SHORT ROTATION COPPICE WILLOW BEST PRACTICE GUIDELINES

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INTRODUCTION

The world's gas and oil reserves are a rapidly depleting and increasingly costly resource to exploit and deliver. Ireland generally has a very limited fossil energy resource and as a result imports the vast majority of its requirement. In excess of 85% of the fossil fuel used to generate electricity is imported, principally oil and natural gas. Indigenous peat resources provide a small contribution (11%) with renewables providing only 3%. If the requirement for heat generation and transport fuels are added to the electricity total then Ireland has a dependency on imported energy in excess of 90% and this figure is increasing.

Total annual energy usage in the island of Ireland is currently almost 20 million tonnes of oil equivalent with an approximate current value of €10 billion. This can be divided into 37% electricity generation and distribution, 34% heat and 29% transport. Energy usage in Ireland has shown a rapid increase in the last decade with forward projections that this trend will continue over the next ten years with a high dependency on oil and gas. There will be a parallel decline in the contribution from peat and an increase to 14% of total primary energy usage from renewables. To achieve these projected figures, progress will have to be made on a wider front involving all the relevant renewable energy technologies – wind, solar, hydro, photovoltaic's, wave, tidal, and ground and air source heat pumps.

Figure 1: Two year old coppice at Oak Park Carlow

One hectare of willow (25% moisture) produces approximately 13 tonne of willow every year with an energy content of 13.2 Giga Joules (GJ) per tonne. Therefore one hectare produces 172 GJ's of energy per year. 1,000 litres of home heating oil has an energy content of 38 GJ's. This means one hectare of willow has the same energy content as 4,500 litres of home heating oil. Variances will occur depending on moisture content and biomass yield. The energy content for miscanthus is similar to willow, however the willow is harvested every second or third year compared to the miscanthus which will be harvested each year.

Coupled with scarcity of energy supply, we also facing the world's greatest challenge of 'Global Warming' caused by man-made green house gas emissions. Carbon dioxide represents 75% of all greenhouse gases. Energy crops such as willow are generally high yielding, and carbon neutral. The plant during photosynthesis takes or captures CO_2 from the atmosphere to build its body. The Carbon atoms within the plants structure were CO_2 gas last year, last week or even yesterday therefore the plant or biomass, the plant makes its structure from CO_2 and in essence locks up that CO_2 within its structure. Unlike fossil fuels such as coal, oil or gas which have been stored in the earth for millions of years and release billions of tonnes of CO_2 into the atmosphere on an annual basis, energy crops have sequestered the CO2 in more recent times so are effectively using the energy from modern sunlight as opposed to ancient sunlight. Crops like willow, miscanthus, hemp, reed canary grass and oilseed rape all have a role to play in reducing greenhouse gas emissions.

Biomass from energy crops is one of the potential technologies that have particular relevance to Ireland, and that has reached a stage in its development where it is ready for commercial deployment.

Renewable Energy

Renewable energy sources provide a sustainable and carbon dioxide neutral source of heat and or power and improve the security and diversity of supply. Some forms of renewable energy have also the potential to create and sustain significant employment in rural areas. The main constraints with renewable sources of energy relate to consumer confidence in supply and reliability (due to the intermittent nature of some renewable energy sources eg wind) and the costs of power generation which are generally reflected in higher delivered energy prices. The increasing interest in renewable energy and its projected potential is a result of a number of converging factors;

- A general worldwide acceptance that emission levels of carbon dioxide urgently need to be reduced to mitigate their effect on global warming;

- This has resulted in a number of internationally binding agreements under the Kyoto Protocol to limit carbon dioxide emission levels to agreed limits by 2012. Already the European Commission is consulting on the necessary controls post-Kyoto;

- The dwindling reserves and spiraling costs of fossil energy, in particular oil and gas, and their vulnerability to political events on a world scale;

- The need to reduce dependency on imported energy with the security of supply that indigenous sources bring; and

- In Ireland, the increasingly vulnerable position of conventional agricultural production in the overall economy and the pressing need to promote alternative and sustainable land use options including the production of energy crops.

Much of the potential that biomass from energy crops has in mitigating carbon dioxide emissions comes from:

- Displacing fossil fuel sources for heat generation in the first instance and with further developments in the technologies, small to medium scale electricity generation;

- The carbon dioxide neutral status of biomass from energy crops where the growing crop consumes as much atmospheric carbon dioxide in its growth processes as is released back to the atmosphere when the biomass is converted to useable energy as heat and or electricity; and

- Total carbon budgets have been calculated for the generation of electricity from biomass, gas, and coal and these show carbon dioxide (CO_2) emissions of 60g, 400g, and 1,000g per kWh electricity, respectively.

- The carbon balance (the ratio of energy used in cultivation compared to that produced) of SRC willow is excellent. Research has provided a wide range of results but at minimum SRC willow will yield 14 times more energy than is needed to produce and deliver the crop and in some situations over 30 times.

Figure 2: Re-sprouting coppice stool following harvest (AFBINI)

Biomass

With the exception of tidal and geothermal, all other sources of renewable energy ultimately gain their energy from the sun. In the case of biomass energy crops, the radiant energy from the sun is converted into stored chemical energy in the plant tissues through the normal photosynthetic growth processes. This can be in the form of cereal grains or oil seeds, the stems of the annually harvested energy grasses, such as Elephant Grass (Miscanthus) or in the case of biomass from short rotation coppice (SRC) willow or poplar, the harvested woody stems. These woody stems represent approximately 60% of the total biomass, the remainder being in the stool which remains after harvesting, the roots, and leaves. In the context of climate and soils, willow (Salix) is the most suitable woody biomass crop for Ireland. Others have been evaluated, such as Miscanthus and poplar, and either have a restricted area in which they may be successful or present practical problems, particularly harvesting.

SRC willow as an energy crop exploits the vigorous juvenile growth associated with Salix and its ability to coppice or re-sprout from the stool that remains after harvest. In summary, the crop is established from cuttings prepared from one-year-old wood produced by specialist nurseries. The cuttings are inserted into the ground in spring and at the end of the first growing season they are cut to ground level (coppiced) to encourage the development of the multi-stemmed stool. Growth is rapid after cut back and can be as much as 4 meters in the first year increasing to 6-8 metres at harvest in three years (short rotation) following cutback. A willow coppice may be harvested six to eight times on a three-year cycle giving the plantation a life of 19-25 years allowing for the first or establishment year. Shorter harvesting cycles (every 2 years) are currently being considered to facilitate the recycling of sewage sludge. The coppice can then be removed and the land returned to conventional cropping.

A wide range of yields can be expected depending on site, weather conditions and all the other factors which normally determine yield from conventional crops but can be expected to be in the range 7-12 tonnes dry matter (tDM) per hectare per year (21-36t DM on a three-year harvest cycle).

In energy terms short rotation coppice willow dry matter has energy content of approximately 19MJ per kg or 45% of the energy in an equivalent volume of light fuel oil. This gives a mean annual production equivalent of 3300 - 5700 litres of oil per hectare per year. Taking a snapshot in time with current prices of €0.65 per litre for light fuel oil this gives willow an equivalent energy value of €290 per tonne. It is achieving a price of just over €80 per tonne on the market in Ireland. Oil prices are projected to continue to rise increasing the opportunity for wood to contribute to the energy market.

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1.0 CROP PRODUCTION

1.1 SITE SELECTION

Willow is not a demanding species in terms of its site requirements. It will flourish on a wide range of soil types and environmental conditions and in common with other crops productivity will be determined by site fertility, temperature, and availability of water and light.

- Soils; most agricultural soils with pH in the range 5-7 will produce satisfactory coppice growth. However, light sandy soils, particularly in drier areas, will have a problem with moisture availability and highly organic or peaty soils should be avoided as initial weed control, which is vital, will be extremely difficult. Medium to heavy clay- loams with good aeration and moisture retention are ideal although they must have a capability of allowing a minimum cultivation depth of 200-250mm to facilitate mechanical planting.

- Water availability; Willow coppice requires more water for its growth than any other conventional agricultural crop and hence requires a good moisture retentive soil. Areas with an annual rainfall of 900-1,100mm are best or areas where the crop has access to ground water. The crop can tolerate occasional inundation but this may have implications for harvesting.

Figure 3: Two year old coppice at AFBINI Loughgall (AFBINI)

- Temperature; Willow in its native environment is a northern temperate zone plant and consequently temperatures in Ireland are unlikely to be an issue. However, elevated sites can result in exposure problems and a reduction in the number of growing days per year. Therefore, production sites should generally be below 100m above sea level.

- Access; Harvesting is carried out in winter in the period December to April and whilst the root system of the growing coppice will support the harvesting and extraction equipment on the coppice site, hard access is required to the site. Slopes in excess of 13% will provide difficulty for harvesting machinery, particularly in wet conditions and should be avoided.

- Area; For logistical reasons there is a recommended minimum sustainable planted area. In most situations a commitment of at least 5.0ha is minimal and furthermore this should be in at least 2.0ha blocks to facilitate the large harvesting machinery involved. Smaller and irregular shaped fields are also more difficult to manage and where rabbit fencing is necessary they will be more costly to fence on an area basis.

- Location in the Landscape; SRC Willow has more similarities with arable cropping than conventional forestry – it has a regular harvest pattern, and its deciduous nature gives a seasonal diversity of texture and colour.

  I. S.R.C willow at the end of a three year growing cycle will be up to 8m tall and therefore creates a three-dimensional mass in the landscape which arable crops do not. Poorly planned SRC plantations have the potential to adversely affect the rural landscape. However, well-designed and carefully sited plantations could bring small but important landscape improvement. In most cases with some thought, the establishment of short rotation coppice is likely to bring, at best, a significant improvement or, at worst, no detrimental effect to most mixed agricultural landscapes.

  II. Sitting in the landscape may well be constrained by existing enclosure patterns. Where these are well developed with hedgerows and trees the problem is limited because sight lines are short. In addition to the deciduous nature of the crop diversity is created with varietal mixtures and harvesting patterns.

  III. Because of the likely small- scale production and use patterns of SRC in Ireland, it is unlikely to be a dominant landscape feature in any particular area. A 1% uptake in a catchment area with a 20km radius (optimal delivery distance for coppice chip to a conversion plant) would provide 1,200 ha or 15,000 tonnes of dry matter, sufficient for 2 MW continuous generation.

  IV. If enclosure patterns are weak, sight lines long, or topography flat, plantings should provide interlocking blocks with organic rather than geometric shapes. Additionally, in a large landscape, SRC plantings should be in scale and link up if possible with existing woodland to give visual and environmental benefits.

Figure 4: Two year old coppice Southern Sweden (Sligo IT)

V. If the extent of planting in any particular landscape is greater than the field pattern, it should conform to the overlying landform rather than larger rectangular blocks.

VI. SRC development is likely to be sited in landscapes, which are already in agricultural use, and it is unlikely that they would impinge on landscapes of species interest or scarcity.

Figure 5: Willow coppice Castlearchdale Co Fermanagh (AFBINI)

VII. Short rotation coppice should not be planted on or adjacent to sites of historical importance or where they would obscure natural landscape features. Power lines will require consultation with the Utility Company involved, remembering that mature coppice can reach to 8m before harvest.

VIII. Areas with specific designations such as Areas of 'Outstanding Natural Beauty' or areas of 'Special Scientific Interest' will also require consultation with the regulatory bodies concerned.

1.2 PRE-PLANTING SITE PREPARATION

Since SRC Willow will be in the ground for a minimum of twenty-five years, thorough site preparation is essential.

- Pre-ploughing herbicide application is required when weeds are still actively growing - Glyphosate (e.g. Roundup at 4.0 - 5.0l/ha). On grassland or set-aside sites an application of Chlorpyrifos (e.g. 3.0 l/ha Dursban) will provide leatherjacket control.

- Where sites have excessively heavy vegetation present, consideration should be given to cutting and removal of the vegetation to allow for effective weed control. If this is necessary, sufficient time should be allowed for re-growth to allow for active herbicide uptake.

- A minimum of ten days after herbicide application is required before the site can be ploughed. Land which has been regularly shallow ploughed and land that has been intensively grazed can both suffer from compaction close to the surface. This will require deep ploughing and/or sub-soiling to allow full root development. Normally this would be carried out in the autumn and allowed to weather over winter. However compliance with the Nitrates Directive makes this impossible. Whatever the site, a minimum plough depth of 20-25cms will be required to allow for the insertion of the cuttings.

Figure 6: Spraying grass with glyphosate in advance of ploughing

- On suitable soils the site can be ploughed and power harrowed and a stale seedbed prepared in mid-March, six weeks before planting. The germinated weeds can then be sprayed off prior to planting using Glyphosate (e.g. 2.0l/ha Roundup). On heavy clay soils this approach is not practical and the site should be power harrowed as close to planting as possible.

- It may be necessary to lift stones after power harrowing as these can interfere with the use of mechanical planters.

- Rabbits and hares, where they are present in sufficient numbers, can be very destructive in a new and establishing coppice plantation and must be excluded with appropriate fencing. This is an expensive operation and where necessary, will represent the single largest cost in site preparation. The fencing may be temporary in nature as established coppice is less susceptible to economic damage. Netting is generally used, with the lower portion buried, or turned horizontally to deter rabbits from burrowing underneath. Machinery is now available to plough in wire netting, and this substantially reduces the cost. Electric mesh fencing has proved satisfactory but it must be kept weed free to prevent shorting out.

- The cost of fencing to exclude deer is prohibitively expensive.

There is considerable interest in developing reduced cultivation techniques for the establishment of SRC willow which could reduce costs and also limit the carbon release associated with normal tillage. A reduced 'strip' cultivation system has been trialled successfully in New York State, USA. The herbage in a strip is killed with herbicide. A disc with a sub-soiler is used to loosen the soil sufficiently to enable the cuttings to be planted using a conventional Step Planter. It was important to carry out this procedure in dry weather in order to prevent smearing, which then reduced rooting by the cuttings. There was also an issue with slugs and snails, in the rotting herbage on the surface, which required chemical treatment. This is not yet considered to be a practical approach in Ireland but ongoing research may make it possible in the near future.

1.3 PLANTING MATERIAL

Salix (Willow) is the preferred genus for SRC in Ireland for a number of reasons:

- It is native to northern temperate zones and therefore thrives in the cool wet conditions and largely heavy soils in Ireland. Other native genera such as Alnus (Alder), Fraxinus (Ash) and Populus (Poplar) have been investigated but have exhibited establishment or coppicing problems and generally have not been as productive.

- It is a pioneer species meaning that it is one of the first woody species to colonise disturbed ground. Pioneer species among other properties generally exhibit vigorous juvenile growth. It is this property which is exploited in the short harvesting cycles imposed on the system.

- It can be coppiced regularly and repeatedly without losing vigour.

- It establishes easily and quickly from unrooted cuttings. In favourable conditions, roots can be produced within ten days of planting, which is important in making the cuttings self sustaining as quickly as possible.

- Willow as a coppice crop is relatively new and considerable advances in productivity and disease resistance are being made in breeding programmes. There are two breeding programmes, which have produced improved varieties for planting. The European Breeding Programme now based at Rothamsted and the Swedish programme initiatedby the Swedish University of Agricultural Sciences in Uppsala and continued by a commercial company, Svalof Weibull AB. Both programmes have produced varieties with significantly increased potential, the Swedish programme focusing on Salix viminalis and its hybrids with Salix schwerinii whilst the European programme exploits a wider species background.

Figure 7: Willow being planted with the use of a step planter

- Commercially available varieties from the Swedish Programme include; Tora, Sven, Torhild, Tordis, Olof, Gudrun and Inger. The older varieties such as Jorr and Joruun etc, are less productive and have poorer disease resistance.

Figure 8: Sludge or manure should be applied

- Commercially available varieties from the European Breeding Programme include; Nimrod, Resolution, Discovery, Endeavour, Beagle, Terra Nova.

- There is new material coming forward both from the European breeding programme and from Rothamsted Research Station. This is important for two reasons it increases the genetic diversity and provides a confidence that this side of the industry iois moving forward. These new genotypes are on trial at Loughgall and Dr Alistair Mc Cracken could provide information.

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- All of these improved commercial varieties are protected by European plant breeders' rights. In practice, this means that it is illegal to produce propagation material for self-use or sale from protected varieties. There is a minor derogation, which allows the gapping up of establishing crops with the material produced at cutback. Generally, therefore, cuttings will be produced by specialist growers in nursery beds and supplied as one-year-old rods for mechanical planting.

Figure 9: Foliar rust (Melampsora) on willow (AFBINI)

Successful establishment depends on cutting quality. Cuttings therefore:

- Should be prepared from one-year-old wood, which has had the unripened wood at the tip of the harvested rod removed (planting rods). Generally, planting rods of 1.5-2.5m will be supplied by the specialist producer for use in the Swedish Step Planter which has become the industry standard for planting coppice willow crops. The planter will prepare the individual cuttings from each rod. Other specialist planters such as the automatic Egedal and adapted vegetable transplanters have been used but the Step Planter has given reliable results in Irish conditions over a number of years.

- Be a minimum of 150mm in length with a minimum diameter of 9mm. This will ensure an adequate carbohydrate reserve to sustain the cutting before establishment.

- Should be sufficiently mature (lignified) to prevent deformation on insertion into the prepared ground.

- Should not show any discoloration or wrinkling of the surface indicating dehydration.

Melampsora, a foliar rust disease, is the primary limiting factor to sustainable production of SRC Willow in Ireland, principally because the disease is favoured by the cool moist maritime type climate. (See section on pests and diseases). An extensive research and development programme has been carried out by the Science Service of Department of Agriculture and Rural Development Northern Ireland (now the Agri-Food and Biosciences Institute) over the last twenty years to develop a non-chemical control strategy. The use of varietal mixtures has been particularly effective in this context. Therefore it is recommended that all commercial SRC Willow plantations should contain at least six varieties representing both breeding programmes, to ensure maximum genetic diversity, and they should be planted in as intimate and random mixture as practically possible. This generally means, when using the Step Planter, that the mixture will be planted as short runs (10 –15 cuttings dictated by the length of the rod used in the planter) of individual varieties followed randomly by short runs of the other mixture constituents as the planting rods are randomly fed into the planter.

It is absolutely imperative that mixtures of willow genotypes are used when establishing a new plantation. These mixtures should contain at least six different genotypes drawn from different breeding programmes and having as great a genetic difference as is practically possible.

Figure 10: Coppice plantation after cut-back showing double-row planting layout (AFBINI)

1.4 PLANTING

Planting season extends from early spring – February/March – when weather conditions allow soil preparation, to late May and even June using cold stored cuttings. Early planting will give early establishment and a longer growing season for the establishing crop with a lower risk of water stress from a late spring dry period. However, since the purpose of the first growing season is to root and establish the crop and cutback will remove the top growth, later plantings can also produce a perfectly satisfactory crop.

- Cutting material is generally harvested in January – February period when the buds are fully dormant. It is important that this dormant state is maintained using refrigerated storage at -2 to -4^{o}C up to the point of planting. Ideally, cold storage should also be provided on-site at planting. This is particularly important where delayed planting in the May-June period is anticipated. Dehydration is the most likely problem to be encountered in storage thus the cuttings and rods should be protected by wrapping in 'polythene' film.

- Planting density: Over the years much information has been collected on a wide range of planting densities. Current commercial practice is to plant 18,000 cuttings per hectare to give a final established crop of 15,000 per hectare.

- Planting design: to facilitate mechanical harvesting and machinery access, the crop is planted in double rows 0.75m apart with double rows spaced at 1.5m. An in-row spacing of 0.6m gives an initial planting density of approximately 18,000 per hectare.

- Where possible rows should be planted parallel to the longest axis of the field to maximize machine efficiency. Avoid running rows across steeper slopes, as this will create difficulties in holding machinery in the row.

- Headlands: unplanted headlands can be a problem at harvest in the soil and climatic conditions that prevail in Ireland. Harvesting and extraction machinery requires the increased carrying capacity that the root system of the growing crop provides. Therefore, the sacrificial planting of marginal rides and headlands should be considered, in all but the lighter soils, accepting the reduced yield in these areas that the compaction and rutting caused by the harvesting and extraction will produce. If open unplanted areas in the coppice are required for environmental reasons, they are more easily managed as internal rides.

Figure 11: Re-sprouting coppice in April following harvest in January (AFBINI)

- Establishment should, in good conditions, be in excess of 90%. This, together with a natural loss of stools in the early rotations, should produce a cropping density of 15,000 per hectare.
- Several types of mechanical planters have been used but the dedicated Step Planter designed in Sweden by Salix Maskiner has become the industry standard in Ireland. This planter plants two double rows at a pass and automatically makes the cuttings from rods inserted into the planting heads. In ideal conditions, it has a capability of 6-8ha per day. However, in the smaller field sizes that are likely to be encountered in Ireland this could be reduced to 4-5ha per day.
- After planting the site should be rolled to consolidate the surface and provide the best possible conditions for the application of residual herbicides to be effective.

1.5 POST- PLANTING ESTABLISHMENT

Management of the crop post-planting up to cutback, after leaf fall in the early winter, is crucially important, particularly in terms of weed control. This can not be over emphasized as newly-planted willow can not effectively compete against most weeds. If adequate weed control is not achieved, then a successful coppice system will not be established.

CUTBACK

During the first growing season, the inserted cuttings will produce 1-3 shoots with a maximum height of 2.0-3.0m. These are cutback as close as practically possible to ground level using a reciprocating type mower, which should produce a clean cut. Other types of swathers or flail mowers can cause excessive damage. This cutback will encourage the established cutting to produce multiple shoots often eight to ten depending on variety. Re-growth is rapid and vigorous with ground cover/canopy closure being achieved by mid-summer in the year following planting.

There is some discussion as to the necessity of cutback. However, in the climatic conditions in Ireland, where weed growth can continue throughout the year, cutback gives a necessary second opportunity for herbicide application.

Following cutback, the coppice enters its cropping cycle of between two and four years. At harvest, the coppice will have attained a maximum height of 7-8m and only the most vigorous of the shoots produced at cutback will survive to this point, the weaker ones having been shaded out.

WEED CONTROL

Weed control can be divided into four distinct phases.

- Pre-ploughing – it is important that this phase is carried out effectively particularly on old pasture land where the presence of perennial weed such as docks and nettles is more likely. A translocated (systemic) herbicide (e.g.Glyphosate at 3-5l/ha) should be applied to actively growing vegetation in early autumn before ploughing in the spring. If necessary the translocated herbicide can be re-applied just prior to ploughing leaving a period of ten days post-application before ploughing.

- Post-planting application of a pre-emergent residual herbicide to keep the crop clean during the establishment phase - There are a number of residual herbicides which can be used but a mixture of pendimethalin and Isoxaben (e.g. Flexidor at 1.0l/ha) has been found to be an effective mix on a range of sites. The residual herbicide should be applied within fourteen days after planting.

- An insecticide, chlorpyrifos (e.g. Dursban at 3.0l/ha) to control leatherjackets, the larval stage of the cranefly or 'daddy-long-legs' (Tipula), should be included with this herbicide application. High volume (500l/ha) applications should be used to give good surface coverage of the herbicide and adequate penetration of the insecticide.

- If weed becomes a problem during establishment, as can be the case particularly on ex-grassland sites, where the seed bank in the soil is greater than on ex-arable sites, there is only a very limited range of contact herbicides available for over-spraying the established crop. Additionally, these are highly specific herbicides with a limited weed spectrum. Effectively, there is only clopyralid (e.g. Dow Shield at 0.5 - 1 l /ha) for thistle control and fluazifop-p-butyl (e.g. Fusilade at 1.5l/ha), cycloxidim (e.g. Laser at 2.5l/ha) or propaquizafop (e.g. Falcon 1.4l/ha) for grass control. Other herbicides e.g paraquat (e.g. Gramoxone at 3.01/ha) can be applied as directed sprays using an inter- row guarded sprayer. However, this is a skilled operation and should only be undertaken with advice as the crop is highly susceptible to the herbicides used. Spot treatment of small areas of troublesome perennial weed (docks and nettles) can be undertaken with appropriate herbicides using guarded knapsack sprayers.

- Following establishment and after cutback, a further herbicide application will be necessary to keep the crop weed free until it achieves canopy closure, usually in mid- summer of the second growing season. The use of the contact herbicide amitrole (e.g. Weedazol (Not available in ROI at time of print) at 10-20l/ha), together with an additional application of residual herbicide – pendimethalin (e.g. Stomp at 3.3l/ha), will provide the necessary control and should be applied before significant flushing but delayed sufficiently after cutback to allow for wound sealing. Willow coppice has shown tolerance to amitrole just pre-flushing and therefore this application is made late March to early April. If weed cover is significant, a later cutback of the established crop in mid- March will delay flushing and will ensure that the weeds are actively growing, when they will take up the amitrole more effectively.

- Mechanical weed control using inter-row cultivators is also an option but less likely to be effective in the climatic conditions in Ireland where the moist growing conditions do not favour the dehydration of the disturbed weed cover. Whatever the herbicide used it is important to follow the manufacturer's instructions and they should not be used if the crop is under any stress particularly moisture stress as crop damage is likely.

1.6 NUTRITION AND FERTILIZATION

As with any crop, fertilizer, from whatever source, should only be applied as the result of formal soil analysis and the consideration of other inputs in perennial crops such as internal recycling of nutrients in the leaf litter. In the case of SRC Willow, in the absence of any long-term direct information on fertilizer and yield, nutrient off-take in the harvested crop should be used in calculating fertilizer requirement. There is evidence that on moderate to fertile soils, particularly in the early rotations, there is not necessarily a positive response to fertilizer applications. Sites with a naturally poorer nutrient capital may need these early applications to maintain productivity.

- Fertilizer application is not recommended on most sites in the first growing season because the nutrient capital is generally adequate for establishment, and the crop will not have developed the necessary root system for effective uptake. Additionally, it is in the establishment year that weed control is likely to be most difficult and fertilizer application may well exacerbate the problem.

- Published nutrient off-take figures for the harvested crop vary but are in the range; 150 - 400kg N, 180 – 250kg K, and 24 – 48kg P per hectare per three year rotation based on an 8 - 10t DM/ha/yr crop.

- There is no recent published work on nutrition of SRC Willow using the modern higher yielding varieties. These varieties grown in mixtures will have productivity levels significantly higher (20-40%) than the traditional varieties used in much of the trial work referred to and nutrient export levels are likely to be higher than those quoted.

- Many soils have excess levels of phosphorous. In Ireland, over 50% of soils tested had high levels of P (index higher than 3 - 26-45mg/l), with significant potential to create surface water quality problems. With the relatively low levels of phosphorous removal in the harvested SRC, the P status of the soil may well be the limiting factor in recycling organic wastes in most circumstances.

- As many soils are well supplied with phosphate and potash (>Index2 - 16-25mg/l P and 121-240mg/l K) it is not likely that additional P or K will be necessary, at least in the earlier rotations. Consequently, fertiliser applications whether in the form of organic wastes or mineral fertilizers should only be calculated following soil analysis and generally should only be applied to balance removals. There is the potential on soils with a low P index, when recycling organic wastes such as sewage sludge, to apply P in excess of removal in the understanding that the P status of the soil will rise over time. In these circumstances the soil index 2 for P should not be exceeded.

- It has been calculated that 170-260kg P in excess of crop removal is required to increase the P levels by 10mg/l i.e. one index level. Allowing for an excess of application over crop removal of 21kg P at an application rate of 45kg P/ha, this would mean that on an index 1 site, it would take a minimum of 8 years and a maximum of 13 years to increase the soil status to index 2.

- The risk of nitrogen leaching from SRC plantations is relatively low compared with normal arable situations given the long term perennial nature of the crop and the absence of soil disturbance through cultivation.

- Willows have a low nitrogen requirement. There is no single value and, in the literature, requirements range from 150 - 400 kg N/ha/rotation. This range may reflect the differing fertility levels of the soils involved and climatic impacts on yields. By comparison intensively managed grass would have a requirement of 900 kg N/ha over 3 years.

- In the nutrient removal figures for the crop, the efficiency of nitrogen use (in the region of 35%) should be taken into account. A significant proportion of nutrients will be used by the soil microflora, lost to the atmosphere, or bound up in the roots and leaves of the coppice, although these latter will eventually be recycled in the leaf litter and fine root turnover.

- The production of mineral fertilizers is heavily dependant on the input of fossil fuels. When these are used on SRC plantations, the energy balance (energy in versus energy out) is adversely affected and actual carbon dioxide emissions increased.

- Potassium can be relatively stable in soils and so unavailable for easy plant uptake. There is the potential of balancing most of the potassium exported from the site at harvest by returning the ash to the site, after conversion of the wood chip to energy.

- Two other important observations have been made over numerous years of growing coppice. Firstly, after the onset of serious rust (Melampsora spp.) infections on plantations in 1986, it was obvious that those stools in least competition for nutrients and light were those which were least affected by rust. In particular, the problems of stool death caused by entry of secondary dieback organisms into the stem tips following defoliation by the rust infection were less obvious. Secondly, it was also evident that in a plantation where vigour had declined through poor nutrition, it was difficult if not impossible to recover that vigour, raising the necessity of maintaining the nutrient capital of the soil by balancing off-takes.

- Consequently as a guide, to be confirmed with soil analysis and expected yield, nutrient application should not exceed the equivalent of 120-150kg nitrogen, 15kg - 40kg phosphorus (see above), and 40kg potassium per hectare per year. Unfortunately, due to the nature of the crop and the available equipment, the application of fertilizer in whatever form is not practically possible in commercial plantations except following harvest and before re-growth prevents the access of machinery.

1.7 PESTS AND DISEASE

Leaf Rust (Melampsora spp.) is the most important fungal pathogen of SRC Willow and potentially the most limiting to sustainable cropping particularly in the cooler maritime type of climate in Ireland which favors the development of the disease. It is a heteroecious rust (has an alternate host) and is first seen on willow in late spring – early summer as small orange coloured rust pustules on the underside of the leaf. These initial infections classically develop from aeciospores which have been formed on the pathogen's alternate host – European Larch (Larix decidua). Development on the host willow is through repeated asexual cycling of urediniospores.

Figure 12: Foliar rust (Melampsora) symptoms and electromicrograph of spores (AFBINI)

This cycle can be as short as two weeks and consequently can lead to serious levels of infection very quickly on susceptible varieties. These levels of infection then lead to premature defoliation with implications for yield and also more seriously for the entry of secondary die- back organisms through the unprotected leaf scars. These die-back organisms (Fusarium sambucinum and Glomerella miyabeana) can cause significant levels of damage to and subsequent death of shoots and stools.

In the moist relatively mild winters experienced in Ireland it also believed that *Melampsora spp.* urediniospores can survive over winter in the bud scales and leaf litter without the need to go through the alternate host. This can lead to early infection and very serious disease levels early in the growing season. Where significant levels of infection have built up and premature leaf fall has occurred high levels of yield loss, in excess of 50% have been recorded. These yield losses result not only from the loss of photosynthetic area caused by premature leaf fall but also from shoot and stool death in the years following infection. Where rust infection occurs early in the year following coppicing, when the crop is at its most susceptible stage, shoot death in single variety plantations has been recorded at levels approaching 60%.

In common with most fungal diseases, control can be achieved using fungicides. However, in the case of SRC Willow, this is not considered a practical solution for a number of reasons:

- Economics - SRC Willow is a high volume low value crop and the necessary repeated fungicide applications could not be sustained economically.

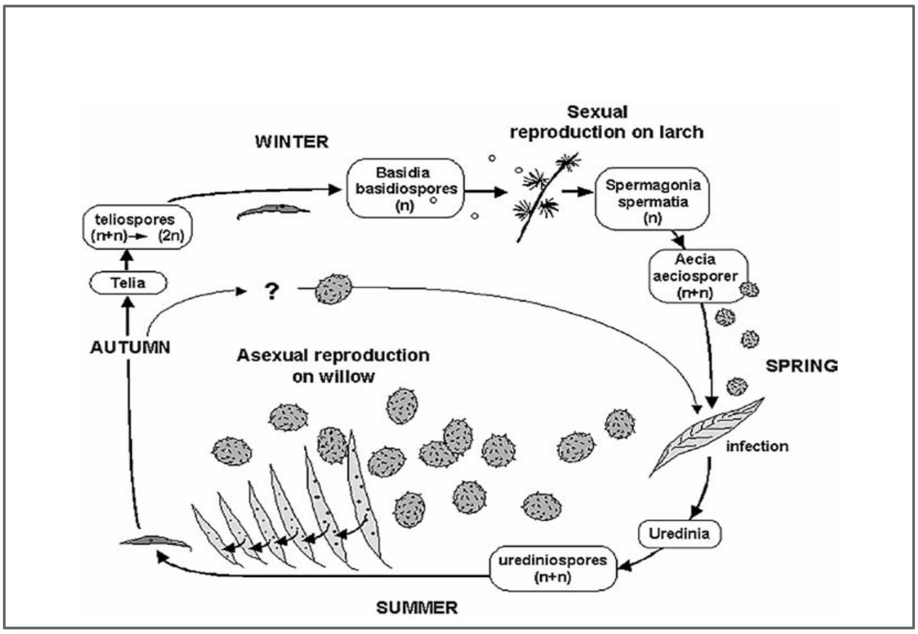

Figure 13: Lifecycle of Melampsora epitea (AFBINI)

- SRC Willow is seen as an environmentally acceptable crop and the intensive use of fungicides would not be compatible.
- Practically, after the early stages of re-growth following coppicing, it is increasingly difficult to achieve the necessary chemical coverage of the plant to effect adequate disease control.

As a result, an alternative non-chemical disease control strategy needed to be developed and this has been the subject of ongoing research since the late 1980's. If the major contributing factor to the development of the disease was the lack of genetic diversity in the single variety plantations used in the early plantations, it was argued that the introduction of diversity by planting mixed variety plantations would be effective in control. This has proved to be a successful approach, with mixtures delaying the onset of the disease and reducing its spread, so that at the end of the growing season, the disease although still present was not at levels where yield was affected. This was considered to be a more sustainable approach and as a result of the work a number of conclusions and from these standard recommendations can be made:

Figure 14: Rust infected plantation showing premature leaf fall and die-back (AFBINI)

- Evidence clearly indicates that where disease pressure is high, as it is in Ireland, the planting of single variety plantations even where the variety is less susceptible or resistant to rust is a short term high risk strategy and not to be recommended. There are examples where a previously resistant variety has become susceptible as the natural rust population has evolved, resulting in severe losses in single variety plantations.

- The yield of the improved varieties from the breeding programmes in Sweden and the UK, together with their superior rust resistance, means that only they should be used in commercial developments.

- Yield from diverse mixtures is greater than the equivalent yield of the mixtures components grown in monoculture even in the absence of the disease.

- Where less diverse mixtures have been planted e.g. mixtures of exclusively Salix viminalis varieties, these yield increases have not been recorded and the disease suppression aspects, whilst present, are not as marked. This is an important aspect since many of the commercially available improved varieties are of Salix viminalis origin.

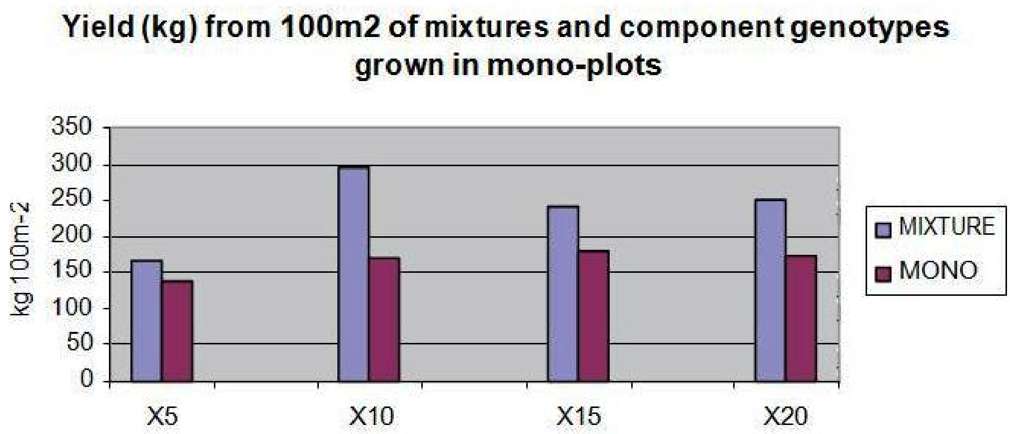

Figure 15: Yield (kg) from $100m^2$ of mixtures and component genotypes grown in mono-plots

- Increasing diversity in mixtures can result in yield compensation. Where individual components of the mixture become susceptible to the disease over time and make increasingly smaller contribution to yield, it has been shown that in a mixture of ten varieties, the loss of up to 30% of component varieties can be fully compensated for and the potential yield loss avoided. This yield compensation occurs as a result of the remaining varieties occupying the space left by those that have become disease susceptible. Consequently, at least six and preferably ten varieties should be included in commercial plantations.

Figure 16: Willow leaf beetle (Phratora vulgatissima) and larvae (AFBINI)

- Where varieties have been shown to have a high level of rust susceptibility, their inclusion in mixtures does not improve their productivity or sustainability.

- Completely random planting of mixtures is the ideal configuration to maximize yield compensation. However, with the planting machinery used the short run, random mixtures achievable with the step planter would be an acceptable compromise.

- There are differences in how individual mixture components contribute to the overall yield of the mixture. Provided that individual components do not have a significant negative effect, their inclusion is justified by the diversity they bring and the positive effect they have as a result on sustainability.

PESTS

Willow beetles (Chrysomelids): This group of beetles represents the major economic pest problem in SRC in Ireland.

Figure 17: Willow beetles (left: Giant willow aphis)

- There are three species of willow beetle involved - brassy or green (Phratora vitellinae), blue (Phratora vulgatissima) and brown (Galerucella lineola). The blue and brown species are more prevalent.

- Overwintering adults emerge from hibernation in April and, after a short feeding period, begin to breed. Egg-laying takes place between early May and late June. Larval stages are found from mid-May into July and develop through three instars before pupating. The new generation of adult beetles appears in July/August and feed until hibernating in the autumn.

- There can be two generations per year –the first emerging from the eggs laid by overwintering adults in May and a second generation in August.

- Adults feed on the upper leaf surface larvae whilst the larvae feed on the underside of the leaf which eventually is skeletonised and turns brown. Unlike rust infections, skelotinised leaves usually remain attached.

- Economic damage has been recorded in UK. However, damage may visually appear severe but defoliation experiments have shown if <30% leaf surface is damaged the effect on yield will be minimal. However, the willow plant has been shown to have increased sensitivity to beetle attack during the initial stages of re-growth following harvest, with significant effects recorded on both root and shoot growth.

- Populations of beetles vary considerably from year to year and just because there may be a heavy infestation in a particular year does not mean that the following year will be equally affected.

- The overwintering adults often hibernate off-site and this provides the only economic opportunity for control. If population numbers are large, they can be reduced by target spraying the borders of the plantation with insecticide when the beetles are re- colonising the plantation from their overwintering sites in early spring. However, this is a one-off operation and routine spraying is NOT recommended for both economic and ecological reasons.
- Mixtures have also been found to be effective in limiting damage as there is a variation in feeding preference of the beetles between the different varieties. The modern improved varieties also have increased resistance to insect damage.

Figure 18: Class Jaguar direct chip harvester Co Wicklow (Sligo IT)

OTHER PESTS

Aphid is a range of other potential pest species feeding on willow and the most obvious of these are the various aphid species. There are two large species which form extensive colonies on the stems in late summer /autumn - the giant willow aphid, Tuberolachnus salignus and black willow aphid, Pterocomma salicis. These aggressive aphid species can grow to 6.0mm long, and can form large colonies on the woody stems of some willow varieties. Both have been shown to have significant negative effects on above ground biomass yield and root systems. However, as with other aphid species, control with insecticides is not desirable either environmentally or economically nor is it possible practically.

There are also various midges (Dasyneura sp.) which can result in the death of the terminal bud or can cause rolling of the leaf margins. Their effect on yield is uncertain and control not practical.

1.8 HARVESTING

The harvesting window for the SRC Willow is from leaf fall to bud burst/flushing in the spring. In normal conditions, this gives a three to three and a half month period from December to mid March. In Irish conditions, soil trafficability is at its worst in this period and hence the need for hard access to the cropping site. Where earlier bud burst can be expected because of favourable site conditions, harvesting time should take account of this. Bud burst results from the mobilisation of a significant proportion of the reserves stored in the roots and stems and their transport to the developing shoots. Their removal in harvested material could weaken the stools, delay flushing and lead to increased weed competition. Consequently, harvesting should be carried out on dormant stools.

Figure 19: Chip produced from Class harvester (AFBINI)

SRC Willow does not fall under the remit of the 1946 Forestry Act, in the Republic of Ireland and is therefore not subject to the felling and replanting requirements.

Figure 20: Harvesting head of Stemster rod harvester (Northern BioEnergy Ltd.Cookstown)

There are three approaches to harvesting: direct chip harvesting, whole rod harvesting and billeting and each has its own advantages and disadvantages. Harvesting is seen as a co- operative or contractors operation because of the specialised nature of the machines and the justification of their cost on relatively small individual holdings. It is unlikely that any single option will be the correct choice across the board. The availability of drying and or storage facilities, the requirements of the supply chain, site conditions etc. will determine choice.

Figure 21: Stemster rod harvester working in three year old coppice, Drogheda. Insets Off-loading harvested rods and field drying rods. (Northern Bioenergy Ltd Cookstown)

DIRECT CHIP HARVESTING

In this option, the crop is cut and chipped in a single pass and the resulting material must be dried artificially immediately following harvest, to prevent deterioration. Most of the machinery developed for this type of operation has been designed to harvest the double row in a single pass and are essentially modified harvesting heads fixed to standard forage harvesters.

- These cut the standing crop, which is then chipped and blown into trailers for removal. Where, initially at least, it is envisaged that in Ireland end users will be mid- to small- scale, conventional silage type trailers can be used to transport this chip from the field for drying and storage and then to the end user.

- As the harvested crop is chipped fresh, the quality of the chip will be maximised and the power requirement for the chipping operation minimised.

- This is the most efficient harvesting operation but will require dedicated drying facilities as the harvested chip will self-heat quickly due to natural degradation, similar to composting. This leads to a deterioration of the chip with resulting loss of energy and the production of mould growth with attendant health and safety implications. Ventilated grain drying floors have been used efficiently for this operation and since harvesting is carried out after the grain drying season has been completed, maximum use can be made of these expensive facilities.

Figure 22: Case IH (Austof) billet harvester. (SWS Forestry Services Ltd)

Figure 23: Product from billet harvester (SWS Forestry Services Ltd)

- This type of harvesting machine has a capacity of 5-6 ha/day. However, in Irish conditions where field sizes are potentially smaller with restricted row lengths, actual capacity is likely to be 3-4 ha/day.

WHOLE ROD HARVESTERS

Here the crop is harvested as entire rods, and whilst in some circumstances it may be the harvesting method of choice, a number of points should be taken into consideration:

- These machines generally produce loose rods which have to be collected and removed to the storage area as separate operations. No fully successful bundling and tying operation has been developed yet and the handling of loose rods with a length of 6-8m can be difficult. The harvested rods will have to be handled a second time when they are chipped prior to use.

- The harvested rods are stacked on a hard standing area and since there is adequate natural ventilation, they will dry naturally over a period of time without any deterioration. This means that the specialised drying facilities required for the direct chip harvest operations are not required. In Irish conditions, because of temperature and more importantly humidity, no drying of the harvested rods takes place until early spring and over the following 8-12 weeks, moisture levels will drop to approximately 30% and depending on conditions can drop to 25% during the summer months.

- The chip produced from this dried material will have a wider range of particle size and increased dust fraction than that produced from the direct chip harvesting method. There is also a higher power requirement for the chipping operation.

- Machines tested have shown a range of capacities from 4-6ha/day but the crop still remains to be gathered and removed from the site for storage.

In Irish conditions, where individual coppice plantations are seen to be small with limited field size and lack of access to sophisticated drying facilities, the harvesting of whole rods may have a place, even if it is the more expensive operation. The ‘Stemster’ whole rod harvester will be undergoing proving trials in Ireland in spring 2007.

BIOBALER

The Bio Baler from Andersons Canada is actual is a revolutionary machine which was developed to allow foresters to make bio-mass from woody weeds into between the rows of the plantations. It also affords the effective harvestng of troublesome regrowth.

The Biobaler Harvesting System is a simple concept has also been developed for willow SRC. In a single pass, with only one operator, the Biobaler cuts and compacts biomass into a dense round bale. Bales can then be collected on site at any time after harvest.

The philosophy behind the Biobaler Harvesting System is to use a small dimension harvester to collect and densify the biomass in the field to reduce the ecological footprint. The shape and density of the bales allow for more cost-efficient transportation from the field to the processing facility with conventional equipment. At this point, the biomass can be processed according to the facility’s specifications with more efficient equipment.

Figure 24: Bales

Bales can be delivered directly to the plant or be stored in the field for future use. Bales of biomass are not expected to deteriorate during the storage process over a long period, even if they are harvested in very wet conditions. An advantage of this technology is that biomass bales dry out naturally without risk of spontaneous combustion, thereby increasing their heat potential, unlike a pile of woodchips, which will rot. Questions regarding damage to willow stools still need to be addressed and fully researched to ensure the biobaler is not damaging crops.

BILLET HARVESTERS

These are intermediate between the direct cut and chip and the whole rod harvesters. They were developed for sugar cane harvesting and produce short portions of entire stem 5-10cm in length, which in a similar way to direct chip harvesting, are blown into trailers for removal. In this case, because of the larger entire stem pieces and improved air circulation, natural drying can occur in much the same way as the whole rod system. These billets will also need to be chipped prior to use, to maximise combustion efficiency, but they can, unlike the whole rods, be easily handled mechanically. Again, chip quality can be poorer because the material being chipped is relatively dry (30% moisture).

1.9 YIELD

The principle on which crop yield is based is the conversion of light energy through the normal growth processes into the chemically bound energy in the economically important part of the crop. In the case of SRC Willow, it is the above ground woody stems. It has been estimated that this represents 60% of the total biological yield, with 10% allocated to the leaves and 30% to the stool/root system. The leaves and fine root system are recycled on an annual basis.

Figure 25: Copy a grain drying floor with willow chip for drying (Rural Generation Ltd)

- For SRC Willow, yield is normally quoted as tonnes of dry matter (DM) per hectare per year. Dry matter (all moisture removed) weights are used because they standardise the figures where fresh weights (including moisture) vary.
- To maximise economic yield, the crop canopy must be maximised as early as possible in the rotation and maintained for as long as possible throughout the growing season. This ensures efficient interception of solar energy and thereby maximising yield potential. On suitable sites, canopy closure or complete site capture usually happens in year two of the first cropping cycle. However, it is delayed to year three on poorer sites with resultant loss of yield. This can be exacerbated with light penetration to the soil allowing weed development to compete with the coppice crop.
- Harvesting is normally carried out on a three year cycle, however other considerations such as use of sewage sludge for optimising yield on poorer sites, cycles outside this norm may need to be considered. This is particularly the case with the new higher yielding hybrids and in mixtures where individual stool size could cause problems with harvesting options in longer rotations.

Figure 26: Detail of grain drying floor.(Sligo IT)

Figure 27: Ventilated chip or grain storage shed

- A wide range of yield data has been published and much of it needs to be considered in the knowledge that the yields quoted come from small experimental plots. Yields in excess of 30 tonnes DM/ha/yr have been obtained where crop nutrient and water requirements have been supplied artificially. However, this should be considered as the theoretical maximum for the species and not a commercial reality.

- Much of the yield data published comes from varieties that have now been outclassed in terms of their productivity. Trials have shown that the most recently available improved varieties have productivity levels significantly above these earlier choices.

- Using the available improved varieties from the two breeding programmes and planting them as recommended in minimum six way mixtures, sustainable yields of 10-12 tonnes DM/ha/yr can be achieved on better sites. Where some factor(s) (soil, fertility, light, exposure, or water availability) makes the site less than ideal, reduced yields can be expected.Using the available improved varieties from the two breeding programmes and planting them as recommended in minimum six way mixtures sustainable yields 10-12 tonnes DM/ha/yr can be achieved on better sites. Where some factor(s) (soil, fertility, light, exposure, or water availability) makes the site less than ideal, reduced yields can be expected.

- Improvement in the planting material in terms of both its productivity and its disease resistance could in the short term give yield figures of 12-14 tonnes DM/ha/yr.

- Yields from the first cropping cycle can be expected to be lower than subsequent cycles because complete site capture is not achieved until the middle of the second year of the first cycle. Thereafter, yields will reach a plateau with the normal seasonal variations, due to the prevailing weather conditions etc.

- Extended cropping cycles have shown that yields can be sustained over 8-10 cycles when improvement in the available planting material could, on its own, justify replanting.

1.10 DRYING AND STORAGE

As a fuel supply is required almost continuously through the year, depending on the end user, some form of drying and storage will be required. This is the part of the supply chain that has been least travelled but there is ongoing work to identify and address the problems involved. Freshly harvested chip will have moisture content in excess of 50% and the need for drying will be determined by the harvesting system used. Generally, it is only the direct harvested chip that requires immediate drying and dedicated active drying facilities. Harvested whole rods and billets do not have the same self-heating potential and will dry naturally. Artificial drying is a costly operation as in Irish conditions heat will need to be used. Estimates of £8-12 per tonne have been calculated to bring the moisture content below 20% when the chips will be stable for the long-term storage necessary to provide a continuity of supply to the end user.

- Chip drying is required because at 50% moisture at harvest and with the chipping operation making the nutrients in the wood more accessible to the fungi and bacteria, which cause the decomposition, the chip can heat to temperatures in excess of 60oC within a short period. This results in a loss of calorific value and a general degrading and loss of quality in the fuel. Spore production from the fungi involved, in particular Aspergillus sp., will cause a health and safety problem.

- The level of moisture reduction necessary will depend on the storage time required. Long term storage will need moisture levels below 20%. Where whole rods and billets are harvested and natural drying employed, moisture levels of 30%, and exceptionally in Ireland in dry conditions, 25% can be obtained. This is adequate where only very short-term storage at the end user is required, as the rods/billets are chipped on demand.

- Generally whilst large-scale combustion facilities will accept chipped material directly from harvest (50% moisture) the smaller facilities will work more efficiently with drier material. Completely dry wood has an energy content of approximately 19MJ/kg. However, in wood at 30% moisture, this is reduced to approximately 14MJ/ kg of usable energy because of the need to use a portion of its own energy to remove the water before combustion can take place.

- Ventilated grain floors have been used successfully to dry wood chip from SRC Willow. They can achieve the required moisture contents for storage relatively quickly (3-6 weeks). Heated air (6-10oC) above ambient to increase its water holding capacity is circulated. This drying operation for direct harvested chip must begin immediately after harvest, as self heating begins very quickly.

- There is a need to develop simple low cost drying systems that can be deployed on a small scale utilising perforated ducts and low rate ventilation from small fans. The practicalities of doing this and using conventional on-farm facilities are currently being investigated. Alternatively, centralised grain-drying type facilities could be provided and operated on a co-operative basis linked to the contract harvesting of the crop.

- A low-cost, simple approach for drying willow chips has been developed and successfully demonstrated. The system employs a single phase fan which blows air through a perforated duct. A clamp is constructed around the ducting into which fresh chips are loaded, the clamp is covered once complete. An air flow rate of 150m3/tonne of wet chips for twelve hours a day over a period of three months was used to dry chips from a moisture content of >50% to <20%. The cost, primarily electricity, was less than €5/ wet tonne.

Figure 28: Farmyard Clamp for Drying Willow Chips (Teagasc)

- Whatever drying system is used it is vital to provide a continuity of supply of a consistent, high quality fuel source to the end user not only to optimise boiler operation but to provide a dry matter base on which to price the fuel. Where the more advanced systems of utilisation are envisaged e.g. for gasification a lower moisture content of 10% is require due to the requirements of the process involved.

1.11 SITE RESTORATION

When a willow coppice has reached the end of its life, the site will have to be restored to either grass or arable production. In many of the heavy wet sites considered suitable for coppice, the root system of the crop will have improved soil structure and its mechanical removal may well cause significant damage.

- After last harvest, allow stools to re-sprout until they are 30-50cm tall (mid-May)
- Willow is extremely susceptible to herbicide, so a single application of a translocated herbicide Glyphosate (e.g. 5l/ha Roundup) is sufficient to kill off the actively growing crop. The crop should be left for at least two weeks after spraying to allow full absorption and translocation of the herbicide.
- Using a heavy rotovator or forestry mulcher, the stools and surface layer of the soil are incorporated to form a shallow tilth layer into which the grass is sown. This leaves the majority of the root system in place without damaging the soil structure.
- This return to grass production will take a full season. Returning to arable will take a longer grass break to allow roots to decay, otherwise, a much more involved and costly mechanical removal and collection of the stools and roots will be required.

2.0 UTILISATION, BIOREMEDIATION AND ECONOMIC EVALUATION

Total energy use in Ireland is divided approximately equally between electricity generation and distribution, transport and heat generation. It is therefore difficult to understand why most of the incentives for the production of renewable energy have been directed towards electricity production.

Additionally, the technologies for heat generation are the most advanced. Therefore, they are of the most immediate interest for deployment at the scale of operation applicable to the structure of the agricultural industry in Ireland. The logistics of supplying large multi- megawatt generation facilities from a large number of small producers is likely to present serious problems.

However, supplying relatively small (<1.0MW) dispersed heat only installations from individual or co-operative groups of growers is a more sustainable and immediate way forward. This approach also raises the opportunity of supplying heat to an end user through an Energy Service Company (ESCO), thereby gaining the advantage of selling the added value product (heat) rather than the raw material (wood chip).

2.1 COMBUSTION, GASIFICATION AND PYROLYSIS

There are three thermo chemical processes, which can be used to convert energy stored in the willow chip to usable energy – heat, and/or electricity; Combustion, Gasification, and Pyrolysis.

At the small-scale level envisaged as practical in Ireland, the direct combustion technologies are largely available 'off the shelf'. However, small-scale Gasification technologies have yet to complete their commercial development and Pyrolysis is still at the research and development stage.

Figure 29: Swebo boiler system showing chip bunker external combustion chamber and boiler (Rural Generation Ltd)

Figure 30: Wood chip store scraper system

COMBUSTION

Generally, this is the most efficient way to produce heat from wood chip. It involves burning the wood chip with sufficient oxygen to complete the combustion process converting the majority of the fuel to carbon dioxide and water. It is an established technology with many systems available 'off the shelf'.

Figure 31: Integrated 120Kw KWB Boiler system (Rural Generation Ltd)

- There are inevitably efficiency losses in all combustion systems but modern, well maintained chip boilers will have a conversion efficiency in excess of 80%.
- Because wood chip from SRC willow has a low bulk density, the energy balance (energy output versus energy input) is maximised if the fuel is used as close to its production site as possible. It is generally accepted that the transport distance should not be more that 30km. In this situation, the energy balance will be in excess of 30:1
- There is a wide range of equipment available ranging in size from a few kilowatts to multi-megawatts. The generated heat can be used directly to produce hot water or air, or it can be used to raise steam to drive a turbine to produce electricity. However, the capital cost of this latter application is likely to be prohibitive at the operating scale envisaged as practical in Irish conditions.
- Generally the more suitable systems have a chip store with the boilers combustion chamber fed by a thermostatically controlled auger with the necessary safety systems to prevent burn-back.
- If the combustion system is being supplied from long term stored chips, they will be below 20% moisture (approximately16MJ/kg) or 30% moisture (approximately 14MJ/kg), where the supply is from open stored rods chipped as required.
- Wood chip can also be manufactured into pellets and used to fuel specifically designed pellet

stoves. However, this process requires the further drying of the chips to below 15% moisture and their reduction in a hammer mill and final extrusion in a pellet mill, all of which are highly energy intensive. This has a major negative influence on the energy balance of chip production in SRC and largely cancels out their cost advantage over oil.

- Pellet production from specifically grown energy crops is therefore unlikely to be sustainable economically. However, a different situation exists where the raw material for pellet production is a waste product such as saw mill residues and therefore has a negative value because of disposal costs.

- Storage volume for wood chip will be approximately nine times the volume required to store light fuel oil with the same energy content and is an important issue in designing installations (1.0m3 of oil will require 9m3 of wood at 30% moisture to provide equivalent energy amounts).

GASIFICATION

This is a form of partial combustion where the stored energy in the wood chip is released in the form of combustible gases, principally hydrogen and carbon monoxide. This is achieved by heating the fuel to high temperatures (>1000 °C) in a controlled deficit of air so full combustion to carbon dioxide and water cannot be completed. This is a relatively simple chemical process and can be completed in a range of systems – updraft, downdraft, fluidised bed – depending on where the air is introduced and its direction of passage through the gasification vessel. Wood gas has a low calorific value of between 4 and 5 MJ/m3 and is not economically practical to store. It is therefore used as it is generated. Gasification is not yet commercially viable and requires further R&D before it will reach market maturity.

Figure 32: 100 kW Combined heat and power system using gasification
(Inset showing generator and heat exchange system) (Rural Generation Ltd)

PYROLYSIS

This is a technology which is still in the research and development phase. It involves the heating of the wood chip to temperatures varying from 400-700 °C, in the total absence of air, to release energy in the chip as a liquid pyrolytic oil, a solid char and/or combustible gasses (Fig 2). The relative proportions of these products depend on the temperatures used and on the residence time of the chip in the reactor. The main advantage of this process is that it produces a liquid oil, which can be stored and transported relatively easily. It has a calorific value of 16MJ/kg but is acidic and has significant water content so is corrosive and tends to be unstable.

FUEL ALCOHOL

Lignocellulosic material, such as the wood chip produced from SRC Willow, can also be converted to fuel alcohol through an enzymatic hydrolysis process. This makes cellulose more accessible for standard fermentation to produce alcohol. This may eventually be the most attractive route for producing energy from SRC Willow. However, the commercialisation of the techniques and processes involved has not been completed and is currently some way off the market.

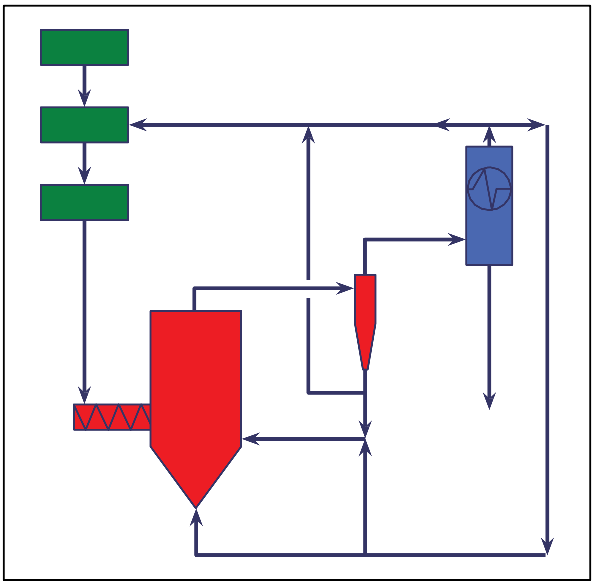

Figure 33: Pyrolysis process diagram

2.2 BIOREMEDIATION

Short rotation willow coppice grown exclusively as a renewable energy crop is only marginally sustainable economically given the current fossil fuel cost/supply situation. In this context, its ability to extract nutrient and non-nutrient elements from polluting waste streams, offers a significant opportunity to improve sustainability. This process, termed bioremediation, is particularly relevant in the current climate, where a proactive approach to whole farm nutrient management is of increasing importance in addressing the Water Framework and Nitrates Directives.

Willow is a particularly good species for the recycling (bioremediation) of dilute wastes for a number of reasons;

- Willow has a significantly higher water use than any other woody or arable crop species grown in Ireland. It has been calculated that willow coppice can use up to 1.0 million litres per tonne of dry matter produced annually.
- The shrub type of Willow used in coppice plantations generally has a fine shallow root system with 85% situated in the top 20cm of the soil profile. This not only improves stability but also provides an excellent receptive surface for the application of liquid and semi-solid wastes.
- Leaf area is maximized early in the year so that by early July the system is at its maximum potential with the leaves providing, through evapotranspiration, the maximum pull through the system of water and nutrients.
- Willow is a pioneer species and therefore produces vigorous juvenile growth. It is this factor which is exploited in the short rotational cycles imposed on the coppice system and maximizes the nutrient off-take in the harvested crop (see Section 1.6 - Nutrition and fertilisation).
- It is this off-take which provides the ‘engine’ for sustainable bioremediation. The guiding principle for all bioremediation systems is that the nutrient input into the system via the waste being recycled should be matched by the nutrient off-take in the harvested crop and in this way the system should be self-sustaining. This can only be achieved by continuing analysis of the waste or effluent being applied.

- SRC is a perennial crop and the lack of regular cultivations makes it more akin to the grassland situation. Even though the soil surface can be relatively bare under a mature plantation, SRC should result in a lower incidence of nitrogen leaching than under arable management.

- Generally it is the P level in effluents/grey waters that is the limiting factor in application rates. Where P levels are high, the area of coppice required for sustainable treatment of the waste becomes unrealistic.

- It is the case that throughout Ireland soil P levels Ireland are often high, with many in excess of index 3, where natural leakage of P into the ground water is already occurring. Soils with these levels of P cannot be used for bioremediation. Sludge's or effluents should only be applied to soils with lower P indices. This allows for the possibility of applying phosphorus in excess of plant/crop removal with only a slow resulting build-up of P index in the soil. However calculations must be made on an individual site basis and application levels are only set after ratification by the appropriate regulatory authority.

- Experience with municipal wastewater at experimental sites in Northern Ireland has indicated that rates up to three times calculated evapo-transpiration can be used. Evapo-transpiration is a measure of total water loss from the coppice system (Fig 35), including evaporative losses from soil and plant surfaces and losses internally from the plant. Evapo-transpiration in a SRC willow plantation in Northern Ireland, equates to approximately 5 million l/ha during the growing season, depending on site location. Application of waste water at this level showed no detectable pollutant attributable to the wastewater detected in the ground water. With the wastewater used, application at calculated evapotranspiration levels (5.0 million l/ha), provided 83 kg N, 56 kg P and 45 kg K.

Figure 34: Loading sewage sludge from a sealed trailer through a closed auger to applicator.
(Rural Generation Ltd)

Figure 35: Applying sludge to a harvested site (Rural Generation Ltd)

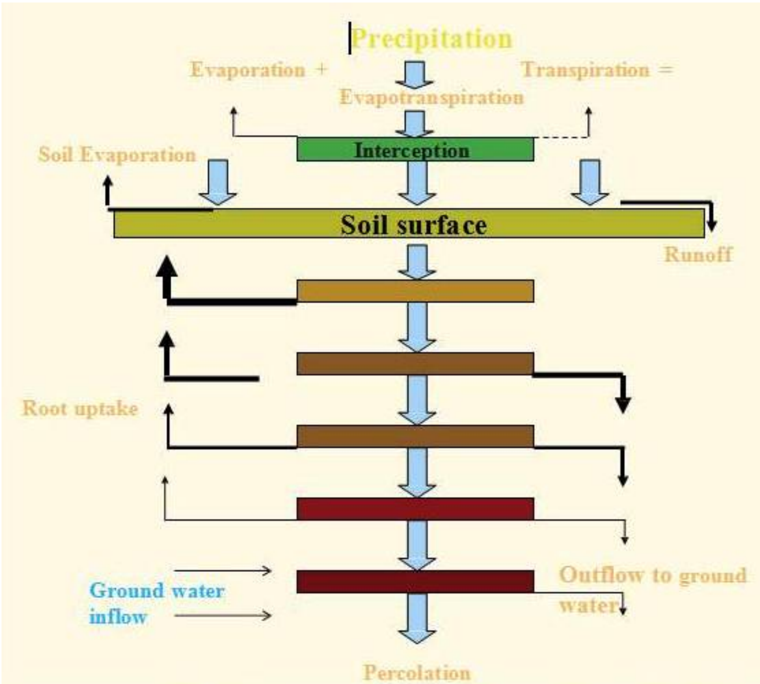

Figure 36: Diagrammatic representation of water loss in a coppice system

- Work to evaluate the ability of the soil/coppice system to deal with reduced winter application when the crop is dormant is being initiated. Bioremediation could create the need for a significant coppice resource – treatment of the sewage sludge, which currently goes to landfill, could require up to 1200 ha in Northern Ireland alone.

The application of waste to coppice plantations should be carefully planned not just in respect of the nutrients being applied but also how they are applied. Semi- solid wastes, such as dewatered sludge cake, should be buried using an adapted applicator with the exposure of the sludge to air kept to an absolute minimum. Dilute liquid wastes e.g. municipal waste water or dirty water from farm operations such as parlour washings should be applied using an installed irrigation system.

Here the guiding principle is that the waste should be applied in small daily doses calculated to take account of soil and climatic conditions. This will ensure that the waste has an adequate residence time in the actively feeding root zone to remove the nutrients present before any percolation through the system reaches the groundwater. They should also be applied directly to the soil surface and not through any type of nozzle to avoid any possible atomizing of the waste and the implications that would have for drift and odour control.

Figure 37: Installed irrigation system for bioremediation of wastewater Co. Londonderry (Rural Generation Ltd)

Figure 38: Detail of irrigation nozzle (Rural Generation Ltd)

It is not appropriate or practical to provide examples of application rates for sludges or effluents as each situation will be highly individual and dependent on the nature of the waste, the nutrients it contains, and the soil and climatic conditions in which it is applied.

LEGISLATION

Figure 39: Slurry applicatior developed by CRL

Figure 40: Rural generation cut a furrow

There are a number of important areas of legislation relating to the recycling of wastes on SRC and the major ones are summarised below. Additionally, there are codes of good practice and specifically the Safe Sludge Matrix, which also provides direction for the recycling of wastes to agricultural land.

The Nitrates Directive 91/676/EEC

http://ec.europa.eu/water/water_nitrates/indexen.htm

This Directive seeks to reduce and prevent the pollution of water caused by nitrates from agricultural sources. It is designed both to safeguard drinking water supplies and to prevent wider ecological damage in the form of the eutrophication of freshwater and marine waters generally.

Waste Framework Directive (WFD 75/442/EC)

http://ec.europa.eu/environment/waste/pdf/directive_waste.pdf

The primary objective of the WFD is to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, and in particular without risk to water, air, soil, and plants and animals; without causing a nuisance through noise or odours; and without adversely affecting the countryside or places of special interest: the prevention and reduction of waste; the recovery of waste by means of recycling, its re-use, reclamation etc; and the use of waste as a source of energy.

Sludge Directive (86/278/EEC)

http://europa.eu/scadplus/legn/en/lvb/l 28088.htm

The purpose of the Directive is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man, thereby encouraging the correct use of such sewage sludge.

2.3 CARBON MITIGATION AND CAPTURE

Short Rotation Coppice Willow and Carbon

One of the major drivers for growing SRC willow is its potential for the reduction of Green House Gas (GHG) emissions. There are potential two ways in which growing willow as a source of renewable energy can off set carbon emissions.

Carbon mitigation:

- The energy content of dry willow wood chip is approximately 19 MJ kg-1. One hectare of SRC willow produces the equivalent energy of 3,300 – 5,700 litres of light heating oil and an average medium sized house will burn around 3000 litres of oil per year, which releases 8.02 tonnes CO_2.
- SRC Willow wood is a carbon neutral fuel. And carbon that is released during its combustion has been absorbed by the plants when they were growing. For every GJ of energy produced from wood chip around 7 kg CO_2 is released compared to 79 kg CO_2 is released when the same amount of energy is produced from oil, resulting in an over 90% reduction in emissions.

Carbon sequestration:

- While growing SRC willow has the potential to sequester (capture) carbon, thus preventing its release as GHG.
- After the above ground biomass has been harvested for wood chip carbon can be stored in three ways: in the non-harvested above-ground biomass (stumps); the below-ground biomass in the form of course and fine roots; and the input of the carbon onto the soil organic matter.
- SRC willow can sequester around 0.12 t of carbon ha-1 yr-1.
- There are a number of factors which will determine the rate of change as well as the total amount of soil carbon sequestered by SRC willow. These include the carbon inputs to the system – i.e. during the net primary production phase; decomposition of the major carbon pools – which is affected by soil moisture and temperature; the initial carbon content of the soil – there is an inverse relationship with the sequestration rate; crop management – e.g. harvest intervals, re-plantation; depth of soil influenced by the willow – which will influence the total amount of carbon sequestered.
- Amount of carbon captured by SRC willow can be further enhanced if plantations are used for the bioremediation of effluents and sludges.

3.0 ECONOMIC EVALUATION

Because willow is in the ground for approximately 20 years and planted once, they are difficult to present or compare to the more conventional farming systems. There are numerous assumptions which can be made. However the following figures are used in determining the calculations in this economic evaluation. Teagasc have developed a spreadsheet which can determine the annual net cash flow based on various assumptions.

- Bank interest rate 7%
- General inflation rate 3%
- Energy inflation rate 3%
- Not VAT registered
- Initial establishment costs borrowed over 20 years
- No willow gate fee for sludge
- No carbon premium
- 50% of the establishment costs covered by grant aid
- Annual Land Opportunity Cost (OC) €400/ha

Establishment costs / hectare:

Willow is quite expensive to establish. The approximate cost per hectare is €2,730 taking operational and material costs into account in year 1. Once the crop is planted and established it will be harvested either on a two year or three year cycle. The willow SRC crop has an expected life-span of 20 years and will re-grow from the coppiced stumps after a harvest. The coppiced crop focuses its energy on growing upwards rather than developing a deep tap root. It should be expected that establishment costs will come down in the next couple of years as machinery and know how evolves to improve the efficiency and cost of the planting, management and harvesting of a willow crop.

VAT:

Farmers who are not registered for VAT will have to pay the VAT on the willow cuttings at 13.5% which can add an extra €257 per hectare. VAT on other materials at 21.5% would add an additional €57 per hectare.

VAT on operational costs is charged at 13.5% this would amount to €75 per hectare if employing a contractor for all the work. The total VAT could therefore potentially amount to circa €390 per hectare if not registered for VAT.

Three year cycle:

Traditionally SRC coppice willow has been harvested on a three year cycle. Any crop planted in April 2009 will be cut-back with a reciprocating type mower in January 2010. This will allow more tillers (shoots) to form. The cost of cut-back is approximately €30 per hectare. The old finger-bar reciprocating type mower is ideal for this.

The first harvest of this three year cycle will be three years from cut-back and the crop will be circa 4 years in the ground at the time of (Dec 2012 – April 2013) harvest.

Table 1: Establishment costs

Willow Costs / ha	€/ha
Spray 1	20
Plough	75
Power-harrow / Cultivate	80
Plant	350
Roll	10
Spray 2	20
Total operational costs	*€556*
Material Costs / ha	
Glyphosate herbicide (4 l/ha)	40
Weedkiller / Insecticide	25
Residual herbicide	60
Management fee	150
Cuttings	1,900
Total operational costs	€2,175
Total establishment costs / ha	*€2,730*

Two year cycle:

Some willow growers and contractors are recommending a two year harvest interval rather than three. The main reasons given are the ease on machinery in getting through a two year old crop as opposed to a three year crop also the potential to apply sewage sludge to suitable sites is possible more frequently on a two year old harvested crop because the sludge is applied after harvest on suitable plots.

Harvesting method:

The moisture level at harvest will be between 50 – 60% moisture content. There are two main methods of harvesting (described in the harvesting section) used in Ireland. Harvesting is generally carried out from December to April. This provides an opportunity for contractors to have their machinery in use at a time of the year when machines would normally be idle.

Whole-stem harvesting:

Whole stem harvesting cost approximately €30 per dry tonne harvested but there are no artificial drying costs. Chipping and transport of the material will be extra. It's costs approximately €10 per fresh tonne for chipping the whole stem rods which then have to be transported in chipped form to the end user.

Direct chip harvesting:

Artificial drying is costly and the estimated cost of force drying is estimated at €30 per dry tonne to bring the moisture content below 20% at which chips will be stable for long-term storage. The cost of direct-chip harvesting is approximately €25 per dry tonner.

Harvest yields:

SRC willow yield is normally quoted in tonnes of dry matter (DM) per hectare per year. Harvesting is normally carried out on a three year cycle. Newer high yielding hybrid varieties which cycle outside the norm may cause machinery harvesting problems for the three year harvest rotation.

Yields of 10-12 tonnes DM/ha/yr can be achieved on better sites. A lot more research needs to be done in order to determine the yields achievable on various soil types. Yields from the first cropping cycle (3 year harvest) can be expected to be lower than subsequent cycles. The yield from the first harvest cycle would be expected to achieve 23 tonne of DM/ha on the first cycle this would be equivalent to 51 tonnes of fresh material at 55% moisture. The yield from subsequent harvests on a 3 year cycle should achieve 30 tonnes of DM/ha.

Markets for willow:

Willow will potentially be used in our power stations, district heating and commercial heating projects. It will mainly be supplied in chipped form at moisture suitable to its recipient boiler.

It's difficult to give a price for willow as the markets are currently in their infancy. Table 4 compares the various feedstock's to that of oil which essentially will be the main commodity displaced from the market by biomass. Rural Ireland is mainly oil dependent because of the absence in rural areas of a gas pipeline. Therefore the price of oil is a good barometer in terms of evaluating the value of willow chip. If we take the value of wood chip at €100 per tonne to the farmer the average net margin per hectare over a 20 year period is €888.

Cost of oil:

One tonne of home heating oil contains 42 GJ of energy and 1,000 litres of oil contains 36.68 GJ of energy. The price of oil continues to fluctuate, however it is possible to benchmark the price of biomass to that of the well established supply chain of home heating oil. One litre of home heating oil contains approximately 10.5 kWh of energy. Table 3 shows that the value of home heating oil at €0.70 per litre is €18.43 per GJ of energy.

Table 2: The value of oil in energy items

Cost per litre	Cent/kWh	Value per GJ
1.30	€0.123	€34.23
1.20	€0.114	€31.60
1.10	€0.104	€28.96
1.00	€0.095	€26.33
0.90	€0.085	€23.70
0.80	€0.076	€21.06
0.70	€0.066	€18.43

Table 3: Fuel cost comparison

Fuel	Price per unit	kWh per unit	Cent per kWh
Willow Chips (30% MC)	€130 per tonne	3,369 kWh/t	€0.04
Wood Pellets (10% MC)	€230 per tonne	4,800 kWh/t	€0.05
Natural Gas	€0.051 cent/kWh	1	€0.051
Home Heating Oil	€0.90 per litre	10.5 kWh/litre	€0.08
Electricity	€0.14 cent/kWh	1	€0.14

Payback on Biomass Installation

Before deciding on converting from oil or gas to biomass most businesses e.g. hotels, nursing homes, hospitals, leisure centres, OPW buildings etc will carry out an economic analysis on the potential payback from the system. Based on the figures presented in table 4 above it's possible to evaluate the potential payback. If we take an example of a nursing home which currently consumes 30,000 litres of home heating oil per annum they are effective using 315,000 kWh (30,000 x 10.5) per annum. This is equivalent to 93.4 tonnes (315,000 / 3,369) of woodchip which would cost the nursing home €12,142 per annum based on a delivered price of €130 per tonne. The home heating oil would cost €21,000 (30,000 x 0.7) based on a delivered price of €0.70 cent per litre. In this situation an annual saving of €8,858 would be made on energy costs. The biomass installation is always more expensive than an oil or gas boiler the annual saving helps the payback on such an installation.

No mechanism to pay for Carbon abated

Willow or miscanthus could be used as a carbon neutral fuel in our peat burning power stations. The combustion of one tonne of peat releases approximately 0.856 g of CO_2 per Kg of peat combusted or 0.856 tonnes of CO_2 per tonne of peat combusted. To put this in context, if a power station had reported CO2 emissions of 846,352 tonnes. Under the National Allocation Plan (NAP) administered by the EPA, if the power station is allowed to produce 627,676 tonnes of CO_2. They exceed their allowances by 218,676 tonnes of CO_2 or 255,462 tonnes of peat. One carbon credit represents the reduction of one metric tonne of carbon dioxide. The power station is now faced with the option of purchasing carbon credits or using a carbon neutral fuel such as biomass.

Carbon is currently trading at €25 per tonne and is expected to increase as the noose tightens further on various emission sources and sectors. Energy crops such as willow and miscanthus are carbon neutral fuels as the CO2 released on combustion of the fuel is equal to that taken from the atmosphere by the growing plant during photosynthesis as opposed to burning ancient energy by taking fossil fuels out of the ground such as coal oil and gas which have been stored for millions of years. On an energy basis 143,371 tonnes of willow at 20% moisture is equivalent to the 255,462 tonnes of peat at 55% moisture. This would give a saving to a power station of €5.5 million (218,676t x €25) which equates to €38 per tonnes of willow supplied. There is currently no mechanism in place for the power station to pay the farmer for supplying a carbon neutral crop which eliminates the need for the power station to purchase the carbon credits. This may change in the future.

Payback to the farmer

The price paid to the farmer should track the price of fossil fuel alternatives i.e. oil and gas. There will be a number of third parties getting involved in the supply chain who will incur transport and quality control costs and possibly chipping / drying costs.

Opportunity Cost (OC)

Opportunity cost measures the cost of any economic choice in terms of the next best alternative foregone. The opportunity cost of deciding not to work is the lost wages foregone. The opportunity cost of using arable farm land to produce willow is that the land cannot be used in that production period to harvest for example potatoes or wheat. When we are considering the opportunity costs of decisions we make, we must use the highest-valued alternative that has had to be sacrificed for the option we have chosen. A simple guide figure to use is the potential rental value of the land on the open market. If estimated correctly this will allow for land type and quality to be taken into account. It will also give an indication of what the alternative enterprises available may return to the farmer. While it may be possible to estimate the opportunity cost for the first few years the longer the investment, say for 20 years, the more difficult it becomes to make an accurate estimate.

Net Present Value (NPV)

The difference between the present value of future cash inflows and the present value of future cash outflows. NPV is used in capital budgeting to analyze the potential returns of an investment or project. Net Present Value takes the affect of inflation on the future returns into account. A euro in your pocket today is worth more than the euro in your pocket in 10 years time, so there is a time value for money. The NPV calculation takes this into account, discounting future figures and putting them into the value of today's money. All the future cash inflows and cash outflows are added to give a positive or negative figure. If the NPV of a project is positive, it should be accepted. However, if NPV is negative, the project should be rejected, unless there is some compelling non financial reason for proceeding with the project. If the current interest rate is used for the discounting process then the calculation allows for a comparison or returns between the proposal and the interest rate.

Internal Rate of Return (IRR)

IRR is a capital budgeting method used to decide whether one should make an investment including an appropriate risk premium. Mathematically the IRR is defined as any discount rate that results in net present value of zero of a series of cash flows.

It is an indicator of the efficiency of an investment (as opposed to NPV, which indicates value or magnitude). The IRR is the annualized effective compounded return rate which can be earned on the invested capital, i.e. the yield on the investment. A project is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternative investments (investing in other projects, buying bonds, even putting the money in a bank account). Thus, the IRR should be compared to an alternative cost of capital including an appropriate risk premium.

Potential Returns

The returns from the crop will vary hugely depending on the assumptions made. In table 4, we compare two different types of harvesting. Whole stem appears to leave the greater return in all cases. The overall return will depend on the price received for the crop. If there is no opportunity cost for land included and the money required to establish the crop is borrowed at a cost of 7% over 20 years the NPV ranges from €2,225 at €60/t to €8,121 at €100/t. If an opportunity cost is included at €250/ha (€100/acre) the NPV ranges from - €643 at 60€/t to €5,254 at €100/t. This is assuming a good crop yield on suitable land.

Table 4: Potential Returns on two year harvests

Returns From Willow Whole Stem Harvest			
Price Received per t 25% mc no opportunity cost	€60	€80	€100
Net Present Value (NPV)	€2,225	€5,173	€8,121
Internal Rate of Return (IRR)	20.6%	32.5%	41.5%

Price Received per t 25% mc Opportunity Cost €250/ha	€60	€80	€100
NPV	- €643	€2,305	€5,254
IRR	1.8%	16.3%	25.6%

Returns From Willow Direct Chip Harvest			
Price Received per t 25% mc no opportunity cost	€60	€80	€100
NPV	€791	€3,740	€6,688
IRR	12.4%	27.2%	27.4%

Price Received per t 25% mc Opportunity Cost. €250/ha	€60	€80	€100
NPV	- €2,076	€872	€3,820
IRR	-	10.5%	21.4%

4.0 ENVIRONMENTAL IMPACT OF SRC WILLOW

Short rotation coppice willow differs from food crops in two major ways that have environmental and biodiversity implications.

- In food crops generally, only a small proportion of the total crop is used and even low levels of cosmetic damage, from whatever source, can reduce the useable yield significantly. However, in SRC where the whole crop is used and cosmetic damage is relatively unimportant, the economic threshold to pest/disease damage is relatively high.

- SRC crops provide a relatively stable habitat compared to annual crops though the harvesting cycle will interrupt this stability. However, if different age class blocks are included, naturally occurring control agents of the pests/disease species are provided with an environment, which they can colonise and develop alongside the pest species. This has been recorded for the major pest species (Chrysomelid bettles) and for Melampsora rust.

Any change in land use from arable or grassland to SRC will inevitably result in changes in the ecology/biodiversity of at least those fields directly concerned. They may also have measurable affects on the surrounding area, particularly if the siting of the crop links it up with other woodland areas or intercepts run-off from intensively farmed areas.

These changes are not disputed. However, the nature and extent of the change and to what degree it would be beneficial, will not be totally clear until the area of coppice expands and significantly older plantations are available for study.

These changes will be modified by the use of herbicides and other pesticides, inorganic and organic manures and fertilisers, and other effluents, and frequency of harvesting. In general, the overall effect on wildlife values, where SRC replaces intensive agricultural production, is likely to be positive but where it replaces improved grassland, it will have little overall effect. Planting on species rich meadows would be detrimental.

Short Rotation Coppice Willow is a forestry crop and as such is required to meet environmental standards of best practice as described in the UK Forestry Standard and accompanying guidelines. Afforestation using Short Rotation Coppice Willow may also be a relevant project under the Environmental Impact Assessment Regulations and require the production of an Environmental Impact Statement.

4.1 FLORA

Conversion from grassland or arable use to a woody perennial crop with a regular harvesting pattern will result in changes to the ground Flora. The species composition of the plant community below an area of SRC, will develop at first rapidly but then more slowly as a succession, until a fairly stable and probably species poorer community is established. The starting point for these changes and the rate of change will depend on soil type, previous land use, and management factors such as herbicide and fertiliser use and frequency of harvesting.

- Plant species diversity is high in SRC plantations – higher than estimates for all British lowland farms. A pattern of succession has been established with annuals germinating from the seed bank after planting. This is followed by short lived perennials which are often aggressive weed species and finally by long lived perennials of a higher nature conservation value and stress tolerant.

- Coppice established on ex-grassland sites will have a more diverse flora with higher percentage of long lived perennials than ex arable sites which would have had a previous history of herbicide usage.

- Harvesting prevents the creation of a fully stable ground flora. The sudden removal of the canopy at harvest has dramatic effects on microclimate, radiation and water usage and results in a temporary increase in species richness. Second and third year crops will be less species rich.

- Herbicides – coppice requires the use of herbicides for successful establishment - at least over two growing seasons. This is likely to have the greatest influence on plantation flora. Subsequently, in an established SRC, the tolerance of the crop to weediness and hence the economic threshold for taking action is high. Through time there will be a reduction in the invasive weed species and an increase in the less competitive, shade tolerant perennial flora.

- Design and locations of SRC should, where possible, include the provision of headlands and rides to help maximise species diversity. However, this is not practical on heavy wet sites, where headlands should be planted to improve machine trafficability.

4.2 INVERTIBRATES

The abundance and diversity of insects in SRC is high compared with other crops. Chrysomelid beetles are the main pest species with sawflies, terminal midges, and stem and leaf aphids identified as potential problem species. This combined with the existence of potentially beneficial insect species, means that the environmental cost of overall insecticide applications would be very high even if, on economic grounds, they could be justified. In the case of insecticide use, as with herbicides, only highly specific targeted spot applications in established coppice can be justified.

Species of conservation importance recorded in SRC include beetles, spiders, flies, moths and butterflies. SRC can have both negative effects (on species associated with disturbed lands) and positive (on phytophagus species).

Earthworm sampling records show a decrease on numbers under SRC, though this may change in longer established plantations and evidence from German records suggests significant increases in numbers in coppice sites, compared with arable sites.

The species diversity of invertebrates on the coppice floor and their population sizes will be heavily dependent on the nature of the ground flora. Intensively managed coppices are unlikely to provide botanically rich sites and consequently are unlikely to be of great value as habitats for ground dwelling invertebrates.

As with the flora, the opening up of coppice sites after harvest, could lead to a rapid increase in diversity and number of invertebrate species but this is likely to be transient.

The invertebrate fauna of coppice is more diverse than that of arable crops and will be encouraged by the presence on a single site of the various stages of the crop through phased planting and consequently harvesting.

4.3 BIRDS

Extensive surveys have shown that SRC holds a relatively large number of species and individuals, when compared with the agricultural crops it tends to replace. This can be attributed to the structural diversity provided by the coppice and its attractiveness because of increased insect diversity and number. The abundance and diversity of birds in a SRC system has more than ecological significance. It has significance in the public perception of the environmental state of a site, whether or not the site has actual ecological importance.

Figure 41: Skylark

Figure 42: Skylark

In an intensive study in Castle Archdale in County Fermanagh, 44 species of birds were recorded over a 4 year period. Many did not hold territories and were recorded as migrants e.g. curlew, snipe and wheatear. However, 22 species did hold a mean of at least 1 territory per year (i.e. tended to breed every year). The most important species in terms of numbers in SRC and edge habitats were blackbird, dunnock, meadow pipit, robin, song thrush, willow warbler, and wren.

Breeding Birds

- SRC has been shown to be of value to nationally declining bird species with six species (skylark, thrush, linnet, bullfinch, reed and corn bunting) recorded breeding. Many of the species would largely be absent from the site if SRC was not present and are direct beneficiaries of SRC.

- Changes in species composition occur as SRC develops – open farmland species being replaced with woodland species.

- It is preferable to have and maintain the various stages of SRC rotation in one location rather than a single stage. This gives a continuity of the different habitats provided by coppice in its various developmental stages and increases species diversity.

Figure 43: Interlocking plantations of different age classes Loughgall Co Armagh (AFBINI)

Wintering Birds

- Fifty one species of wintering birds have been recorded, highlighting the importance of SRC for wintering species. Thirteen species of conservation importance have been recorded, again underlining its importance for declining bird species.

- Species composition – as SRC develops, buntings, finches, skylark, and snipe decrease, whilst the numbers of woodland species, including, pheasant, blackbird, and tits increase.

- Overall density of wintering birds in SRC was high in year of planting but decreased in years 2 and 3, with an increase again in years 4 and 5, reflecting the change from open land species to predominately woodland species.

4.4 MAMMALS

SRC could provide valuable habitat for small mammals, if a similar structural mosaic to that of traditional coppice is allowed to develop. However, short rotation coppice is unlikely to provide an optimal habitat for small mammals because of the lack of seasonally important food items, such as berries as well as insufficient ground cover and nest sites.

- Conflict with larger mammals – deer, hare and rabbit can all cause considerable damage through browsing, particularly to establishing crops or those re-growing after coppicing. However, since they are likely to be excluded from plantations wherever they pose a threat, they cannot be considered as a 'game benefit'.

- Squirrels are unlikely to be attracted to SRC because of a lack of a suitable food source.

- Where there are suitable roosting sites nearby, bats may find coppice plantations valuable feeding sites, benefiting from the abundance of flying insects above the canopy.

- Hare numbers could decline further if planting of SRC were to become widespread. This species favours mixed farmland and is unlikely to thrive in densely planted coppice stands. This is less of an issue in Ireland with the small scale planting envisaged.

4.5 INFLUENCE OF SRC ON WATER

Due to its heavy water usage, production sites for SRC must be carefully chosen to ensure that growth and therefore yield, is not restricted from lack of precipitation or availability of ground water. At the same time, the presence of SRC should not so deplete the available water resource as to cause adverse hydrological impacts – such as seriously reducing aquifer recharge and/or stream flow, which may in turn feed weedlands, water meadows, or other fragile ecosystems.

- SRC willow uses more water than nearly all other vegetation and annually is only exceeded by mature coniferous forest. It uses an average 35-45% more water than similar arable area growing potatoes or cereals.
- Willow uses large quantities of water because of its rapid juvenile growth rates and a more rapid transfer of water vapour though the stomata.
- Total water use (evapo-transpiration) is a combination of transpiration (the largest component of water use determined by soil availability and rainfall) and interception and evaporation.
- On a clay site with 700mm rainfall, SRC will use 600mm compared to 400mm for barely and 650mm for pine forest.
- Water use will vary – in first year after harvest; it will be less than in subsequent years. However, in an area, this will largely be made more uniform by sequential harvesting operations and this should be encouraged.
- Average rainfall (estimated using a Swedish model) required over the growing season to meet fully the needs of SRC to produce an annual yield of12 t DM ha-1, is 550 – 600 mm. This equates to an annual precipitation level of1200mm. If annual rainfall is below this level, then, either yield will be reduced or large deficits of soil water will be produced on deeper soils.
- Interception losses (evaporation) are equivalent to 20% of rainfall in the third year of coppice growth. In comparison, most arable crops have interception levels of 15% or less. During the dormant period, these losses are reduced to 10-12%.
- Reduced aquifer recharge could be a serious issue in low rainfall years, where ground water becomes the major supply source. However, in NI, with half the average rainfall occurring in the growing season (500mm) and the unlikely situation of large areas of coppice in any particular catchment area, aquifer recharge is not seen as a major problem.
- In an area with annual rainfall of 600mm, if 1200ha of SRC was planted within a radius of 20km, the reduction in effective precipitations would be negligible (in the region of 0.5%).

Newer varieties with higher water use efficiencies are being looked for in breeding programmes. Reduction of edge effects, as in large block plantations, can reduce water usage. However, this is at variance with advice on landscape considerations and a compromise will have to be considered. However, again with the small-scale production and use envisaged in Ireland, this may well not be an issue.

APPENDIX 1 RENEW

Renewable Energy Networks for Environmental Welfare (RENEW)

RENEW was a cross-border, European funded (INTERREG IIIA) project to encourage the planting of SRC willow and its utilisation for heat production in a range of situations and organisations. There were fifteen collaborators including farmers, councils, colleges and science organisations. This was highly successful project co-ordinated by the Agri-Food & Biosciences Institute, which delivered on all of its objectives. Willows were planted in Counties Londonderry, Down, Tyrone, Antrim, Donegal and Louth. Wood-chip boilers were installed at Gartan Outdoor Centre, Co. Donegal, Cookstown Leisure Centre, Co. Tyrone, South West College (Omagh campus) and Omagh Council Offices, Co. Tyrone. At all of these installations there have been very significant economic and carbon savings. A new drying and storage shed for willow wood chip was built at a farm in Co. Louth and a new header for a willow harvester, a willow planter and a chip delivery trailer were purchased to improve the willow wood chip supply chain.

The Collaborators were:

Government Research and Development:

Agri-Food & Bioscience Institute (NI) and Department of Community, Rural & Gaelthacht Affairs (ROI)

Production and project management:

Rural Generation Ltd.

Local Councils:

Cookstown District Council and Omagh District Council

Colleges of Further and Higher Education;

South West College (Omagh Campus) and the Institute of Technolgy, Sligo

Housing Associations:

Rural Housing Association

Technical support: Delap and Waller

Outdoor Centres:

Gartan Outdoor Centre, Co. Donegal

Farmers:

McGuiness Brothers Co. Louth; James Cowan (Northern Bioenergy) Co. Tyrone;

John Martin (Gordonall Farms Co. Down; James Leslie Co. Antrim; Charles Henry Co Donegal; John Gilliland (Brook Hall Estate) Co. Londonderry; and George Mills Co. Donegal.

Aims

- Establishment and production of short rotation coppice (SRC) willow to provide a renewable energy fuel.
- For heat conversion in a range of boiler systems in NI and RoI.
- To co-ordinate production and consumption on a managed supply chain.
- To integrate public and private sector partners.
- To disseminate the outcomes to as broad an audience as possible.
- To evaluate SRC as a bioremediation system.

Project Objectives

Sewage sludge may be used in agriculture, provided that Member States regulate its use.

- By end 2008 to produce 2 megawatts of installed thermal capacity at a maximum of six locations, 3 in the Republic of Ireland and 3 in Northern Ireland.
- By end 2005 to establish 40 additional hectares of short rotation willow coppice in Northern Ireland and the Republic of Ireland.
- By end 2007 to integrate into the Project boiler sizes in the range of 25kW and 500kW thermal output.
- To provide an active dissemination of information through at least one organisation in the Republic of Ireland and one in Northern Ireland.
- To produce logistical and technical support for the producer and consumers involved in the Project.
- To carry out studies on the use of short rotation coppice as a bioremediations system and to demonstrate legislative compliance in both jurisdictions.

APPENDIX 2 LEGISLATION

It should be noted that whilst these are the main EC Directives involved in recycling wastes on Short Rotation Coppice willow their implementing legislation may differ in detail between member countries and always should be referred to before application. There are other significant areas of legislation such as The Ground Water Regulations, The Urban Wastewater Treatment Regulations, Environment impact - uncultivated semi-natural areas regulations, Shellfish and bathing waters Directives which are involved but relate more directly to specific situations.

The Nitrates Directive

Requires Member States to;

To apply agricultural Action Programme measures throughout their whole territory or;

To apply agricultural Action Programme measures within discrete Nitrate Vulnerable Zones.

An Action Programme consists of statutory measures of good agricultural practice, including:

- Limiting nitrogen fertilizer use to crop requirement only;
- Limiting organic manure use (170kg N/ha annually across the agricultural area is this figure still current?);
- Controlling the spreading period of nitrogen fertiliser and organic manure;

- Keeping adequate farm records; and
- Having sufficient slurry storage to comply with annual closed periods for spreading manure.

The Wastes Framework Directive

The WFD states that any establishment, or undertaking, which carries out waste disposal or recovery operations must have a permit (e.g. a waste management licence) or be registered as exempt from the need for a permit.

The Waste Management Licensing Regulations 2003 provides limited exemptions from licensing for the treatment of certain types of waste by spreading it on or injecting into land where this results in benefit to agriculture or ecological improvement. This might remove the need for a licence but would still involve registration and would be subject to other constraints e.g. quantity and quality of waste spread per hectare.

Agricultural benefit is assessed by reference to whether the application of sludge will result in an improvement of the soil for the purpose of growing crops and the relevant criteria for assessment will be;

- That the addition of total nitrogen is carried out in accordance with any requirements imposed in the implementation of an action programme under the Nitrates Directive.
- That the addition of nitrogen, phosphorus and other plant nutrients in the waste takes account of the soil nutrient status, other sources of nutrient supply and is matched to the needs of the planned crop rotation.
- That the addition of organic matter which improves the moisture holding capacity of the soil is a benefit.

Sludge Directive

Sewage sludge may be used in agriculture, provided that Member States regulate its use.

- The Directive lays down limit values for concentrations of heavy metals in the soil (Annex IA), in sludge (Annex IB) and for the maximum annual quantities of heavy metals which may be introduced into the soil (Annex IC).
- The use of sewage sludge is prohibited if the concentration of one or more heavy metals in the soil exceeds the limit values laid down in accordance with Annex IA. The Member States must take the measures necessary to ensure that these limit values are not exceeded through the use of sludge.
- Sludge must be treated before being used in agriculture but the Member States may authorise the use of untreated sludge if it is injected or worked into the soil.

The use of sludge is prohibited:

- on grassland or forage crops if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed (this period, fixed by the Member States, may not be less than three weeks);
- on soil in which fruit and vegetable crops are growing, with the exception of fruit trees;
- on ground intended for the cultivation of fruit and vegetable crops which are in direct contact with the soil and normally eaten raw. This is for a period of ten months pre- ceding the harvest of the crops and during the harvest itself.

The sludge and the soil on which it is used must be sampled and analysed.

The Member States must keep records registering the following.

- the quantities of sludge produced and the quantities supplied for use in agriculture;
- the composition and properties of the sludge;

- the type of treatment carried out;
- the names and addresses of the recipients of the sludge and the places where the sludge is to be used

APPENDIX 3 FURTHER READING

Crop Production

- Energy from Biomass – summaries of projects carried out in the Energy from Biomass project area of the DTI's New and Renewable Energy Programme 1998 – 2004, URN No. 05/1110
- www.dti.gov.uk/publications
- DEFRA Best Practice Guidelines Growing Short Rotation Coppice. DEFRA publications, Admail 6000, London 2002
- Tubby, I. & Armstrong, A. 2002 The establishment and management of Short Rotation Coppice – a practitioner guide. Forestry Commission Practice note – Forestry Commission Edinburgh.
- Danfors, B. Ledin, S. & Rosenqvist, H. 1998 Short Rotation Coppice Willow – Growers Manual. Swedish Institute of Agicultural Engineering ISBN 91-7072-123-8
- Boyd,J. Christerson, L. & Dinkelbach, L. 2001 Energy from willow. Booklet published as part of the REgrow ALTENER II Programme of EC. Published by SAC Edinburgh.
- Larsson,S. 1996 Willow coppice Short rotation forestry. Eds Murphy D.P.L. et al Semundo Ltd Cambridge.

- Bell, S. & Macintosh, E 2001 Short rotation coppice in the landscape. Forestry Commission Guideline Note 2 Forestry Commission Ediburgh.
- Rust diseases of Willow and Poplar. 2003 Eds. Pei M.H. & McCracken A.R. CABI. 2003 Publishing Oxfordshire, UK.
- Sage, R.B. (1999). Integrated Pest Management in Short Rotation Coppice for Energy - A Growers Guide. Game Conservancy Limited, Hampshire 30p.
- Willoughby, I. & Clay, D. 1996. Herbicides for Farm Woodlands and Short Rotation Coppice. Forestry Commission Field Book 14. HMSO London.

Utilisation, Bioremediation and Economics

- E4tech 2003 Biomass for heat and power in U.K. A techno-economic assessment of the potential of biomass energy in the U.K. to 2020 DTI Publication. www.dti.gov.uk/ publications
- Hasselgren, K. 2002 (SWECO VIAK AB).Short-rotation Willow Biomass Plantations Irrigated and Fertilised with Municipal Wastewater. Final report of EC FAIR Project. www.sweco.se/upload/bwcwslut.pdf
- Bioenergy crops and Bioremediation – A Review. A contract Report by ADAS for the Department of Environment, Food and Rural Affairs www.defra.gov.uk/science/ project_data/documentlibrary/nf0417_2072frp.doc
- Rosenqvist, H. & Dawson, W.M. 2005. The economics of willow growing in Northern Ireland. Biomass and Bioenergy 28: 1, 7-14.

Environmental Impact of SRC Willow;

- M.D., Bishop, J.D., McKay, H.V., & Sage, R.B. (2004). Arbre Monitoring - Ecology of Short Rotation Coppice. DTI Publication URN 04/961, 157pp
- Environmental Aspects of Energy Crops Proceedings of workshop in DTI's Biofuels Seminar Series. The Moller Centre Cambridge November 2001 Ed. N. Beale FES.

APPENDIX 4 CROP MANAGEMENT

PRESCRIPTION FOR WILLOW PLANTING -			
1	Glyphosate 360 (Roundup)	3 litres/hectare	Mid April
	Water	One sprayer application (200l/ha)	
2	Rabbit fence where necessary €0-€2.20/m x ?m		
3	Plough at least 14 days after Glyphosate + Durzban Spray		Early May
4	Power harrow, lift stones & level ground as soon as conditions allow before the end of April to make a stale seed bed. In heavy soils, stale seedbed not needed and planting can take place immediately. In this case go straight to item 7 on the prescription		
5	Leave stale seedbed for 6 weeks to allow weeds to germinate		
6	Within 48 hours before planting, burn off germinated weeds with		
	Glyphosate 360 (Roundup)	2 litres/hectare	
	Water	One sprayer application (200l/ha)	
7	Plant willows with step planter keeping soil disturbance to a minimum at a willow population density of 18,000 per hectare		
	NB: ALL WILLOW CUTTINGS MUST BE KEPT IN COLD STORE (-2 TO 4ºC) UNTIL DAY OF PLANTING		

8	Roll site keeping soil disturbance to a minimum		
9	ithin 14 days of planting, spray onto a moist soil a pre-emergence weed killer & pesticide for leatherjackets. A high water volume of 500 litres per hectare is essential to give a good coverage of chemical on the soil		Early May
	Stomp	3.3 litres/hectare	
	Flexidor 125	1.5 litres/hectare	
	Durzban	1.5 litres/hectare	
	Water	One sprayer application (500l/ha)	
10	May-August	Walk fields on weekly basis. Check for rabbit & leatherjacket damage. Monitor weed populations.	
11	February	Cut back willows not higher than 10cm using low ground pressure vehicle	
12	End March, early April	Before the willow buds start to burst open, spray with weed killer in dry weather.	
	Weedazol/Amitrole	10 litres/hectare (Rates may vary depending on active used)	
	Stomp	3.3 litres/hectare	
	Water	One sprayer application (200l/ha)	

PRESCRIPTION & COSTS FOR WILLOW PLANTING - GRASS LEA		
1	Pre-ploughing perennial weed control and leatherjacket control when weeds are actively growing. Preferably September, if not second week of April	
	Glyphosate 360 (Roundup)	4 litres/hectare
	Durzban	1.5 litres/hectare
	Arma	0.25 litres/hectare
	Water	One sprayer application (200l/ha)
2	Rabbit fence where necessary €0-€2.20/m x ?m	
3	Plough at least 14 days after Glyphosate + Durzban Spray	
4	Power harrow, lift stones & level ground as soon as conditions allow before the end of April to make a stale seed bed. In heavy soils, stale seedbed not needed and planting can take place immediately. In this case go straight to item 7 on the prescription	
5	Leave stale seedbed for 6 weeks to allow weeds to germinate	
6	Within 48 hours before planting, burn off germinated weeds with	
	Glyphosate 360 (Roundup)	2 litres/hectare
	Water	One sprayer application (200l/ha)
7	Plant willows with step planter keeping soil disturbance to a minimum at a willow population density of 15,000 per hectare	
NB: ALL WILLOW CUTTINGS MUST BE KEPT IN COLD STORE (-2 TO 4ºC) UNTIL DAY OF PLANTING		

8	Roll site keeping soil disturbance to a minimum	
9	Within 14 days of planting, spray onto a moist soil a pre-emergence weed killer & pesticide for leatherjackets. A high water volume of 500 litres per hectare is essential to give a good coverage of chemical on the soil	
	Stomp/PDM330	3.3 litres/hectare
	Flexidor 125	1.5 litres/hectare
	Durzban	1.5 litres/hectare
	Water	One sprayer application (500l/ha)
10	May-August	Walk fields on weekly basis. Check for rabbit & leatherjacket damage. Monitor weed populations.
11	February	Cut back willows not higher than 10cm using low ground pressure vehicle
12	End March, early April	Before the willow buds start to burst open, spray with weed killer in dry weather.
	Weedazol/Amitrole	10 litres/hectare (Rates may vary depending on active)
	Stomp	5 litres/hectare
	Water	One sprayer application (200l/ha)

WORSE CASE SCENARIOS		
1	For a bad thistle infestation	
	Water	One sprayer application (200l/ha)
	Shield	1/2 litre/hectare
2	For a bad perennial grass weed infestation	
	Water	One sprayer application (200l/ha)
	Falcon	1.4 litre/hectare
3	For slug infestation	
	Draza	Slug Pellets 5kg/hectare
		Application of Pellets

APPENDIX 5 ENERGY CALCULATIONS

Bulk Density and Storage of various fuels		
Material	Typical Bulk Density	Storage Space Requirements
	Metric	Metric
	t/m3	m3/t
Wheat	0.78	1.28
Barley	0.7	1.43
Oats	0.56	1.78
Softwood chip (Sitka Spruce) 45% moisture	0.28	3.57
Hardwood chip (Beech) 45% moisture	0.35	2.86
Softwood chip (Sitka Spruce) Dry Weight	0.15	6.66
Hardwood chip (Beech) Dryweight	0.19	5.26
Miscanthus bale (8x4x3)	0.13	7.69
Miscanthus chip	0.09	11.1
Willow Chip (25% moisture)	0.15	6.66
Wood pellets	0.65	1.54

Fuel cost comparison			
Fuel	Price per unit	kWh per unit	Cent per kWh
Wood chips (30% MC)	€120 per tonne	3,500 kWh/t	3.4 cent/kWh
Wood pellets	€200 per tonne	4,800 kWh/t	4.2 cent/kWh
Natural gas	4.6 cent/kWh	1	4.6 cent/kWh
Heating oil	€0.70 per litre	10.2 kWh/ltr	6.8 cent/kWh
Electricity	€0.14 cent/kWh	1	14 cent/kWh

ENERGY CONTENT OF DIFFERENCE BIOMASS FUELS AT 0% M.C				
	NCV		GCV	
	(GJ/t)	kWh/t	(GJ/t)	kWh/t
Soft	18,8	5.222	20,2	5.611
Hard	18,4	5.11	19,8	5.500
Willow (short	18,4	5.11 1	19,7	5.472
Straw of	17,	4.778	18,5	5.139
Straw of	17,	4.917	18,9	5.250
Cereals,	17	4.722	18,4	5.111
Rape.Se	26,5	7.36	28,1	7.806
Rape,	20	5.556	21,8	6.056
Cer eals	17, 1	4.75	18,4	5.111
Miscanth	17,	4.917	18,	5.028
Hay	17,	4.75	18,4	5.111

TYPICAL MOISTURE CONTENT OF BIOMASS FUELS AND CORRESPONDING CALORIFIC VALUES AS RECEIVED							
The GCV is only calculated for fuels with high moisture content.							
	GCV				NC		
	Moisture content %	kWh/kg	GJ/t	toe/t	kWH/kg	GJ/t	toe/t
Green Wood direct from the forest, freshly harvested	60%	2	7, 2	0,1 7	1,6	5,76	0,14
Chips from short rotation coppices after harvest	50-55%	2,5	9	0,21	2, 1	7,56	0,18
Recently havested wood	50%	2,6	9,36	0,22	2,2	7,92	0,19
Saw mill residues, chips etc	40%	3, 1	11,16	0,27	2,9	10,44	0,25
Wood, dried one summer in open air, demolition timber	30%				3,4	12,24	0,29
Wood, dried several years in open air	20%				3,4	12,24	0,29
Pellets	8-9%				4	16,92	0,
Wood, dry matter	0%				4,7		0,45
Silomaize	30%				4	14,4	
Rape seed	9%				7, 1	25,6	0,61
To compare with:							
Heating oil					4,1	15	0,36
Peat					2,8	10	0,24

APPENDIX 6 WILLOW PLAYBACK CALCULATIONS

Willow

Bank Interest (%)	6.00%	**1st Harvest**	25	**Subsequent harvests**	25		
General Inflation (%)	2.00%	Weight in DM / t per ha = 14.00		Weight in DM / t per ha = 20			
Energy Inflation (%)	2.00%	Weight 25.00 % moisture 18.67		Weight @ 25 % moisture 26.67		Per T/ DM	
Gate Fee (€/tonne)	0	Harvest Cost W.Stem				€29	
Price Per Tonne	€65.00	Compare to price of oil at	0.50	cent/litre Harvest	Whole Stem Harvest Cost D.Cut	€25	
Price (€/GJ)	€4.94	€13.62 per GJ			2 Drying Cost D.Cut	€30	
VAT Registered	Yes	Chipping Cost W.Stem				€10	
Bank Borrowings €/ha	1,292	over 5 years = 6.00%				€160	**Per Ha**

Costs per ha:	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**		
Operations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20		
Plough	75																					
Cultivate / Roll	91																					
Spray1	20	20		22		23		23		24		25		26		27		29		30		
Spray2	20																					
Plant	400																					
Spread Sludge	0																					
Harvest	0	30		€439		€653		€680		€707		€736		€765		€796		€828		€862		
Chipping	0			€202		€294		€306		€319		€332		€345		€359		€373		€388		
Drying	0																					
VAT (13.5%)	0.00	0.00	0	€0	€0	€0	0	€0	€0	€0	0	€0	€0	€0	0	€0	€0	€0	0	€0		
Sub-total	*606*	*50*	*0*	*665*	*0*	*970*	*0*	*1009*	*0*	*1050*	*0*	*1093*	*0*	*1137*	*0*	*1183*	*0*	*1230*	*0*	*1280*		
Annual land opertunity	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*		
Materials																						
Round-up (4 l/ha)	40																					
Weed Killer / insecticide/ beetle Ctrl	25			€163		€170		€177		€184		€191		€199		€207		€215		€224		
Selective herbicide (Stomp	58	40																				
Management Fee																						
Cuttings	1650																					
Fertiliser	0																					
VAT (21%)	0	0		€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0		
VAT cuttings (13.5%)	0	0																				
Sub-total	*1773*	*40*	*0*	*163*	*0*	*170*	*0*	*177*	*0*	*184*	*0*	*191*	*0*	*199*	*0*	*207*	*0*	*215*	*0*	*224*		
Total	**2379**	**90**	**0**	**828**	**0**	**1140**	**0**	**1186**	**0**	**1234**	**0**	**1284**	**0**	**1336**	**0**	**1390**	**0**	**1446**	**0**	**1504**		
Income:																						
Est. grant	1,088	363																				
Fuel sale		0	0	1,313	0	1,952	0	2,031	0	2,113	0	2,198	0	2,287	0	2,379	0	2,476	0	2,576		
Gate fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
EU Energy Payment	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Carbon premium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Total	**1,088**	**363**	**0**	**1,313**	**0**	**1,952**	**0**	**2,031**	**0**	**2,113**	**0**	**2,198**	**0**	**2,287**	**0**	**2,379**	**0**	**2,476**	**0**	**2,576**		
Start up loan	**1,292**																					
Loan Principle		**229**	**243**	**257**	**273**	**289**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
Loan Interest		**77**	**64**	**49**	**34**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
Total Repayment		**307**	**307**	**307**	**307**	**307**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
Net cash flow	**0**	**-34**	**-307**	**178**	**-307**	**506**	**0**	**845**	**0**	**879**	**0**	**915**	**0**	**952**	**0**	**990**	**0**	**1,030**	**0**	**1,072**	6718	335.9
Profit/loss	**0**	**195**	**-64**	**436**	**-34**	**795**	**0**	**845**	**0**	**879**	**0**	**915**	**0**	**952**	**0**	**990**	**0**	**1030**	**0**	**1072**	8010	400.48
Cum. disc. profit/loss	0	195	131	567	533	1328	1328	2173	2173	3052	3052	3967	3967	4918	4918	5908	5908	6938	6938	8010		
Mean annual	**0**	**98**	**44**	**142**	**107**	**221**	**190**	**272**	**241**	**305**	**277**	**331**	**305**	**351**	**328**	**369**	**348**	**385**	**365**	**400**		
Cum. Cash Flow	**0**	**-34**	**-341**	**-162**	**-469**	**37**	**37**	**882**	**882**	**1,761**	**1,761**	**2,675**	**2,675**	**3,627**	**3,627**	**4,617**	**4,617**	**5,647**	**5,647**	**6,718**		

Annual dicount rate	5.0%	
Annual land opertunity	0	**Note:** The higher the NPV (Net Present Value)the more viable the investment, negative NPV should not be entertaine Average Net Cash Flow
NPV (using int rate as disc)	€2,962	If the annual land opportunity cost is 0 and the discount rate is equal to the borrowing rate of interest available
Internal Rate of Return	24.0%	then the NPV is what could be paid for land purchased /ha over this time scale.

Contacts	Address	Web	E-mail	Telephone
Government				
Teagasc	Teagasc, Oak Park, Carlow	www.teagasc.ie	barry.caslin@teagasc.ie	Barry Caslin 059 / 9183413
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AFBNI		www.afbini.gov.uk	Alistair.mccracken@afbini.gov.uk	Dr. Alistair McCracken +44 (0)28 90255244
DAFF, Forest Service,	Agriculture House, Kildare Street, Dublin 2	www.agriculture.gov.ie/forestservice		01/6072000
DAF Biofuels Policy Unit,	Kea-Lew Business Park, Mountrath Road, Portlaoise.	bioenergy@agriculture.gov.ie		057/8692231 / 40
CAFRE	22 Greenmount Road, Antrim, Co. Antrim, BT41 4PU	www.cafre.ac.uk	nigel.moore@dardni.gov.uk	0044 (0)28 9442 6648
Sustainable Energy Authority Ireland,	Wilton Park House, Wilton Place, Dublin 2	www.seai.ie	pearse.buckley@seai.ie	01/8369080
Commercial				
Farrelly Bros / Timber Pro ,	Kieran Cross, Carnaross, Kells, Co. Meath	www.timberpro.ie	Info @timberpro.ie	046/9249392
Natural Power Supply (NPS),	Ballymountain, Ferrybank, Waterford	www.nps.ie	info@nps.ie	051/832777
Rural Generation,	Brookhall Estate, Derry	www.ruralgeneration.com	tom.brennan@ruralgeneration.com	0044 (0) 78 94411903
Biomass Energy Northern Ireland (BENI),	Countryside Services, 97 Moy Road, Co.Tyrone. BT71	www.biomassenergyni.com	jcmartin@biomassenergyni.com	0044 (0)78 08060037
Action Renewables Innovation Centre,	NI Science Park, Quenns Road, Belfast BT3 9DT	www.actionrenewables.org		0044 (0)28 90737821
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IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Italy, Netherlands, New Zealand, Norway, Sweden, UK, USA.

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