

SHORT ROTATION COPPICE WILLOW BEST PRACTICE GUIDELINES



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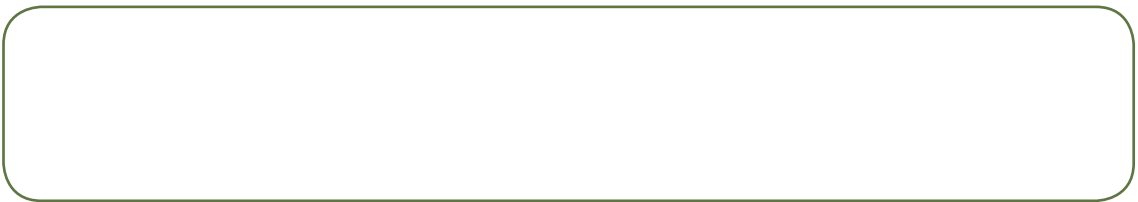
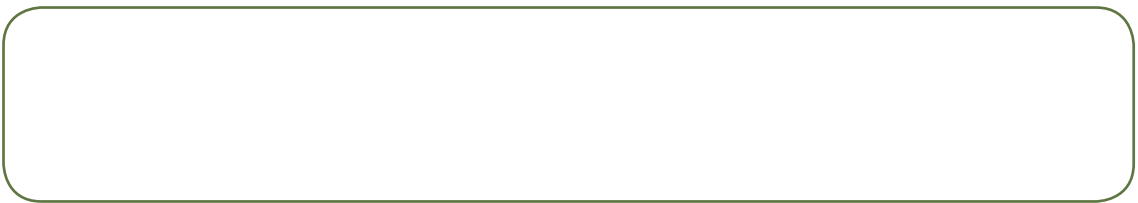

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Introduction

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 only providing 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 wide front involving all the relevant renewable energy technologies – wind, solar, hydro, photovoltaics, wave, tidal and ground and air source heat pumps.

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 that is ready for commercial deployment.

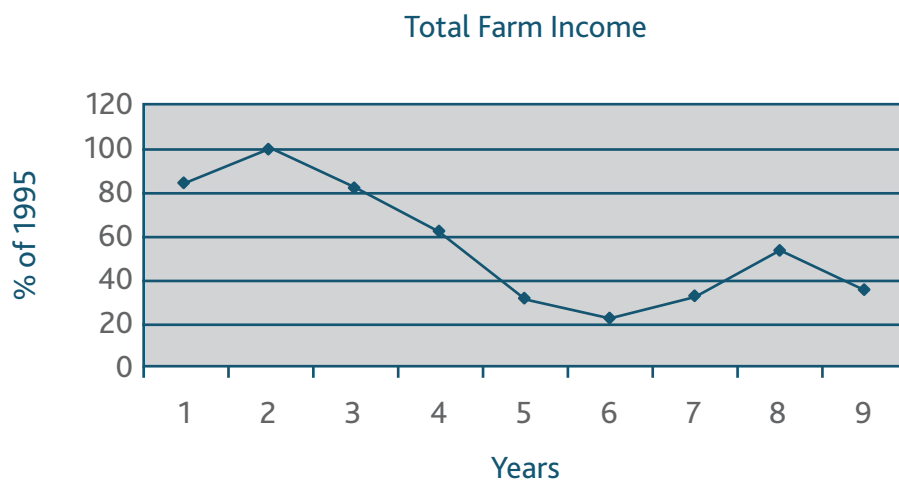
Renewable Energy

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

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 seed, 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 are successful or present practical problems in harvesting in particular.

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 6-7 meters 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. The coppice can then be removed and the land returned to conventional cropping.

A wide range of yields can be expected depending of 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 to 3300-5700litres of oil per hectare per year. Taking a snapshot in time with current prices of €0.45 per litre for light fuel oil this gives willow an equivalent energy value of €202 per tonne. It is achieving a price of just over €80 per tonne on the market in Ireland. Similarly (other comparisons) Oil prices are projected to continue to rise increasing the opportunity for wood to contribute to the energy market.

1.0 CROP PRODUCTION

1.1 Site Selection

Willow is not a demanding species in terms of its site requirements and 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 availability of water, light and temperature.

- Soils; most agricultural soils with pH in the range 5.0-7.0 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 9-1,100 mm 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.
- Temperature; Willow in its native environment is a northern temperate zone plant 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 further more 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, 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 8 m 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. Siting 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 they are unlikely to be a dominant landscape feature in any particular area. A 1% uptake in a catchment area with
- iv. A 20 km radius (acceptable delivery distance for coppice chip to a conversion plant) would provide 1200 ha or 15,000 tonnes of dry matter, sufficient for 2 MW continuous generation.
- v. 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.
- vi. 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.
- vii. 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.
- viii. 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.
- ix. 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 in September when weeds are still actively growing – 4.0-5.0l/ha Glyphosate. On grassland or setaside sites an application of 3.0l/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.

- On suitable soils the site can be ploughed and power harrowed and a stale seed bed prepared in mid-March six weeks before planting. The germinated weeds can then be sprayed off prior to planting using 2.0l/ha Glyphosate. 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 establishment. 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.

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 initiated by 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.
- 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.
- Commercially available varieties from European Breeding Programme include; Nimrod, Resolution, Discovery, Endeavour, Beagle, Terra Nova. Stott, and Parfitt
- All of these improved commercial varieties are protected by European plant breeder's 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.

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.
- Should 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 Northern Ireland's Department of Agriculture and Rural Development (now the Agriculture 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.

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°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 0.6 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 maximise 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.
- 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 emphasised 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 (e.g. Stomp at 5.0l/ha) 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 crane fly 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 -1.0/ha) for thistle

control and fluazifop-p-butyl (e.g. Fusilade at 1.5l/ha), cycloxdim (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 3.0l/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 knapsac sprayers.

- Following establishment and after cutback a further herbicide application will be necessary to keep the crop weed free till it achieves canopy closure usually in mid-summer of the second growing season. The use of the contact herbicide amitrole (e.g. Weedazol at 10-20l/ha) together with an additional application of residual herbicide – pendimethalin (e.g. Stomp at 5.0l/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 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 no 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 FERTILISATION

As with any crop, fertiliser, 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 coppice in the absence of any long-term direct information on fertiliser and yield, nutrient off-take in the harvested crop should be used in calculating fertiliser requirement. There is evidence that on moderate to fertile soils particularly in the early rotations there is not necessarily a positive response to fertiliser applications. Sites with a naturally poorer nutrient capital may need these early applications to maintain productivity.

- Fertiliser 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 fertiliser 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 a 10 – 12t 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 genotypes used in much of the trial work referred to and nutrient export levels are likely to be higher than those quoted.
- As many soils are well supplied with phosphate and potash (>Index 2 –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 fertilisers should only be calculated following soil analysis and should only be applied to balance removals.
- Many soils have excess levels of phosphorus. 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 phosphorus removal in the harvested SRC the P status of the soil may well be adequate in most circumstances.
- 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 180 - 405 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 and 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 fertilisers is heavily dependant on the input of fossil fuels and 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* sp) 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 is 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, phosphorus and 40kg, potassium per hectare per year. Unfortunately due to the nature of the crop and the available equipment the application of mineral fertiliser is not practically possible in commercial plantations except following harvest and before re-growth.

1.7 PESTS AND DISEASE

Leaf Rust (*Melampsora* sp.) 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 disease's alternate host – European Larch (*Larix decidua*) Development on the host willow is through repeated asexual cycling of urediniospores. This cycle can be as short as two weeks and consequently can lead to serious levels of infection very quickly on susceptible genotypes. 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* 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 genotype 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
- SRC Willow is seen as an environmentally acceptable crop and the intensive use of fungicides would not be acceptable
- 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:

- Evidence clearly indicates that where disease pressure is high, as it is in Ireland, the planting of single genotype plantations even where the genotype 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 genotype has become susceptible as the natural rust population has evolved resulting in severe losses in single genotype plantations.
- The yield of the improved genotypes from the breeding programmes in Sweden and the U.K. 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 genotypes are of *Salix viminalis* origin.
- Increasing diversity in mixtures can result in yield compensation where individual components of the mixture become susceptible to the disease and make increasingly smaller contribution to yield, It has been shown that in a mixture of ten genotypes the loss of up to 30% of its component genotypes can fully

compensate for the potential yield loss. Consequently at least six and preferably ten genotypes should be included in commercial plantations.

- Where genotypes 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 line 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 any individual component does 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

- There are three species of willow beetle involved with the blue and brown species more prevalent, - Brassy (green) willow beetle *Phratora vitellinae*, blue *Phratora vulgatissima* and brown *Galerucella lineola*).
- 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 were found from mid-May into July and developed through three instars before pupating. The new generation of adult beetles appeared 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 upper leaf surface larvae whilst the larvae feed on the underside of the leaf which eventually is skeletonised and turns brown. Unlike rust infections skeletonised 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.

Other Pests

There are 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 a quarter of an inch 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 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 stool, delay flushing and lead to increased weed competition. Consequently harvesting should be carried out on dormant stools. 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.

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.

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, leading 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.
- 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 less than 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 loosed 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 off the harvested rods takes place till early spring and over the following 8-12 weeks moisture levels will drop to approximately 30%.

- The quality of the chip produced from this dried material is likely to be lower than the direct chip harvesting method with a wider range of particle size and increased dust fraction. 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 as well as 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.

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.

- 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. Canopy closure or complete site capture usually happens in year two of the first cropping cycle on suitable sites 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.
- 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 their earlier choices.
- 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 and estimates of £8.00 - £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 60 °C within a short period. This results in a loss of calorific value and a general degrading and loss of quality in the fuel.
- 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 (6-10°C) 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 facilities could be provided and operated on a co-operative basis linked to the contact harvesting of the crop.

- 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 required due to the requirements of the process involved.

(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 till they are 30-50cm tall (mid-may)
- Willow is extremely susceptible to herbicide so a single application of a translocated herbicide (e.g. 5l/ha glyphosate) 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 logistical 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 envisaged as practical in Ireland the direct combustion technologies are largely available 'off the shelf', small-scale Gasification technologies have yet to complete their commercial development and Pyrolysis is still at the research and development stage.

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'.

- There are inevitably efficiency losses in all combustion systems but modern well maintained chip boilers will have 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 maximum transport distance should not be more than 20km. In this situation the energy balance will be in excess of 30:1

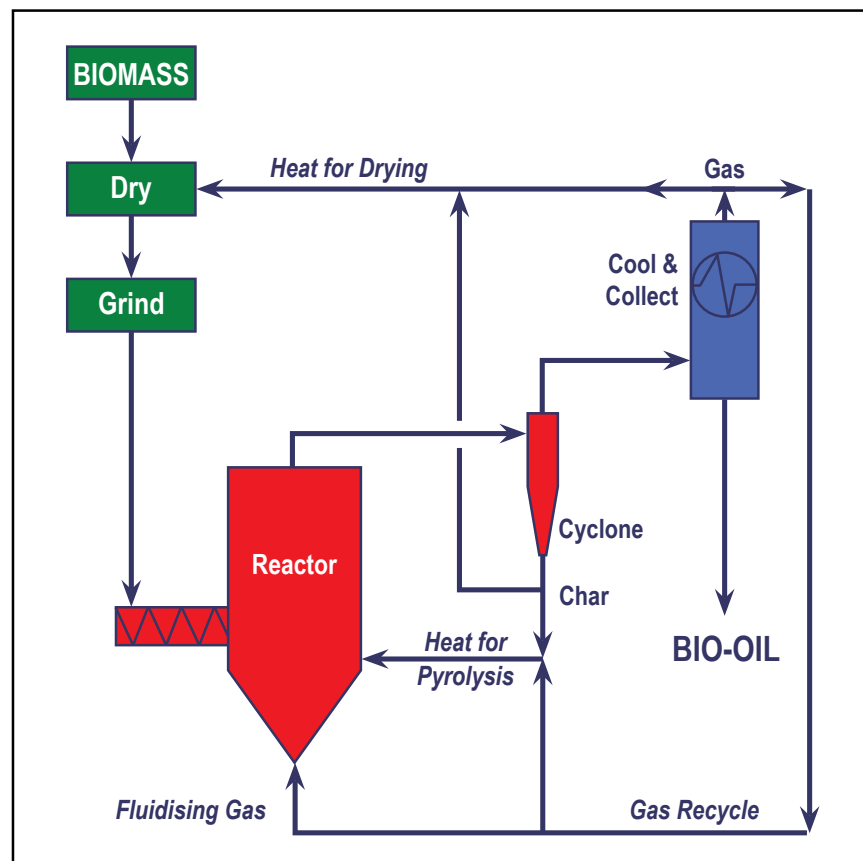
- There is a wide range of equipment available ranging in size from a few kilowatts to multi-megawatts. The generated heat can be used directly to produce hot water or air, or it can be used to raise steam to drive a turbine to produce electricity. However the capital cost of this latter application 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 boiler's 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 (approximately 16MJ/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 10% 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 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 volumes for wood chip will be approximately nine times the volume required to store light fuel oil with the same energy value and are 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 degrees 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.

- The gasses produced are cooled and cleaned and the combustion is completed in a standard internal combustion engine. Generally a compression – ignition (diesel) engine is used, as it is more tolerant of gas which is variable in nature. A small background of diesel fuel (10%) is used to assist with the gas combustion. This has the added advantage that where the supply of gas from wood is unavailable the engine can run on 100% diesel fuel.
- Where wood gas is used to fuel a diesel engine it will only deliver 75-80% of the power it would if fuelled with diesel.
- Small systems rated at 100-250kW electrical output have been developed but have not got to the point of commercial guarantee. The conversion to gas is relatively problem free but the cleaning of the gas from particulates and tars in particular to allow trouble free combustion in an engine has proved to be a more difficult problem.
- Efficiency figures for conversion to electricity using an engine and generator are only in the region of 25-30%. However if the co-generated heat is also used in a combined heat and power configuration the efficiency figure can be increased to 75-80%.
- 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.



Pyrolysis

This is a technology which is still in the research and development phase. It involves the heating of the wood chip at temperatures varying 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. 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.

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.

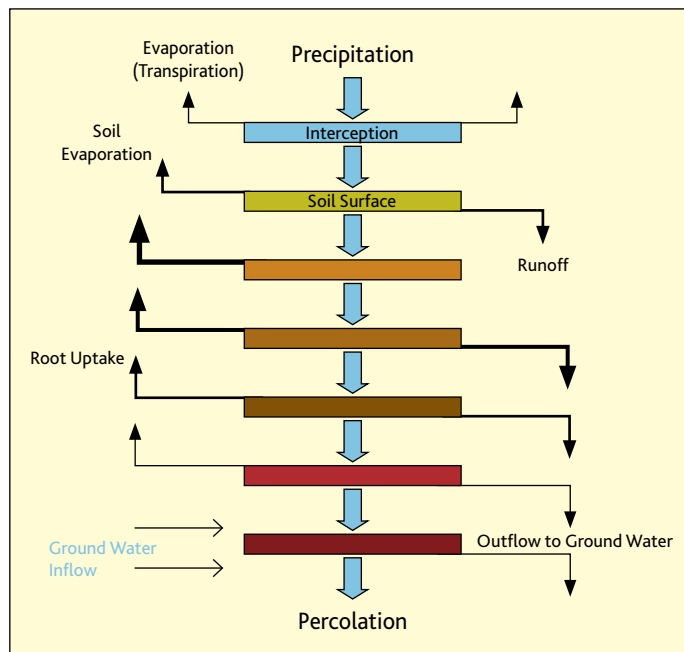
Willow is a particularly good species for the recycling (bioremediation) of dilute wastes for a number of reasons;

- Willow has a significantly higher water use than any other woody or arable species grown in Ireland. It has been calculated that willow coppice can use up to 1.0 million litres per ton 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 6 Nutrition and fertilisation Section).
- 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.
- P levels in soils in Ireland are high with many in excess of index 3 where natural leakage of P. into the ground water is already occurring. Sites for bioremediation should be of lower indices and here there is the possibility of applying phosphorus in excess of plant/crop removal with a slow resulting build-up of P index in the soil – calculations would have to be made on an individual site basis.
- Experience with municipal wastewater at experimental sites in Northern Ireland has indicated that rates up to three times calculated evapotranspiration can be used. Evapotranspiration is a measure of total water loss from the coppice system including evaporative losses from soil and plant surfaces and losses internally from the plant. Evapotranspiration in a SRC willow plantation in Northern Ireland, equates to 5 m l/ha during the growing season. At this level no detectable pollutant attributable to the wastewater could be detected in the ground water. With the wastewater used, application at calculated evapotranspiration (5.0ml/ha) provided 83 kg N, 56 kg P and 45 kg K.
- 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.

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

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 provide 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, re-use, reclamation etc; 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 COSTS AND ECONOMIC EVALUATION

Establishment Costs; These costs have been reasonably reliably established with a total of over 500ha of SRC having been planted in Northern Ireland during 2004 -2006. Review of these costs and comparison with costs in Sweden where a significant area in excess of 17,000ha exists shows a clear cost penalty for growers where the area established has not reached the economy of scale required to reduce costs. The establishment costs below are actual costs for 2007. (based on an exchange rate of £1.0 = € 1.51).

	€ / ha
Ground preparation Herbicide, Plough,& power harrow	€ 181
Mechanical planting	€ 980
Willow cuttings 15,000 cuttings/ha, carriage and cold storage	€ 1,132
Post planting rolling plus residual herbicide and leather jacket control	€ 230
Cut back, after first year's growth Reciprocating finger bar mower	€ 56
Weed and pest control Including post cut back herbicide and post planting leatherjacket control	€ 151
Total establishment costs	€ 2730 /ha

NB: Rabbit fencing may be required @ approximately €2.5/m The total cost for fencing should be calculated on a project-by-project basis, as it is dependent upon field size and shape and the local rabbit/hare population.

Approximate costs with fencing	€ 3,180/ha
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At the present time accurate economic forecasts are difficult for short rotation coppice willow as an energy crop for two reasons;

- there are relatively few established commercial plantations of coppice to provide accurate management and harvesting costs,
- it has been shown that pioneer producers of any new crop will incur increased costs

because of the absence of critical mass / economy of scale.

Accepting these limitations and excluding any support the gross margins for short rotation coppice willow production taking a yield of 10 tonnes dry matter annually and a return of €70/t DM are €130 – €150/ha/yr. These are hardly attractive figures given the normal conacre rental figures.

Gross margins for SRC Willow at a range of yields and returns per tonne of dry matter.

Yield t/ha DM	€ per tonne dry matter			
	€ 45	€ 60	€ 75	€ 90
6	- 151	- 77	- 3	71
8	- 128	- 29	69	169
10	- 104	20	143	267
12	- 81	68	216	364
14	- 57	115	263	462

However if the establishment grant of approximately €2,800/ha available in Northern Ireland under the SRC Challenge Scheme and the EU energy crop subsidy of €45/ha are factored in then the gross margin increases €419/ha/yr. At this stage in a developing industry this illustrates the need for support to achieve at least a nucleus of the industry to allow economics of scale to take over.

The economics of the crop can be considered in another way viz. the costs of production versus the energy equivalent value of the crop.

Assuming

- 25 year growing cycle – 8 harvests
- Av yield 10t/ha/yr DM
- Drying €13t (50% DM-20% DM)
- Establishment £2000/ha
- Harvest (every 3 yrs) yield 36t @80% DM) €600/ha
- Management cost of €370/ha (after each harvest)
- Root removal – site restoration €740/ha

Production costs can be estimated at €47.6/ t DM

Production Costs (€/t Dry Matter)		€	Energy Equivalent value	
Establishment		9.8	Light fuel oil	€456/t
Harvesting		15.4	Energy content of Light fuel oil.	40 GJ/t
Drying		11.2	Energy content of biomass	19 GJ/t Dry Matter
Restoring Site Management		2.8 8.4		
Total		€47.6/t	Biomass energy equivalent value	€214/t

On this basis the fuel for a heating system could be supplied from biomass at 40% of the cost of the light oil alternative. There are however significantly higher capital charges for the biomass boiler system but with the reduced fuel costs the payback period is short.

Short rotation coppice systems also provide an opportunity to recycle organic wastes such as sewage sludge and wastewater using the Coppice system as a vegetation filter (bioremediation). This not only effectively removes the polluting nutrients in the waste materials but also provides the background nutrition for the crop.

The use of the crop for bioremediation has a significant effect on the return that can be expected from the crop. This has been calculated below as net farm income (figures from Rural Generation Ltd Londonderry).

Net Farm Income €/ha/yr *

Sale price €/t	- Estab Grant	+Estab Grant	-Estab grant +3 Sludge	+Estab Grant +3 Sludge
60	-214	233	675	1,025
106	236	539	981	1,330

- No land opportunity cost
- No Farmer income
- 7 years (Establishment + 3x2-year rotations)
- €33/t gate fee for sludge recycling

These figures again show the necessity of an establishment grant to allow the area to expand to the point where economy of scale starts to reduce costs. It also clearly shows that adding value to the crop by attracting gate fees for the recycling of wastes has a

major impact on the economic sustainability of the crop.

3.0 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 beetles) and for Melapsora 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 effects 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 till 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.

3.1 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 seed bank after planting followed by short lived perennials often aggressive weed species and then long lived perennials of a higher nature conservation value and stress tolerant.
- Coppice established on ex grassland sites 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.

3.2 Invertebrates

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 phytophagous species).

- Earthworm sampling records a decrease on numbers under SRC though this may change in longer established plantations and evidence from Germany records significant increase 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.

3.3 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.

- In an intensive study in Castlearchdale in County Fermanagh, 44 species of birds were recorded over a 4 year period. Many did not hold territories and were records 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) most important in terms of numbers in SRC and edge habitats were Blackbird, Dunock, Meadow Pippit, 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.

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 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.

3.4 Mammals

SRC could provide valuable small mammal habitat 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 unlikely to be attracted to SRC – lack of 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 density planted coppice stands. This is less of an issue in Northern Ireland with the small scale planting envisaged.

3.5 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.

- S.R.C. willow uses more water than nearly all other vegetation and annually is only exceeded by 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 through the stomata.
- Water use is a combination of transpiration (the largest component of water use determined by soil availability and rainfall) and interception and evaporation - evapotranspiration.
- On a clay site with 700 mm rainfall SRC will use 600 mm compared to 400 for barley and 650 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 a crop of 12 t DM ha⁻¹ annually totals 550 – 600 mm – corresponding to an annual precipitation level of 1200 mm. If 1200 mm not available either yield will be reduced or large deficits of soil water will be produced on deeper soils.
- Interception losses (evaporation) 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 consideration where because of low rainfall ground water is the major supply. However in NI with half the average rainfall occurring in the growing season (500 mm) 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 600 mm if 1200 ha of SRC was planted in an area with a radius of 20 km 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 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;

1. To apply agricultural Action Programme measures throughout their whole territory or;
2. 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 fertiliser use to crop requirement only
- Limiting organic manure use (170kg N/h annually across the agricultural area)
- Controlling the spreading period of nitrogen fertiliser and organic manure
- Keeping adequate farm records
- 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 for a period of ten months preceding 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 2 Glossary

Calculations made on the basis of:

- £1.00 = € 1.51
- 28Sec oil 31p/l
- 1.0kg wood @0% moisture =19MJ
- 1.0kg wood chip @ 30% moisture = 14MJ
- 1.0l oil 42 MJ

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

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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.

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Rust diseases of Willow and Poplar. Proceedings of an International Symposium. Belfast, Northern Ireland 11-13th September 2003. Eds. Pei M.H. & McCracken A.R. CABI. 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

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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.



