade balance.

Ireland has a total primary energy demand of about 550 PJ. Only 2% of this is produced from renewable sources at present. The only significant use of biomass is fuel-wood for domestic and process heating, which amounts to about 4 PJ, less than 1% of the total primary energy demand. About 3% of electricity is produced from a renewable source (mainly hydro). Within the EU, Ireland has one of the lowest proportions of renewable energy.

Over 2 million tonnes of diesel fuel (90 PJ) are used annually, of which about 40% is used in road vehicles. Petrol consumption amounts to about 1 million tonnes (45 PJ). To date there is no liquid bio-fuel production in Ireland.

1.5.2 Processed board manufacture: Four existing plants produce chip-board, medium density fibre-board and oriented strand board from forest thinnings and saw-milling waste. At full capacity they would require about 1.5 Mt of raw material per year. There is an interest in alternative raw materials, especially for fibre-board manufacture.

1.5.3 Flax fibre production: Ireland had a substantial flax industry in the first half of the twentieth century. The possibility of re-starting this industry using modern production and processing technology is worthy of consideration.

1.6 National incentives

The main national incentive for renewable energy industries has been the introduction of the Alternative Energy Requirement tendering scheme for electricity generation (Table 5, O’Donnell, 1995). The effect of the first and third phases of this program (AER 1 and 3) has been to stimulate electricity production from wind and land-fill gas. The second phase

(AER2) was aimed at procuring one major (10-30 MW) plant based on biomass or wastes. A proposal to build a waste-to-energy plant for municipal solid waste, still in the planning application process, was the only outcome of this phase. To date there has been no biomass plant built in response to AER 3.

Table 5: Alternative Energy Requirement (AER) phases and targets

Category	AER 1	AER 2	AER 3	Total
		Target MWe		
Biomass/waste	15	30	7	52
Hydro	10	0	3	13
Wave	0	0	5	5
Wind	30	0	90	120

Source: Department of Public Enterprise, 1999.

The European Commission energy futures analysis envisages a contribution from biomass to Irish energy supply of about 16 PJ (3% of demand) by 2000, and 42-48 PJ (7-8.5% of demand) by 2010 (European Commission, 1996).

The TERES II report, in dealing with Ireland, envisages a growth in energy from renewables to between 7 and 10% of primary energy demand by 2005, and to 9-14% by 2015, depending on national policies adopted. Biomass crops and residues are seen as the major components of this expansion (ESD, 1996).

With regard to liquid bio-fuels, enabling legislation was introduced in the 1995 Finance Act for the remission of excise on bio-fuel produced in approved pilot projects. Similar legislation has been used in France, Germany, Austria and Italy for the support of bio-diesel and bio-ethanol production. Criteria for project approval were drawn up. However, to date no applications for excise remission under this scheme have been approved.

1.7 Greenhouse gas abatement

Following the Kyoto Protocol of Nov. 1997, Ireland has been allocated a target to contain the increase in greenhouse gas emissions to 13% in the period from 1990 to 2010. This limit has already been reached, and in the absence of corrective action, the increase will exceed 25% by 2008 (Department of Public Enterprise, 1999).

In an initial response to this problem, a study of the sources of emissions and possible abatement strategies was commissioned (Environmental Resources Management, 1998); a Green Paper on meeting energy needs in a sustainable way has also been published (Department of Public Enterprise, 1999).

From these documents it appears that the main initial planks of government strategy for greenhouse gas abatement will be:

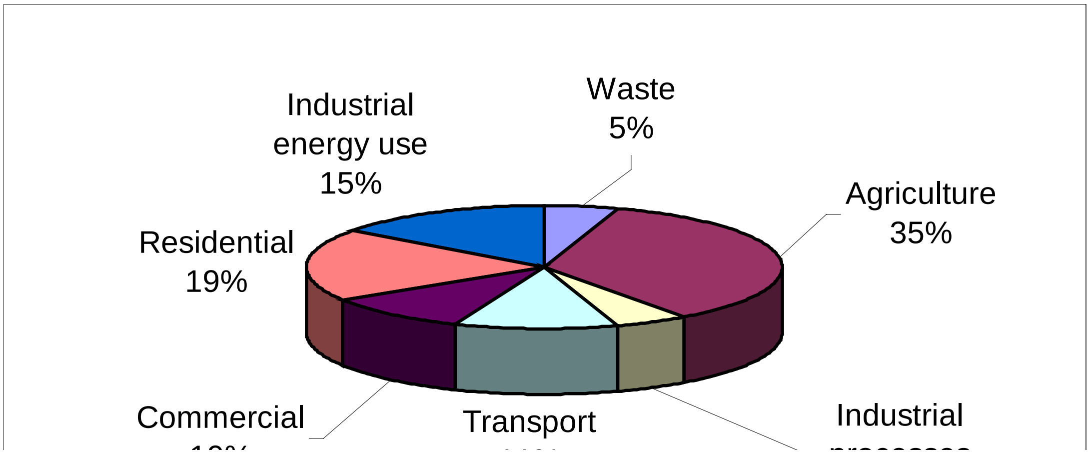
- Stimulation of renewable electricity generation (500 MWe by 2005) by tax relief and other fiscal measures, by inviting further AER tenders, by facilitating access to the grid and streamlining the processing of applications for planning permission. Wind energy may be expected to dominate this process.
- Substitution of natural gas for coal and oil at existing generation plants.
- Increase of energy use efficiency in homes, services and industry.
- Transfer of land from animal enterprises to forestry.

The Irish agricultural sector accounts for 35% of gas emissions, so efforts to address the problem will inevitably focus on this sector (Fig. 1). Actions could take two forms:

(i) Curtailment of emissions from current farming enterprises

(ii) Use of agricultural biomass to increase the carbon sink and provide a renewable energy source

Fig. 1: Greenhouse gas emissions by sector (Source: Environmental Resources Management, 1998)



In relation to current arable farming, input reduction is the most direct way of reducing emissions. Reduction of N and P fertiliser would reduce N_2O emission as well as the energy input, and would also reduce the N and P levels in water supplies. This may militate against the use of set-aside for non-food crops.

The expected increase in the forest area in the country will slowly reduce the global warming effect by building up an increased carbon sink. If forest residues could be used more widely as a heating fuel, a greater contribution to emission abatement could be achieved. However, in the absence of market support, it is very difficult for any biofuel to become competitive.

1.8 Scope of review

This review includes the results of studies of the feasibility of various industrial crop options. Those chosen for review include

1. Oil crops for fuel production.
2. Production of sugar, starch or ligno-cellulosic crops for ethanol production.
3. Crop production for heat and/or electricity.
4. Crop production for processed board use.

2. Liquid biofuel production from vegetable oils

2.1 Current situation

To date there is no liquid bio-fuel industry in Ireland. Several studies have been made of the potential for bio-diesel (Kinsella, 1994; Rice, 1992); research in this area is still on-going.

Research on the use of degummed vegetable oil as an engine fuel in blends with mineral diesel has been carried out (McDonnell, 1995). The results suggest that some degummed oil can be included in blends without either immediate or long-term adverse effects on engine performance. Commercial uptake will require the acceptance of this fuel by engine and lubricating oil manufacturers, which is unlikely to be forthcoming in the near future. In the longer term, the reduced processing requirement may provide valuable cost saving.

Work on the use of unprocessed vegetable oil as heating fuel has started recently (McLoughlin, 1996). In the absence of market distortion, good arguments could be made for the use of vegetable oil as a heating fuel rather than in engines. However, the prospects of commercialisation are poor at present; the current excise on mineral heating fuel is much lower than on vehicle fuel, so de-excising, the support mechanism favoured in the EU, would not be sufficient to make it viable.

While Directives 92/81 and 92/82 seek to harmonise excise rates on vehicle fuels throughout the EU, a separate Directive has allowed member states to set reduced excise rates for liquid bio-fuels. The Irish 1995 Finance Act contained provisions to allow government to remit excise on approved pilot bio-fuel projects.

2.2 Bio-diesel production

2.2.1 Production from rape-seed oil: The acceptance of rape methyl ester (RME) produced to an agreed specification as a replacement fuel for diesel engines is now almost complete. In Ireland, a demonstration project has been completed in which a range of vehicles have travelled over 100,000 km on RME (Rice, 1995). Few technical problems were encountered, and the reaction of fleet managers was generally positive. Public reaction to the concept of an indigenous, renewable fuel with several environmental advantages was enthusiastic.

The main deterrent to the establishment of a bio-diesel industry in Ireland is the cost of rape-seed production; the second problem is the availability of set-aside land in sufficient quantities to achieve a scale of production needed to run a cost-efficient plant. Farmers' decisions about rape production on their 'eligible' land are based on their assessment of its profitability in relation to other enterprises, mainly cereals. In the past, few have opted for rape, although yields have been generally high. As a result, the Irish base area is only 4,250 ha. In any case, the price available for rape grown on eligible land is usually too high for the fuel market.

While the provisions for non-food use of set-aside land could all be met by rape-seed grown for bio-diesel production, its economic feasibility in Ireland is marginal. Table 2.2 shows that spring rape is more attractive than winter, and that for this crop producers would require a price of £77/t (equivalent to 17p/litre of oil) to meet the cost of materials and interest, and £150/t (34p/litre) to cover all costs.

Rape-seed oil is an excellent raw material, from which it is easy to produce bio-diesel of a high quality. However, a bio-diesel plant operating in Ireland, solely on rape and on a relatively small scale, would have considerable difficulty paying the grower an acceptable price for the raw material and selling at a price near to that of mineral diesel, even with a complete removal of excise from the bio-fuel. At a rough estimate, the price might be expected to vary between 35 and 45p/litre, the main factors affecting the price being raw material cost and the lower extracted oil yield from the simpler mechanical presses in the smaller systems that would be most likely to find application in Ireland.

2.2.2 Production from lower-cost raw materials: Several possibilities exist for the reduction of feed-stock cost:

(i) Alternative oil-seed crops: Oils from alternative oil-seed crops could be used on their own or in blends with rape. An alternative oil-seed crop suited to the Irish climate, *camelina sativa*, is being examined at Oak Park. Its oil yield is similar to that of rape, but it requires lower fertiliser and pesticide inputs, which leads to a lower production cost

and a more favourable energy ratio (Table 6). It also ripens earlier than rape, and is more durable at harvest.

Table 6: Rape and camelina seed production costs and returns

Costs and returns	**Rape**		**Camelina**	
	Winter	**Spring**	**Winter**	**Spring**
Materials + interest (£/ha)	329	217	158	124
Less set-aside material costs (£/ha)	25	25	25	25
Material costs over set-aside (£/ha)	304	192	133	99
Total costs (£/ha)	631	449	376	312
Less total set-aside costs (£/ha)	75	75	75	75
Total costs over set-aside (£/ha)	556	374	301	237
Assumed yield (t/ha)	3.2	2.5	3.0	2.5
Seed price to meet material costs (£/t)	97	77	44	40
Seed price to meet full costs (£/t)	174	150	100	95

One of the factors which limits the use of camelina oil as a bio-diesel feed-stock is the low-temperature properties of the ester, which are slightly inferior to those of rape ester (Table 7). This problem could be overcome by the use of suitable additives. In Oak Park tests, two additives improved the cold filter plug point (CFPP) and pour point of the ester to a level that would make the fuel acceptable in Irish winter temperatures (Table 8).

Table 7: Low-temperature properties and iodine values of esters from alternative sources

Oil	**Iodine value**	**Cloud point**	**CFFP**	**Pour point**
			°C	
Rape	115	+2	-4	-7
Waste vegetable	100	+3	-3	-3
Camelina	160	+4	-2	-2

An alternative approach is to blend camelina methyl ester with mineral diesel. The low-temperature properties of blends of varying proportions of these materials are given in

Table 9. These figures suggest that a blend with roughly equal amounts of ester and mineral diesel would have adequate low-temperature properties for Irish winter conditions.

Table 8: Effect of additives on the low temperature properties of camelina methyl ester

Ester + additive	Cloud point °C	CFPP °C	Pour point °C
Camelina ME no additive	+4	-4	-8
Camelina ME + 250 ppm CP7134[a]	+3	-5	-16
Camelina ME + 500 ppm CP7134	+1	-12	-12
Camelina ME + 600 ppm CP7134	+3	-13	-14
Camelina ME + 1000 ppm CP7134	+3	-12	<-19
Camelina ME + 2000 ppm Lubrizol 7670[b]	+3	-9	<-18

[a] -Product of Elf Aquitaine SA. [b] Product of Lubrizol Ltd., Merseyside.

Table 9: Low-temperature properties of blends of camelina ester and mineral diesel.

Camelina ester %	Gas-oil %	Cloud point °C	CFPP °C	Pour point °C
100	0	+3	-3	-4
80	20	+3	-7	-6
60	40	+3	-9	-9
40	60	+3	-11	-12
20	80	+3	-13	<-18
0	100	+3	-15	<-21

The second problem with camelina bio-diesel is its high iodine value (Table 7). This might be expected to cause the lubricating oil to thicken if it became diluted by the bio-diesel. Information on this subject is still inconclusive, but for the present a maximum iodine value of 115 has been set in the EC draft specification for methyl esters as motor fuels, and this is likely to remain for the medium-term future (Commission of European Communities, 1993). This rules out the use of camelina oil on its own for bio-diesel production. However, in blends it would have some desirable properties, such as a low viscosity.

The reduced cost of camelina oil arising from its lower input requirements could make a very significant saving over rape of £37-55 per tonne of seed, or 9-13p per litre of bio-diesel produced (Table 6).

(ii) Waste vegetable oil: Over 100,000 tonnes of vegetable oil are imported annually into Ireland (Central Statistics Office, 1996). At a rough estimate, 50,000 tonnes is used by the catering industry, and 10-20,00 tonnes could be collected for re-cycling. Less than half of this is currently collected and used in animal feed compounds; it is evident from fatty acid analysis that most of this is rape-seed oil. Oil that is not collected for re-use ends up as a source of pollution in sewers and land-fills.

Waste cooking oil esterified at Oak Park after preliminary cleaning has largely met the the draft EU biodiesel specification (Commission of European Communities, 1993). In light transport vehicles, engine performance and fuel economy have been satisfactory, and no technical problems have been encountered. Some processing problems remain to be resolved, such as low ester yields and some contaminant levels near the limit of permitted values.

The initial cost of waste oil is very low, but assembly is expensive and a reduced percentage yield may be expected. The bio-diesel produced would still be much lower cost than that from virgin oil.

(iii) Tallow: About 100,000 t/year of tallow is produced in Ireland. It is very variable in price and quality; much of the lower-grade material is sold as animal feed, and the market will continue to be distorted by restrictions on the use of bovine offals for this purpose in the aftermath of the BSE crisis.

In preliminary tests at Oak Park, good quality bio-diesel has been produced from tallow, though yields have been low. The high melting point and poor storage properties in liquid form of tallow cause some additional problems. The low-temperature properties of the ester would rule out its use as a sole feed-stock, but as a minor ingredient in blends its iodine value of about 50 would be a useful advantage (Table 7).

(iv) Blends of the above materials: The main aim in blending these materials is to look for an ester which has an acceptable iodine value and reasonable low-temperature properties. For example, the following blends all have iodine values close to 115:

Waste oil 75%	Camelina 25%	
Waste oil 65%	Camelina 30%	Tallow 5%
Waste oil 55%	Camelina 35%	Tallow 10%
Waste oil 40%	Camelina 40%	Tallow 20%

To date, additives which improved the low-temperature properties of vegetable oils have had little effect on tallow, so it has not been possible to produce a satisfactory bio-diesel including more than 5% tallow. Blends of up to 25% tallow ester with mineral diesel had reasonable low-temperature properties. Separation of tallow ester from other blend components at low temperatures is a problem that has yet to be overcome.

2.2.3 Niche markets for bio-diesel: Bio-diesel should be used in applications which make best use of its desirable features: reduced smoke, absence of sulphur, low toxicity in water and high lubricity. However, an investor is concerned with the conversion of these benefits into an increased price for the fuel. It would be difficult to command a premium for applications such as urban buses or taxis unless it is supported by the type of Clean Air Acts that apply in many cities in the US. There would also be difficulties promoting bio-diesel use in boats, since they are allowed to use low-excise mineral diesel at present. One promising outlet would be vehicles operating in high-amenity areas, or in confined spaces where ventilation is restricted. Another potential market is for drivers who suffer allergic reaction to mineral diesel emissions. Finally, its addition to low-sulphur mineral diesel could overcome a lack of lubricity which is causing some difficulties with this fuel.

2.3 Conclusion

While the technical problems of bio-diesel production and utilisation have been largely overcome, uncertainties surrounding the availability of land for non-food crop production make it difficult to start up a bio-diesel industry based on home-grown crops. The cost of oil-seed crops as raw materials is also a problem. Substantial cost reductions could be made by the use of crops such as camelina, but support in the form of reduced excise would be required for the foreseeable future. This can be justified by the favourable macro-economic impact of a bio-diesel industry (quantified by Kinsella, 1994), and by the environmental benefits, valued at 5-7p/litre by Vermeersch, 1994.

The best prospect for a viable industry at present is to make the greatest possible use of lower-cost feed-stocks such as waste vegetable oil, consistent with the achievement of a high-quality product. The bio-diesel produced should be directed towards niche markets where the maximum environment and health benefits could be realised, and where these benefits can be converted into a higher price for the fuel.

If an industry using 15,000t of waste vegetable oil could be established, it would almost achieve the 5% substitution of road vehicle diesel envisaged in the Altener program. If the feed-stocks are considered as wastes, and no allowance made for the energy used in their production, the CO_2 abatement would be about 0.06 Mt, or 4% of the overall Altener target for all renewables. If the bio-diesel could be used in urban fleets, waterways or areas of poor ventilation, then additional local environmental benefits could also be achieved. For this size of industry to be established, improved collection systems for waste cooking oil would be needed. Action would also be needed to discourage dumping of this material into sewers and land-fill sites.

3 Ethanol production from crops and residues

3.1 Introduction

There are three ways in which ethanol could be used as fuel for spark-ignition engines:

(i) Petrol-ethanol blends may be used in conventional unmodified spark-ignition engines. An EU Directive permits the use of up to 5% ethanol in blends with petrol (Commission of European Communities, 1985). This approach is widely used in the US, but has not been favoured in the EU, due to technical problems with the handling and storage of the fuel, caused by its solubility in water and high vapour pressure.

(ii) Blends of the ethanol derivative ETBE (ethyl tertiary butyl ether) and petrol may also be used in unmodified engines. The 1985 Directive authorises up to 15% ETBE in blends. This has been the most favoured approach to ethanol use in the EU. ETBE can replace MTBE as an octane enhancer in lead-free petrol. A problem in Ireland would be the additional plant requirement for the conversion of ethanol to ETBE.

(iii) The use of larger proportions of ethanol in blends, or of ethanol as the sole engine fuel, has been widely practised in Brazil. This requires engine modifications, starting with the replacement of susceptible plastics in the fuel handling system, and eventually requiring a re-designed carburettor system and an increased compression ratio. This scenario has little relevance for Ireland.

3.2 Feed-stock materials

To date, the most widely used raw materials for ethanol production are maize (USA), sugar-cane (Brazil), sugar-beet (France) and wheat (France). For the future, cheaper cellulosic materials such as straw, maize stalks and wood are expected to be used as processing technology is developed.

A list of potential Irish feed-stocks, with corresponding ethanol yields, is given in Table 10. Attainable crop yields were estimated on the basis of national statistics and Oak Park trial results. Carbohydrate contents and ethanol yields were assumed on the basis of work in Teagasc and elsewhere.

The crop areas required to produce ethanol equivalent to 5% of petrol consumption vary from about 11,000 ha of sugar beet to 36,000 ha of barley. For grass, two alternative scenarios are examined: in the first, only the water-soluble carbohydrates are converted, in the second the cellulose is also utilised. Two alternative processes are also examined for wood-chips: one assuming that only cellulose is utilised, the other assuming that both cellulose and xylose are converted.

Table 10: Ethanol yields from various feed-stocks

Crop/by-product	Assumed yield (t/ha)	Carbohydrate		Ethanol yield (l/tonne)	Ethanol (l/ha)
		Material	Content		
Sugar beet	55	Sucrose	16.5	101	5555
Chicory	55	Inulin	17.0	99	5445
Potatoes	50	Starch	14.0	91	4550
Wheat	7.0	Starch	60.0	369	2583
Barley	5.5	Starch	48.5	298	1693
Grass (1)	60	WSC	5.0	15.4	929
Grass (2)	60	WSC, cellulose	45	38.5	2249
Straw	-	Cellulose	37.0[1]	183	-
Wood-chips(1)	-	Cellulose	48.0 [1]	237	-
Wood-chips (2)	-	Cellulose, xylose	71.0	340	-

Source: 1. Marrow et al, 1987.

3.3 Processing

Most commercial bioethanol is produced by the fermentation of sucrose and glucose (the latter usually obtained from starch), the most abundant sugars in agricultural crops. Some ethanol is also produced by the fermentation of lactose.

The technology for the production of industrial ethanol has improved considerably, but the underlying principles remain the same: extraction of fermentable carbohydrate from the feed-stock (hydrolysis if it is a polysaccharide such as starch or inulin), followed by fermentation and recovery of ethanol in a three-stage distillation. The most energy-intensive part of the process, fermentation and recovery of ethanol, is the same for all raw materials;

where the individual processes differ is in the extraction and preparation of fermentable carbohydrates. For example, sucrose in molasses can be fermented directly, sucrose in sugar beet needs to be extracted, but feed-stocks with polysaccharides need to be pre-treated and hydrolysed before fermentation can take place. Methods of hydrolysis of polysaccharides also differ considerably in complexity and cost.

3.4 Costs

The cost of ethanol production includes the cost of raw material, transport to distillery, storage and processing, with a credit allowance for the value of by-products.

***3.4.1 Feed-stocks and by-products**:* Assumed feed-stock and by-product costs and adjusted feed-stock costs (i.e. allowing for the value of by-products) per litre of ethanol are listed in Table 11. Market prices for many of these materials and their by-products are very variable; for others there is as yet no market. Two alternative costs are included for sugar beet (A- and B-quota). Grass price was based on production costs and a profit margin of IR£250/ha, and chicory was assumed to have the same price as sugar beet. Other costs were assumed on the basis of recent market prices.

Table 11: Feed-stock costs less credit for by-products

Feed-stock cost			By-product					Net
	Cost (£/t)	Cost (£/l)	Material	Ratio (%)	Value (£/t)	Credit (£/t)	Credit (£/l)	(£/litre)
Beet A	38	0.38	Pulp	7	118	8.26	0.08	0.30
Beet B	27	0.27	Pulp	7	118	8.26	0.08	0.19
Chicory	38	0.38	Pulp	7	118	8.26	0.08	0.30
Potatoes	60	0.66	Pulp	6.9	134	9.25	0.10	0.56
Wheat	105	0.29	Distiller’s grain	34.0	134	45.6	0.12	0.17
Barley	95	0.32	Distiller’s grain	34.0	134	45.6	0.15	0.17
Grass (1)	12.5	0.81	Pressed grass	12.6	73	9.2	0.60	0.21
Grass (2)	73	0.31	Grass protein	29.7	134	39.8	0.17	0.14
Straw	35	0.19	Lignin	10.0		5.5	0.03	0.16

3.4.2 Processing costs: Precise processing costs depend on plant scale and design, labour and energy costs, hence reported values vary considerably from author to author (Table 12). However, processing costs in the same study, such as those for sugar beet, grain and potatoes reported by Mercier,1986 should give a good indication of the relative costs of ethanol processing from different feed-stocks.

Ethanol processing from ligno-cellulose materials, such as straw and grass, are not yet carried out on an industrial scale, so processing costs were obtained from pilot plant scale experiments. The Voest-Alpine processing costs (Voest Alpine 1992) are in line with those reported by Mercier, 1986 for traditional crops using cellulose hydrolysis. It is expected to be more expensive than starch hydrolysis. However, it is unlikely that the wood-ethanol process would be cheaper than the simple grain-ethanol process. The amount of ethanol per tonne of raw material is nearly the same in the two processes, but the former requires a higher energy input.

Table 12: Ethanol processing costs per unit of ethanol produced

Literature source	Conversion technology	Processing cost (£/litre)
	Cereals	
Marrow et al. (1987)	Batch fermentation	0.10
USDA (1980)	Batch fermentation	0.29
Mercier (1986)	Batch fermentation	0.23
Alpha Laval	Biostil process	0.20
	Sugar Beet	
OECD/IEA (1995)	Batch fermentation	0.20
Marrow et al. (1987)	Batch fermentation	0.16
Mercier(1986)	Batch fermentation	0.19
	Potatoes	
Mercier et al. (1986)	Batch fermentation	0.23
Rexen & Munck (1984)	Batch fermentation	0.21
	Grass	
Voest-Alpine (1992)	cellulose hydrolysis	0.30
	Straw	
Voest-Alpine (1992)	cellulose hydrolysis	0.28
	Wood-chips	
Wyman (1995) (calculated)	cellulose hydrolysis	0.12

3.4.3 Transport and storage costs: A rough estimate was made of the cost of transporting the various feed-stocks an average distance of 30 km to the processing plant. For all feed-stocks except grass, transport costs amount to 1p to 4p/litre. Long-distance transport of grass is clearly not realistic (Tables 13, 14).

The feed-stock costs include an allowance for short-term storage prior to processing. However, if the full annual capacity of the process plant is to be realised, some feed-stock may have to be stored long-term for processing at times of the year when fresh material is not available. The materials to be stored would be those which can be stored cheaply with the least deterioration or storage loss, such as cereals, straw and dry wood-chips. Planning an optimum year-round feed-stock mix would require detailed study, and is not attempted here. No matter what feed-stocks are used, some additional cost made up of store capital costs, storage losses and working capital may be incurred. This could add up to 5p/litre to the calculated production costs.

Table 13: Production costs of ethanol from conventional feed-stocks

Feed-stock	Feed-stock cost less by-product value	Processing	Transport	Total production costs
		(£/litre)		
Sugar beet A	0.29	0.19	0.04	0.52
Sugar beet B	0.19	0.19	0.04	0.42
Chicory	0.30	0.20	0.04	0.54
Potatoes	0.56	0.23	0.04	0.83
Wheat	0.17	0.23	0.01	0.41
Barley	0.17	0.23	0.01	0.41

Table 14: Production costs of ethanol from ligno-cellulose feed-stocks

Feed-stock	Feed-stock, less by-product	Processing	Transport	Total production costs
		(£/litre)		
Grass (1)	0.21	0.20	0.13	0.67
Grass (2)	0.14	0.30	0.07	0.51
Straw	0.16	0.28	0.04	0.48

***3.4.4 Total costs**:* Tables 13 and 14 show a range of production costs from 37 to 83p/litre, depending on the feed-stock materials, feed-stock price and transformation process.

Ethanol has a calorific value about two-thirds that of petrol. On this basis, its value as a petrol replacement, before tax or distribution cost, is less than 10p/litre. If a comparison is made with the price of methanol, based on its octane-enhancing properties, this is currently about 13p/litre. Even a full remission of road excise would make only the lowest-cost wood-chip scenario competitive; further economies would have to be achieved to reduce costs with all the conventional conversion systems.

The main advantage of ethanol production as an outlet for arable crops is that it can be produced from such a wide range of feed-stocks, many of which are already being grown, so the technology for production, harvesting, drying and storage is already in place. If used as an additive to petrol, a distribution and marketing system is also in place, so the process plant is the only additional requirement.

In spite of the apparently unfavourable economics of bio-ethanol production to date, it has become well established in the US, and several major installations are planned in France. In the US, bio-ethanol production is stimulated by the need to oxygenate mineral fuels to comply with clean air legislation. Current US long-term projections are for an industry producing large volumes of bio-ethanol from low-cost by-product or residue ligno-cellulose materials at a cost approaching that of petrol. The long-term availability of suitable raw materials in Ireland, and the benefit of a low-value outlet for by-product or residue ligno-cellulose materials, needs to be further evaluated.

3.5 Ethanol from sugar beet

Ethanol production from sugar beet merits special consideration because of its potential synergistic relationship with the existing sugar industry. Facilities already in place for the organisation of crop production under contract, and for transport, reception, pre-cleaning and juice extraction; only the fermentation and distillation plant would need to be added.

Ireland currently plants about 35,000 ha of sugar beet. Land for the production of extra beet would be available; with sugar yields continuing to increase and at best a constant sugar quota, it would at least ensure that the area under beet would be maintained at current levels for the medium-term future. Sugar beet is a high-input crop; as well as creating a demand for farm labour and other inputs for the production of the crop, it also generates many spinoff benefits, such as animal feed supply, labour for haulage and processing, and local farm machinery production.

Beet for ethanol production could be grown on eligible arable land, on set-aside, or on land outside the arable pool. In practice, it is likely to be grown on eligible land for the following reasons:

- There is a limited amount of set-aside land available.

- If it is grown on set-aside, area aid support is not available.

- Since an important aim would be to produce the full amount of A-quota sugar, it might not be clear at sowing time how much of the extra beet would end up as sugar and how much would go to ethanol.

Beet grown on eligible land would probably displace a cereal crop, most likely spring barley. So while there would be an overall benefit in terms of increased farm employment and turnover, the negative effect due to the displaced crop would also have to be taken into account.

Teagasc estimates the variable costs of sugar-beet production for 1999 at £1060/ha (O'Mahoney, 1999). At the B-quota price of about £27/t, a yield of 39.3 t/ha would be required to recoup these costs. Given that the present average yield is about 45 t/ha, beet production at this price might be expected to have limited attraction for growers. However, other issues, such as the avoidance of outside-quota prices in high-yield years, would also play a part in farmers' decision-making.

3.6 Ethanol from grass in Ireland

The use of grass as a feedstock would have several advantages in Ireland. The mild climate and adequate moisture supply leads to a long growing season and high yields. A very high proportion of the land is already producing grass, and harvesting technology is in place.

However, with a low carbohydrate level and high moisture content, the costs of transporting grass and producing ethanol by conventional technology are very high (Grass 1, Table 10). Two other possibilities exist.

(i) Increase ethanol yield by using new technology to convert hemicellulose to ethanol (Grass 2, Table10).

(ii) Use expressed juice for ethanol production, and find an alternative food or non-food use for the remainder. Possibilities would include animal feed or further processing to extraction hemicellulose sugars. In ryegrass, the most significant of these were found to be xylose (12-16%), glucose (3-5%) and arabinose (2-3%).

At present, the conversion of hemicellulose to ethanol appears to be the most promising option, but the cost still appears to be too high to make it feasible.

3.7 Impact on environment

When ethanol is produced from crops such as cereals or sugar-beet, the energy in the ethanol is only slightly greater than the energy used in crop production and processing, so the net reduction of fossil energy use is slight. When the energy in the animal feed by-products is included in the balance, the energy ratio increases to almost two. Recent studies in France suggest that, in the long-term, substantial further improvements in the energy ratio can be made (Poitrat, 1994). The processing of ligno-cellulosic residues would also have a more favourable energy balance. However, for the short-term future it must be accepted that a bio-ethanol industry would make only a small contribution to the reduction of CO_2 emissions.

The main advantages of bio-ethanol as an additive to petrol are:

(i) its oxygenating effect, leading to a reduction of CO in vehicle emissions and a reduced potential for ozone formation in the atmosphere.

(ii) its effect as an octane enhancer, as an alternative to lead compounds or MTBE.

(iii) the absence of sulphur, which contributes to acid rain.

(iv) reduction of hydrocarbons in the emissions.

These properties have led to its widespread promotion and use in cities with serious air pollution problems in the USA.

3.8 Conclusion

The establishment of a bio-ethanol industry in Ireland would bring benefits in terms of increased turnover and employment, though the effect on farmer incomes would probably be small. Reduction of CO_2 emissions would be slight, but the enhancement of vehicle emissions would be a significant benefit.

The cost of production of bio-ethanol will need to become more competitive with its mineral equivalent before a sustainable industry can be established. While some further efficiencies can be achieved in the production of ethanol from cereals and sugar-beet, these will always be expensive raw materials. The development of technology to produce ethanol from ligno-cellulosic materials should bring about a big reduction in raw material cost, but is not likely to reach commercial reality for at least five years. The likelihood of suitable ligno-cellulosic raw materials becoming available in Ireland at that stage, and the benefit of a low-value outlet for such materials, needs to be further examined.

4. Crops for heat/electricity generation, fibre and board manufacture

4.1 Introduction

Short-rotation forestry, straw, cereal grains, and whole-crop cereals and rape have potential as fuels which could be burned to meet local heating needs, to generate electricity, or in combined heat and power (CHP) plants. Miscanthus also has attractions for this purpose given its high dry matter yields, but little is known to date about its moisture at harvest or the problems of storing/drying to meet a year-round demand. Low-cost crop establishment systems also need to be developed, and more information is needed about production costs and economics. Hemp is an annual crop with potential to give a high dry matter yield at low moisture content, and with good combustion properties. Currently the focus of most international attention is on the residues of forestry harvesting and timber processing, and on the short-rotation forestry arable energy crops, willow and poplar. Many of these crops also have potential for fibre board manufacture, to supplement supplies of forest thinnings and sawmill residues. Flax has potential for the production of high-quality fibre for spinning and weaving, or short fibres as a plastic reinforcement.

Many of these materials have problems with storage, transport and combustion due to their variable and frequently high moisture contents at harvest, combined with low energy densities. Table 15 illustrates these problems, which are a particular problem in the moist Irish climate.

Table 15: Approximate characteristics of various biomass crops as fuels (Landen, 1992).

Fuel	Net cal. value (MJ/kg)	Density (kg/m^3)	Energy density (GJ/m^3)	Assumed price (£/t)	Energy cost (£/GJ)
Coal	33	1,300	43	120 (home)	3.6
				40 (industry)	1.2
SRF (25% m.c.)	12	300	3.3	35	3.2
Cereal straw	14	150^1	2.1	35	2.4
Rape straw	14	120^1	1.7	30	2.1
Whole-crop wheat	12.5	160^1	2.0	50	4.0
Whole-crop rape	18	160^1	2.9	50	2.8
Hemp	15	150^1	2.1	40	2.9

[1] Large rectangular bales

The cost of these materials as fuels is generally higher than that of their mineral equivalents (Table 15). The current cost of electricity from large combined-cycle gas-fired plants has been estimated at 2.5p/kW h (6.9 £/GJ) (O'Donnell, 1995); biomass-fed plants, with higher feed-stock costs, scale limitations and under-developed technology, could hardly be expected to match this price, at least in the short-term future.

Within the Alternative Energy Requirement programme, contracts may be offered by the ESB for the supply of electricity from renewable sources at prices above the current market price e.g. up to 4p/kWh for a 10-30 MW plant in the AER2 programme (O'Donnell, 1995). AER3 included a target of 7 MW installed electricity generation from small-scale biomass and/or waste to be achieved by the end of 1999, but no progress has been made with this to date.

4.2 Feed-stocks

4.2.1 Straw: The total area of cereals in Ireland was 274,000 ha in 1995. This would give an estimated straw production of about 1million tonnes, with a calorific value of 13,000 TJ. The mushroom industry requires 1 tonne of straw per 2.5-3 tonnes of compost, so the current production of about 200,000 t of compost requires about 70,000 t of straw. The remainder is either used on the farm or sold for animal feeding or bedding. The decline in the area of cereals (down from 336,000 ha in 1987) and the expansion of the mushroom industry has led to increased straw prices; in particular, it has strengthened the price for wheaten straw, about 20% of which goes to compost production. It may be expected that straw prices will continue to fluctuate widely, but large supplies are unlikely to be available at prices that would make its widespread use as a fuel economical.

4.2.2 Annual arable crops: These crops would have their best opportunity on set-aside land on arable farms, where the existing machinery complement could cope with the extra area, and where opportunities for the non-food utilisation of the set-aside area are limited. The most likely possibilities are hemp and whole-crop cereals and rape. The decline in the area of rotational set-aside has dampened the short-term prospects for the production of any non-food annual crop in sufficient volumes to support a new industry (Table 2).

4.2.2.1 Hemp: The reported high yields and large number of potential uses of hemp prompted an examination of its production, starting in 1995. In an earlier evaluation in

1960-66, stem yields of 10 t/ha and fibre yields of 2.5 t/ha were reported (Neenan, 1969). A reasonable quality fibre was achieved, but the establishment of an industry did not seem viable. The objectives of the re-evaluation were to establish the yields attainable with low-THC varieties and to identify any industries with potential uses for the material.

Typical yields from these trials are shown in Table 16. Total yields of more than 20 t/ha of dry matter have been common, although about a quarter of this was leaf material. Total yield could be increased by reducing the seed rate, though this also had the effect of increasing the stem diameter, which would in turn reduce the quality of the fibre produced (Table 17). Sowing date also had an important influence on stem yields (Table 17).

Table 16: Hemp total and stem yields (mean of five low-THC varieties, 1997)

Total DM yield (t/ha)	Leaves (%)	Stem yield (t/ha)
21.2	24.5	16.0

Table 17: Effect of sowing date and seed rate on hemp stem yields, 1998

Sowing date	Seed rate (kg/ha			
	20	30	40	50
Apr 1	15.3	14.0	14.6	12.8
Apr 17	11.2	11.1	11.1	10.8
May 7	10.5	10.0	9.2	9.6
May 13	8.4	9.6	9.9	8.8
Stem diam (mm)	10.6	10.2	9.8	7.9

In each year it has been possible to bale the harvested crop at moisture contents of less than 20%. Crop heights have been about 3 metres, and the high yield, crop height and fibre strength can lead to many problems for harvesting machinery.

These results suggest that for fibre board or energy production, hemp should be sown in early April at a seed rate of 20-30 kg/ha. Consistently high yields of low-moisture biomass can be achieved. Some improvement to the harvesting system would be required before a commercial operation could be got under way.

4.2.2.2 Whole-crop cereals and rape: The use of a forage harvester in cereal crops greatly reduces field losses, and increases in total yield of about 30% have been measured in Oak Park and elsewhere. However, the bulkiness of the chopped straw makes drying, transport and storage difficult. Drying and storage in conventional indoor structures would be very expensive Drying trials at Oak Park in cheap outdoor plastic-covered structures gave reasonable drying rates and maintained product quality, but the difficulty of maintaining such structures and working within them would be unlikely to achieve acceptance on farms.

4.2.2.3 Flax for fibre production: A three-year study was made in 1988-90 of the feasibility of flax production for fibre use in Ireland. The crop had been widely grown in the northern portion of the country early in the century, but this had died out when the costs and water pollution risks associated with traditional water retting system became unacceptable, and the climate in that region was too cool for successful dew retting.

The objective of the study was to examine the feasibility of producing high yields of high quality long-fibre flax by dew retting in any part of Ireland. Trials were located at various sites in the south and south-east of the country, where it was felt the temperatures would be adequate for dew retting. The produce was retted, baled and exported to Belgium for scutching and final assessment.

It was found that the achievement of high yields of long fibre required adequate rainfall during the stem extension period in May and early June. On the other hand, successful retting required mainly dry weather in Aug-Sept, otherwise the fibre had low strength and poor quality. This combination of conditions occurred infrequently at any site. It was therefore concluded that it would not be possible to establish flax production based on dew retting in Ireland.

4.2.3 Arable perennial crops: The most appropriate species for perennial energy crops in Ireland are willow and poplar managed as short-rotation forestry or the C_4 grass species, miscanthus. Land for the production of these crops is likely to come from two existing uses:

(i) Non-rotational arable set-aside.

(ii) Land outside the existing arable pool, currently in beef or sheep production.

While the pool of perennial set-aside land has increased in recent years, much of it is in small lots sown to grassland. It is difficult to estimate how much of this could be attracted into alternative crops. Planting on land currently in animal enterprises would depend on the relative attractiveness of the two enterprises to the farmer.

4.2.3.1 Short-rotation coppice: Teagasc research on short-rotation began with an investigation into the biological and economic aspects of short-rotation forestry production on land marginal for agriculture (Neenan & Lyons, 1980). Of the broadleaf species selected for the trials, *Salix* spp. (willow) and *Populus* spp. (poplar) proved the most viable. It was recognised that fertilisation would be required on soils of poor nutrient status.

Subsequent research has concentrated on *Salix* and *Populus* clones, mainly on arable agricultural land. Yields of 7 to 11 oven-dry tonnes per hectare per annum have been recorded for individual willow clones. Yields for poplar of up to 13 oven-dry tonnes per hectare per annum have been recorded in experimental plots, on a rotation of 5 years.

These results show that on suitable soils short-rotation forestry is capable of yielding 7 to 11 oven-dry tonnes of biomass per hectare per annum. The midlands and south-east are most suitable for growing short-rotation forestry, though sites can be found in all parts of the country. The planting, management and harvesting technologies required for optimum biomass production from short-rotation forestry have been described in detail (Bulfin *et al.*, 1995A, Kent *et al.*, 1996).

The problems of utilising short-rotation forestry as a feed-stock have been set out in detail by O'Donnell (1991). Harvested in the winter months it has a moisture content of about 50%, at which it heats rapidly in storage in chipped form. It can be burned in simple heating units at high moisture, but it must be dried for use in gasification or CHP plants. Drying in forced ventilation systems incurs substantial capital costs. Field curing of whole felled trees increases handling and working capital costs.

4.2.3.2.Miscanthus production for energy or fibre-board use: Miscanthus Giganteus is a C4 perennial plant which has given high dry matter yields in many countries. Evaluation in Ireland began in 1993, when in-vitro propagated plants were used, many of which were killed by frost in winter 1993-4. Further planting was done in 1994 and 1995.

In 1995, dry matter yields of the 1993 and 1994 crops were 6.6 and 2.6 t/ha respectively. In 1996, the most favourable year to date, yields of the 1993, 1994 and 1995 crops were

26.9, 16.5 and 9.0 t/ha respectively. In 1997, the corresponding yields were 16.4, 16.7 and 9.0 t/ha. A major problem with all these crops was that moisture levels remained high at harvest. Dry matter contents at harvest were typically between 35% and 40%. This is much lower than the levels recorded in most other countries, and is presumably caused by the mild winters in Ireland. Since the crop is harvested in Spring, it would be very difficult to remove this moisture by field drying.

It is concluded that, while occasional very high yields may be obtained from Miscanthus in Ireland, the average levels are not much higher than those of other biomass crops. Crop storage problems and transport costs would be exacerbated by the high moisture content, and energy uses would also be adversely affected.

4.3 Economics of energy production from crops

The economics of energy crop production has been detailed in several projects. Bulfin et al (1995A) carried out a detailed economic analysis of the production and supply cost of wood fuel from short-rotation coppice. A methodology for the estimation of costs was developed by beginning with the lowest cost production scenario and then introducing constraints to this scenario. Table 18 gives the results of this analysis.

Table 18: Economics of biomass production from short-rotation coppice willow.

Scenario	Cost of wood fuel (£/oven dry tonne)
Least Cost Option	£36 - £47
Introduction of Technical Constraints	£41 - £51
Introduction of Economic Constraints	£112 - £123

The Least Cost Option was estimated by adopting the most productive method of carrying out each management operation and optimising these operations within an overall production and supply route. The following technical constraints were then applied to this system resulting in the increase in cost. These were:

1. A year round supply of wood fuel.
2. Storage for nine months as harvesting is carried out over the three winter months.
3. Reduction in harvesting machinery productivity if soil becomes untrafficable in winter .

Economic constraints were applied to reflect the income the grower might expect to receive from selling wood fuel. The agricultural systems energy crops would most likely replace are cattle and arable production (Power & Roche, 1993). The three elements that make up the cost of fuel are the production costs of the fuel, the income the grower currently receives and the premium necessary for the grower to switch from his current activity into energy crops. In this study it was assumed that a premium equal to 25% of current income would be needed, in which case the average price the grower would require is £112 to £123 per oven dry tonne.

4.4 Biomass-to-energy conversion systems

There are several levels of operation at which the use of these fuels for heat/electricity production could be considered:

4.4.1 Domestic heating: Firewood remains the single biggest biomass-energy use in Ireland. Each year approximately 140,000 dry tonnes of wood is used for domestic purposes. This market will continue to be supplied from conventional forestry, with little opportunity for energy crops.

4.4.2 Heat-only production for industrial heating: This could apply to an industry with a high heat requirement, such as the dairy or wood-processing industries, or possibly a district heating scheme for a new housing development. As an example, a project is considered in which solid biomass is used to fire a 5 MW(th) boiler running for 7,500 hours per year at a conversion efficiency of 80%. Twenty-one thousand tonnes of fuel are required annually, supplied on a continuous basis. The principal economic features of such an investment are given in Table 19. It is assumed that the fuel has a moisture content of about 50% and a net calorific value of 8 GJ/tonne.

Table 19: Economic parameters of a biomass-fired 5 $MW_{(thermal)}$ boiler for heat only

Economic parameter	Costs
Plant capital cost	£500,000[1]
Production and supply cost of fuel	£1.75 - £3.13/GJ[2 & 3]
Operation and maintenance cost	c. £83,561 per annum
Price of energy	0.8p - 1.3p/kW $h_{(thermal)}$

Sources: 1.Walsh et al, 1995 2.Mitchell *et al.*, 1990 3.Coggins, 1993

The capital cost of £500,000 is equivalent to a cost of £100 per kW(th) installed capacity. If the fuel supply price of £2-3/GJ could be achieved, the heat price of 0.8p to 1.3p per kW(th) compares very well with fossil fuels (Myers, 1994). This option may be attractive to wood processors, if higher-value markets can be found for the white chip, bark and sawdust that they are currently using as fuels.

4.4.3 Small-scale electricity/heat production: This would operate at local level to meet a local power demand and supply excess to the grid, or in a CHP plant where there is a local demand for low-grade heat and power. The size of power unit could be from 100 kW to 500 kW. The use of SRF for electricity production in this type of unit has been considered favourably in an AFRC report (Sells, 1990); however, the study is based on an electricity price of 6p/kW h. The CHP option has been studied in a pilot plant based on a gasifier and internal combustion engine at Castle Archdale in Fermanagh (Dawson, 1995). Two small units (100 kW and 200 kW) have been built in Northern Ireland, and a 300 kW unit is at an advanced planning stage in Co. Tipperary.

The use of the internal combustion engine in these plants leads to a low efficiency of conversion to electricity, and increases the importance of heat utilisation. This type of operation may be of interest to process plants located in rural areas which have a suitable heat/power load ratio (Table 20).

It is assumed that the coppice fuel is dried to a moisture content less than 10% and has a net calorific value of 17 GJ/tonne. The capital cost of £80,000 is equivalent to a cost of £800 per kW(e) installed capacity. The wide range of electricity costs reflects the range of raw material prices described in Table 15.

Table 20: Economic parameters of small-scale gasification

Economic parameter	Cost
Plant capital cost[1]	c. £80,000
Production and supply cost of fuel:	£2.6 - 8.8/GJ
Operation and maintenance cost[2]	£18,660 per annum
Price of electricity	
- no heat sales	£0.07 - 0.19 per kWh
- 120kW heat sold @ 1.7p/kWh	£0.05 - 0.17 per kWh

Source : 1. ETSU, 1993 2. Buckley, 1996

4.4.4 Central electricity generation in plants from 5 MW upwards, with the full output fed to the grid: The problems of variable moisture, low energy density and high transport costs would be more serious at this level of operation. A project of this type has been evaluated (Bulfin *et al.*, 1995B). Its location is assumed to be in the midlands to utilise the existing extensive grid infrastructure and the ability of many of the soils to support willow coppice productively. A total of 20,000 ha would supply 190,000 tonnes to a 30 MW(e) plant on a continuous basis. A vibrating-grate combustion unit is assumed to have a conversion efficiency of 30.7% (van den Broek *et al.*, 1995). The plant was assumed to run 7,500 hr/yr with 14 staff. The plant life expectancy is 20 years. The economic parameters of the plant are given in Table 21.

Table 21: Economic parameters of a 30 MW power plant for electricity

Economic parameter	Cost
Plant capital cost[1]	£45,000,000
Production and supply cost of fuel	£2.6 - 8.8/GJ
Operation and maintenance cost[1]	£5,680,000
Price of energy	5.6p - 12.9p kWh

Sources: [1] van den Broek et al, 1995

It is assumed that the fuel has an average moisture content of 35% and a net calorific value of 14 GJ/tonne. The capital cost of £45,000,000 is equivalent to a cost of £1,500 per kW(e) installed capacity. The costs for fuel are the same as in the small gasification plant, and again the wide range of costs reflects the raw material prices in Table 15. It is assumed that any gains made through economies of scale in production are balanced by the administrative costs incurred by the necessity for an intermediary organisation to ensure the secure supply of fuel. What is clear is that the fuel supply is the major cost of energy production and that currently there are big risks to the production and supply of so much fuel. The plant itself is standard technology. It could be argued that the potential for greater efficiencies in combustion technology is limited, and that gasification will develop rapidly as an efficient system for the conversion of wood fuel on this scale (Blaney, 1995).

4.5 Environmental aspects

Due to their low input requirements and high energy output, wood crops are very efficient at recycling CO_2. The energy economy i.e. energy output relative to input, of these crops is about 20:1 (Christersen, 1996). Precise calculation of CO_2 abatement is complex, but an estimate based on a reduction of 1.5 tonnes per dry tonne of wood consumed is included in Table 22.

Table 22 Potential displacement of annual CO_2 emissions

Biomass Source	Target utilisation ['000 tonnes]		Energy content [TJ]*	Approx CO_2 abatement ['000 tonnes]
	dry	25%m.c.		
Forest Residues	200	266	2.9	300
Wood Industry Residues	300	400	4.4	450
Firewood	170	226	2.5	255

*assumes net calorific value of wood is 11 MJ/kg (at 25% m.c.)

Perennial energy crops can also provide a substantial CO_2 sink. In the case of short-rotation coppice this could amount to about 50 tonnes of carbon per hectare.

4.6 Conclusions

Large-scale electricity or heat generation from dedicated biomass crops is not a feasible option in Ireland at present. Although many of the technical problems of production and utilisation have been resolved, major economic hurdles remain. The main difficulties are the decline in set-aside land, the absence of subsidy for the establishment of short-rotation forestry, competition for available land from alternative subsidised farming systems, the continuing low price of electricity generated from mineral fuels, and competition from wind energy for AER support for renewable electricity. The additional environmental benefits and employment potential of a biomass-energy industry are not reflected in the support available for its establishment. The lack of an efficient technology for small-scale electricity generation from biomass is also a handicap

The rapid expansion of the board processing industries has increased the demand for raw materials for board manufacture and process heat. If this outstrips the supply of forest thinnings and saw-milling residues, opportunities may arise for crops to make up the deficit. Of the crops that might be considered for this purpose (hemp, miscanthus, cereal straw and short-rotation coppice), hemp appears to be the most attractive option. In addition to a high yield, its low moisture would ease storage problems and transport costs. As an annual crop, it would also be easier to adjust production to meet annual demand.

5 General conclusions

In all the biomass-energy systems included in this review, raw material procurement is the predominant cost component. To produce energy at a cost approaching that of conventional mineral fuels, stable supplies of low-cost raw materials are essential. These are most likely to be residues or wastes for which competing uses are either low-value or non-existent.

In Ireland, in the immediate future the most likely material in this category is waste vegetable oil. A 15,000t/yr industry based on these materials could come close to meeting the ALTENER 5% substitution target for road diesel use, add up to 0.06 PJ of renewable primary and abate 0.06 Mt of CO_2 emissions. This is achievable from the residue materials available, but would require de-excising to make it viable.

The cost of production of bio-ethanol will need to become more competitive with its mineral equivalent before a sustainable industry can be established. While some further efficiencies can be achieved in the production of ethanol from cereals and sugar-beet, these will always be expensive raw materials. The development of technology to produce ethanol from ligno-cellulosic materials should bring about a big reduction in raw material cost. The likelihood of suitable ligno-cellulosic crop residues becoming available in Ireland, and the benefit of a low-value outlet for such materials, needs to be further examined.

Any further development of energy production from agricultural biomass will require that energy crops begin to play a role. Major developments are needed before this can become a reality. Further improvements in crop production and conversion technologies are needed to reduce the cost gap between biomass and conventional fuels. In addition, changes in land use policies are required to reduce competition between food and non-food enterprises, and to provide long-term stability for energy crop production. Present difficulties include the decline in set-aside land and uncertainty about its future, the absence of subsidy for the establishment of permanent energy crops other than conventional forestry, competition for available land from alternative subsidised farming systems, and the continuing low price of electricity generated from mineral fuels. The environmental benefits and employment potential of a biomass-energy industry are not reflected in the support available for its establishment. Targets for energy crop production set out in various EU studies (ESD 1996, European Commission 1996) will not become a reality until these problems are addressed.

Of the non-energy industrial crop uses, the most promising appears to be hemp for fibre board production. Its high yield, low dry matter and ease of establishment would be useful advantages. Demand will be dependant on the rate of expansion of the fibre board industry in relation to the availability of forest thinnings and saw-milling wastes.

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