Final Report

Helyg i Gymru

Willow for Wales

1 March 2004 - 31 December 2008

The Development of Sustainable Heat and Power fuelled by Biomass from Short Rotation Coppice Willow in Wales.

http://www.willow4wales.co.uk/

The Development of Sustainable Heat and Power Fuelled by Biomass from Short Rotation Coppice Willow in Wales

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The report, together with updates and a related report on 'The biodiversity of short rotation coppice in the Welsh landscape' by Danielle Fry and Fred Slater of Cardiff University, will be available on the above website.

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[1] IBERS was formed in April 2008 following the merger of the Institute of Grassland and Environmental Research with Aberystwyth University's Institute of Rural Studies and the Institute of Biological Sciences, with the support of BBSRC and WAG.

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EXECUTIVE SUMMARY

"We will harness the sun and the winds and the soil to fuel our cars and run our factories." (Barack Obama 21st January 2009).

While the primary drivers of bioenergy are concerned with climate change and to a lesser extent energy security, bioenergy offers many opportunities for business development and job creation and for sustainable forestry and agriculture. Several studies have shown that more local jobs are created by biomass technologies than by any other renewable energy technologies. It has been estimated that 300,000-550,000 jobs could be created in the biomass supply chain in Europe by 2020, though these estimates probably need revising.

It is clear that a range of biomass resources, including energy crops, will be required if there is to be a continuous supply meeting projected demand. The high potential for job creation upstream of primary production of biomass suggests that policy makers need to take account of the needs of the whole economy, the needs for renewable energy and sustainable rural and urban development. Even so, the agricultural sector itself may benefit by greater diversification in the face of risks faced by the industry

It is against this background and the realisation of the need to diversify Welsh agriculture in the wake of a devastating foot-and-mouth epidemic that the Helyg i Gymru – Willow for Wales project was set up in 2004 to demonstrate and monitor production from short rotation coppice willow across Wales.

CHAPTER 1 considers the factors affecting suitability of SRC for growing in Wales. It describes the selection, establishment and management of commercial farm sites, their harvesting, drying and storage and the monitoring of yields. It highlights that willow is suited to a wide range of land conditions across Wales and explains that there are few insurmountable technical barriers to willow production. Local planting and harvesting machinery would reduce costs and make logistics easier. It emphasises that good weed control is essential to maximise yield. It discusses the logistical and financial implications of not having a local source of planting material or planting and harvesting machinery and highlights the potential benefits of developing co-operative groups.

Most respondents in an anonymous survey of growers involved in the project found involvement in the project very useful and intended to maintain the willows planted on their farms. Furthermore, they would increase their involvement with energy crops if there were a planting grant and technical support. Even though SRC willow is not currently rewarded by current agri-environmental schemes, respondents saw environmental value as the main attraction of growing willow. Half of the respondents saw home energy use as an attraction. All respondents considered difficulties with Single Farm Payment as a drawback of growing SRC willow, even though such difficulties should not exist.

The chapter highlighted that further research and development would be justified on

- weed control based on reduced herbicides, minimal cultivation and the use of mulches or cover crops
- harvesting machinery and systems better suited to marginal areas and small fields
- Drying and storage

CHAPTER 2 considers the environmental impacts of production of SRC in Wales. It highlights significant reductions of carbon emissions through the use of biomass for heat and power and for next generation lignocellulosic biofuels. It can be calculated that 0.461-0.646 Mt of C equivalents, about 30-40% of the total emissions from Welsh agriculture, would be saved per 100,000 ha of energy crops in Wales. This does not take into account the substitution of methane from animals (about 40% of total agricultural emissions). These are much higher reductions than those that could be obtained from annual biofuel crops.

SRC plantations could effectively be used to reduce nitrogen runoff, particularly if plantations were used as buffer strips along watercourses. The use of energy crops (particularly willow) in phytoremediation of contaminated soil and water is an important environmental benefit.

Monitoring of biodiversity on the farm sites by the Wales Biomass Centre demonstrated SRC in Wales to be an important resource for invertebrates, birds and mammals. Inclusion of SRC in any future agri-environmental schemes could be justified by its value for carbon mitigation and sequestration, the delivery of environmental goods and services such as clean water and air and positive impact on biodiversity.

CHAPTER 3 addresses the identification of the best varieties adapted to Welsh conditions such as low temperatures, higher rainfall, greater wind speeds and lower fertility. If only those few varieties that have been developed for lowland England are tested, the best varieties for Welsh conditions are likely to be missed.

Sixty-three native willow clones have been collected from various altitudes. These represent a major Welsh resource in terms of adaptation to cold, wet, windy and marginal conditions. It opens up the possibility of developing breeding populations for selection for greater adaptation to Welsh conditions, in partnership with an existing willow breeder.

CHAPTER 4 considers wider supply chain issues**.** It presents the results of a new economic model for SRC willow production based on levels of actual inputs obtained in the Willow for Wales project costed at 2007 levels (Valentine et al, 2008), showing that attractive returns can be obtained but a kickstart is needed to overcome the initial high costs of establishment. The importance of fair and transparent production contracts to supply chain members is also considered in this chapter.

CHAPTER 5 outlines the scale of demand for energy crops for heat and power, in particular the needs of end-users at different scales involved in the Willow for Wales consortium.

It has been estimated that by 2010, there will be a demand for 130MWe and 285MWh, requiring 1.5 M t of biomass, rising to 230MWe and 500MWh requiring 2.5 Mt of biomass in 2020 (Jones, 2007). These amounts cannot be met by forestry and recycled timber alone and will either have to be imported or grown on Welsh farms. A recent assessment of the Welsh wood fuel industry's views on the current market concluded that competition between energy customers for biomass materials is beginning to take place (Horne & MacDermott, 2007).

CHAPTER 6 summarises the project's technology transfer activities and its participation in consultations.

Farms were used for real 'touch–and–see' demonstration events to inform farmers and others on the role of renewable energy sources in mitigating CO_2 emissions, how to grow willow, likely returns, end-uses and benefits to biodiversity. The balance of attendees at Open Days switched from being dominated by people with a general interest in green energy when we held events in 2004 to later being dominated by land owners.

During the life of the project, the team gave nine presentations at national and international conferences.

CHAPTER 7 A number of issues that act as barriers to take-up by farmers and the development of robust supply chains are highlighted in the concluding chapter. Good scope is identified for industry to develop supply chains and for supply chain participants, particularly heat and power generators and crop developers, to seek Convergence or government support for planting and harvesting machinery and infrastructure.

INTRODUCTION

Why Bioenergy?

Global warming is the major environmental problem of our time. It is generally accepted that increased carbon dioxide and other greenhouse gases are its major cause. The evidence for this includes the close association between the rise in emissions and the rise in global temperatures, and the understanding of the mechanism of the greenhouse effects in terms of the enhanced trapping of infra-red radiation which warm the atmosphere. Raised carbon dioxide levels are derived from the use of fossil fuels (coal, oil and gas) which convert the past fixation of carbon to energy.

Long-term fuel security has also been cited, particularly in N America, as another driver for the replacement of fossil fuels.

The necessary reduction in emissions over the next 50 years has been visualised as a stabilisation triangle, in which reduction is achieved through the use of a series of 'stabilisation wedges' such as energy efficiency, the retention of carbon sinks in forests and soils, carbon capture and sequestration and the use of renewable energy (Pacala and Socolow, 2004). Renewable energy is in turn divided into a number of technologies, such as wind, marine, photovoltaics and bioenergy. A mix of technologies will be needed in order to achieve at least a partial reduction of greenhouse gas emissions.

While the primary drivers of bioenergy are concerned with climate change and, to a lesser extent, energy security, bioenergy offers many opportunities for business development and job creation and for sustainable forestry and agriculture. The job creation potential of biomass is considered later.

Biomass resources

It is clear that a range of biomass resources will be required if there is to be a continuous supply meeting projected demand. Biomass resources include

- Forests – low grade small roundwood, forest operation residues, arboricultural arisings, wood processing co-products
- Short-rotation forestry including agro-forestry and dual purpose stands
- Perennial energy crops – Miscanthus and possibly reed canary grass; short rotation coppice, mainly willow but possibly poplar, potentially ryegrass
- Annual energy crops – cereals, oilseed rape, sugar beet
- Wastes or co-products – straw, animal manures, municipal waste, recovered wood wastes e.g. pallets
- Marine or freshwater biomass – as yet largely untapped
- Imports

Project aims and background

It is against this background that the Helyg i Gymru – Willow for Wales project was set up in 2004. Its aim was to demonstrate and monitor production from short rotation coppice willow (SRC) as the raw material for a sustainable and renewable energy from biomass industry across Wales. We deemed that any development needed to be appropriate to Wales' unique landscape and agriculture, cultural heritage and tourism industry.

The suitability of SRC willow (mainly *Salix viminalis*, the osier willow and *S.alba*, cricket bat willow) as a perennial energy crop lies in its fast-growing nature, ability to coppice, its deciduous habit allowing harvest of 'dry' matter and recycling of nutrients and its high content of lignin, cellulose and hemicellulose.

The project was funded by European Region Development Fund through the Wales European Funding Office with matched funding from the Welsh Assembly Government Pathways to Prosperity and SMARTCymru funds and Industry (as part of the Economic Regeneration of West Wales and The Valleys Objective 1 Programme). The Programme aimed to increase economic activity and jobs particularly in peripheral rural areas of Wales and to raise incomes nearer to the UK average. The project was concerned with pump-priming demonstration and stimulation of the economic and wider value of cleaner and renewable energy from SRC willow biomass. We sought to obtain information under commercially realistic conditions which would be relevant to the whole biomass supply chain.

The project reflected the actions recommended by the Welsh Assembly Woodland Development and Biomass Strategy Group (WDBSG) and adopted by the National Assembly in plenary. It is an eligible activity in terms of support for the exploitation of renewable energy sources (with priorities including biomass energy generation), with knowledge links to Industry and to universities researching biomass gasification and pyrolysis (through the £11m EPSRC Supergen project).

In the face of decreasing subsidies for sheep and in the wake of the 2002-03 foot-and-mouth epidemic, WAG policy as recognised by "Farming for the Future" was that Wales needed to develop alternative enterprises which will have major benefits for Welsh farm incomes and safeguarding and creating jobs and healthy communities. Employment opportunities could be created inside and outside agriculture - for instance, in the harvesting machinery, planting material suppliers, haulage, plumbing and equipment sectors.

The project is a unique UK model of how to develop an energy crop supply chain. It contrasts with the Arbre project, in which farmers were encouraged to plant SRC willow for unproven conversion technology.

Among a range of activities, this report will

- describe the establishment and management of commercial farm blocks of SRC willow
- summarise the use of variety trials to identify genotypes adapted to Welsh conditions
- present results of an economic model using varying yields and prices and levels of actual inputs obtained in the project
- highlight the case for inclusion of SRC willow in a new generation of agri-environmental schemes
- comment on the development of commercially viable supply chains for end-users at different scales.
- describe extension activities delivered through the Grassland Development Centre at IBERS and consortium members that have delivered key outcomes and messages targeted at a broad spectrum of audiences from farmers and landowners to industry stakeholders and policy makers.

Some of this work has also been published as Valentine et al (2005), Valentine et al. (2008), Duller and Valentine (2008) and Fry and Slater (2008).

What's happening elsewhere in the UK?

Significant plantings of willow have been made elsewhere in the UK. Between 2001 and 2006, the cumulative planting of SRC had reached 1180 ha. A further 1420 ha of plantation have been approved for 2007 making a cumulative total of 2600 ha producing SRC under the Energy Crops Scheme (DTI 2006). Including the planting applications obtained under a number of different grant schemes across the UK, the total area of SRC planted under all grant schemes may be considered approximately 6000 ha. The vast majority of SRC plantations under such schemes may be assumed to comprise of willow. (http://www.tsec-biosys.ac.uk/index.php?p=8&t=1&ss=2)

Between 2001 and 2006 the cumulative planting of Miscanthus had reached 3356 ha. This area will nearly triple in 2007 with approved planting for 2007 making a cumulative total of 12627 ha producing Miscanthus (DTI 2006). (http://www.tsec-biosys.ac.uk/index.php?p=8&t=1&ss=4).

Much of the plantings have been undertaken by Renewable Fuels Ltd, a partner to this project. They have offices in Yorkshire serving the Drax power station and in Edinburgh serving the 44MW E.O.N. dedicated biomass plant at Stephen's Croft near Lockerbie. Co-firing at Drax uses SRC originating from 1,100 ha of SRC grown locally by the Producer Group, Renewable Energy Growers (http://www.draxgroup.plc.uk/media/press_releases/?id=1438). The Lockerbie plant is largest dedicated biomass plant in the UK. It is fuelled by sawmill co-products, recycled fibre and 20% willow from 4000 ha of locally grown short rotation coppice (EPSRC, 2008). The Wilton power station (30MW) in Teeside also uses willow from 3400 ha of SRC.

The job creation potential of biomass

A report by ADAS (2003) considered the impact of different renewable energy technologies on rural development and sustainability in the UK. Based on a number of case studies, the report concluded that there were significantly more local job opportunities associated with biomass than wind or hydropower.

BERR (2008) stated that ‘biomass offers the greatest potential for job creation among all the renewable technologies. A switch from traditional food crop production to non-food biomass production can potentially help reduce the decline of jobs in agricultural regions. It is estimated that Europe-wide, over 300,000 jobs could be created from biomass fuel production by 2020 (source: EC Altener study)’.

A briefing note produced by the Energy Saving Trust updated in 2007 states that according to the DTI, biomass offers the greatest potential for job creation in Scotland of all the renewable technologies. Most technologies create jobs during the construction phase. However, for biomass there is a considerable amount of employment during the operations phase (6.5 jobs per megawatt, compared to 0.1 for wind and 0.5 for photovoltaics). It states that a switch from traditional food crop production to non-food biomass production can potentially help stall the decline of jobs in agricultural regions.

Thornley, Rogers and Huang (2008) have quantified job creation potential using technical, economic and environmental assessments to compare fuels, scale and technologies. Significant employment impacts of bioenergy plants were identified, with 25MWe plants typically creating around 160 FTE positions during the lifetime of the plant, much larger than the 20 or so people directly employed there.

Several of these reports cite the Altener II project study reported in 1997 in which 300,000 jobs could be created from biomass fuel production in Europe by 2020 and the EUROFORES 1999 study which calculated that by 2020, 515,000 new jobs might be created throughout Europe in the biomass fuel production chain alone.

It should be noted that the agricultural labour requirements for energy crops is estimated at 0.001 FTE positions per hectare for SRC and 0.0014 for Miscanthus (Thornley, Rogers and Huang,2008). The comparable wheat reference case is 0.01, an order of magnitude larger than the energy crop figures. So a substantial number of agricultural jobs are being displaced. The significance of this depends however on the sustainability and profitability of the existing agricultural enterprises and the value that one places on diversification (Martin Turner, Exeter University, personal communication). In the latter context, the spiralling costs of controlling animal diseases such as BSE, TB, Foot and Mouth, Avian Flu and Blue Tongue, the perceived health risks (coronary heart disease and bowel cancer) associated with high meat consumption and future political pressure requiring Welsh farms to be carbon neutral may need to be taken into account. These are not trivial issues. Recently the UK government has been unable to compensate Welsh farmers for losses of income due to the foot and mouth epidemics, put at

£40m. Red meat consumption may also reduce with dietary advice aimed at improving human health calling for consumption of leaner meat and smaller portions. A recent global report on cancer recommended limiting red meat consumption to 500g per week. Lastly, ruminants such as sheep and cattle are responsible for 42% of total Welsh agricultural greenhouse gas emissions.

The high potential for job creation upstream of primary production of biomass suggests that UK and Welsh policy makers need to take account of the needs of the whole economy, the needs for renewable energy and sustainable rural and urban development. Even so, the agricultural sector itself may benefit by greater diversification in the face of risks faced by the industry.

CHAPTER 1

Production of SRC willow on farms in Wales and monitoring of yields against Forest Research's database

This chapter will consider the main factors that govern the suitability of SRC willow for Wales, the establishment of commercial farm blocks, site selection, plantings in 2004, 2005 and 2006, harvesting, drying and storage, monitoring of yields by Forest Research, non-energy uses of SRC, the provision of local employment and results of a farmer questionnaire.

The suitability of SRC willow for Wales

The main factors are

- Altitude and related factors

Yield productivity of forest species in the uplands has been well studied in Sitka spruce following decades of afforestation. Following early work by Mayhead (1973), Worrell and Malcolm (1990) reported that the variables of elevation, temperature and windiness accounted for 72-78% of the variability in productivity and that productivity declined on average by 3-4 m^3 ha^{-1} yr^{-1} for every 100m increase in elevation. Wind exposure is affected by aspect, elevation, topex (geomorphic shelter), valley shape and valley direction.

Upland areas generally have later spring growth and earlier autumn conditions. The difference in growing season can be about four weeks. However, at higher sites there may be fewer pests and disease burdens and greater rainfall whereas yield in lowlands is affected by lower summer rainfall or perhaps higher rainfall during the period when root growth is critical.

Being broadleaved, SRC is likely to be more affected by exposure to wind than Sitka spruce which has needle shaped leaves more resistant to desiccation and other stresses.

Figure 1.1

This site established at 300 metres has to contend with thin stony soils as well as significant exposure to wind

While most SRC trials have been undertaken at lower altitudes (less than 200 m), Heaton (2000) used an area in ADAS Pwllpeirian, Cwmystwyth, Ceredigion (above Devil's Bridge) at 365 m for her studies. The site, which we now would clearly recognise as unsuitable for willow production, rated as severely exposed (tatter flag rate of 14.97 cm^2 per day estimated). None of the neighbouring hills offered any shelter. The site is seasonally waterlogged, with an acid organic surface layer (approx 30 cm) overlying a clay loam (15 cm). The native vegetation was rush and *Molinia*, on which one would not now be allowed to plant willow, and the site would also be deemed too wet for machinery. Old willow varieties including Jorunn were used.

A maximum yield of only 2.25 oven dry tonnes (odt/ha/yr) was obtained in the third year. This would hardly be economic. Heaton noted that rainfall and temperature sum were higher and the growing season longer than in Swedish studies where yields of up to 14 odt/ha/yr had been reported. Wales was warmer and wetter but in this instance lack of growth was due to severe wind exposure leading to damage and desiccation of growing points. Soil acidity and waterlogging may also have been major factors.

- Soil conditions

SRC can be established on a wide range of soils. The ideal soils are sandy or clay loams (Defra 2002) which can be described as medium textured, well aerated but hold a good supply of moisture (Tubby and Armstrong, 2002). More specifically, the information based on 49 trials throughout the UK (Armstrong 1997) suggested that heavier brown earth soils with high clay content and often gleyed below 40 cm were well suited to SRC. A rootable depth of 30 cm is desirable (Tubby and Armstrong, 2002). Peaty soils are unlikely to be suitable as they are likely to become waterlogged which decreases production and are unable to hold the weight of harvesting machinery. In addition, disturbing such soils is likely to release sequestered carbon.

Work at Cranfield has examined the growing of willows on restored soils. Martin and Stephens (2005) demonstrated that growth was greatly reduced on Oxford clay landfill cap soil and that production was unlikely to approach that on good agricultural soils. They reported that it might be possible to rectify nutritional deficiencies of Oxford clay by using end-products of the landfill industry such as composted municipal green waste or landfill leachate. Irrigation with the latter, as part of a leachate management system, would reduce the effects of water stress on biomass production during dry periods and lower the volume of leachate needing to be stored or treated. However, this has not been tested under field conditions and is likely to be impractical in the SSAs. Nor would upland areas seem suitable hydrologically for application of sewage sludge.

The usual recommendation for fertiliser application is that none is needed in the initial establishment year. Root systems are small in the establishment years – one would only be fertilising weeds and causing competition problems. Willow has a low demand for nitrogen (N) and the current recommendations are 40, 60, 100 kg/ha N / yr in years 1, 2 and 3 after cutback (Johnson 1999), rates being reduced where the soil has high N levels from previous cropping or a high soil organic dry matter level. In practice, it is difficult to apply fertiliser in year 2 and impossible in year 3.

- Acidity

The recommended range of pH is fairly broad, from 5.5 (acid) to 7.0 (neutral).

- Weed control / competition

The Defra Growing Guidelines indicate the importance of weed control in order to establish willow. This is achieved by use of one or two doses of glyphosate-based herbicide in the summer/ autumn and if necessary an additional application in spring before planting. A pre-emergence residual herbicide is then applied 3-5 days before planting.

Glyphosate is a very effective and cheap contact herbicide which destroys a critical enzyme in plants. It is translocated within plants, making it a very effective control of rhizomatous perennial weeds such as couch grass. After 2-3 weeks, the plants yellow and die. Some plants may escape if the herbicide runs off or the sprayer misses part of its target.

Figure 1.2

Areas untreated with residual herbicides (left of picture) can soon develop significant weed burdens

Other weeds are annuals. Even in a long-term grass ley, seeds of arable weeds lie dormant in the seed bank. When the soil is cultivated, light activates these seeds.

Willow biomass, with its minimal input needs and inherent environmental benefit, has something to offer organic farming systems. However before uptake on organic farms can be implemented, innovative non-chemical weed control methods need to be developed. Developing a premium market for ‘organic willow’ is unlikely to be available so from a policy perspective work is also needed to ensure Organic Farming Scheme payments would be available to growers. This would also have immediate and useful implications for ‘conventional’ willow cropping by further reducing inputs and minimising environmental impact.

- Diseases and pests

Melampsora rust is the most important fungal disease of SRC. It is manifested as orange pustules on the leaves which reduce green leaf area. The disease competes for nutrients. Some modern varieties have genetic resistance. This is a major objective of research associated with the breeding programme at Rothamsted Research. However, rust populations are able to evolve and overcome resistance. For this reason, SRC willow plantations are planted as random (intimate) mixtures of at least five genetically different varieties. This protects existing resistances and in the event of disease, slows the epidemic down so that high levels do not build up until it is too late in the season to affect yields. There is some evidence that yields in mixtures are increased in the absence of disease, presumably because different varieties occupy slightly different ecological niches.

There is a school of thought that varieties should be planted in blocks so that underperforming varieties can be replaced with superior varieties as they are produced by breeders. This could be unsafe in the event of disease and if recommended rather than leaving the grower with choice, could possibly lead to legal action. It is understood that planting in blocks could jeopardise the Defra planting grant in England.

Willow is also host to a variety of insects. Most of these are tolerated and good for insect and bird biodiversity. Kendall et al, (1996) showed that removal of leaves in August, simulating damage by leaf-cutting beetles, had little effect on yield whereas removal of leaves in June reduced yield by 40%.

Willow crops are frequently colonised by a range of aphid species, particularly from late summer onwards and feed on the sugars in the stems through until winter. Control is recommended if the crop is experiencing any significant stress (e.g. water, weed competition or spray damage) then if aphids develop in large numbers. Pirimicarb or lambda-cyhalothrin can be used effectively on young crops. More mature crops will generally cope with aphids unless under extreme drought or waterlogging.

Figure 1.3

Giant willow aphids (*Pterochlorus viminalis*)

Establishment of commercial farm blocks

Hitherto, SRC trials have involved relatively small blocks in parts of fields. These tend to over-estimate actual commercial yields and give very little information on effects on the whole farm enterprise and the environment.

The 'normal' methods for growing willow are outlined in Growing Short Rotation Coppice (Defra 2002) http://www.defra.gov.uk/erdp/pdfs/ecs/src-guide.pdf Establishment and Management of Short Rotation Coppice (Tubby and Armstrong, 2002) and the Willow4Wales Guide to Growing Short Rotation Coppice Willow http://www.willow4wales.co.uk/documents/willowsforwales2.pdf .

The most popular planting machine currently used for establishing SRC is a step planter which cuts a slot and plants a 15 cm cutting vertically into a seed bed in a double row arrangement with 0.75 m between rows, 0.59 m between plants in a row and 1.5 m between double rows to allow access for cultivation and harvesting machinery, giving a planting density of 15,000 plants/ha. Without 15 cm depth of cultivated ground, the willow cuttings are likely to be damaged and left proud of the soil at planting – being prone to desiccation and with poor establishment success. An alternative is a lay flat planter which does not require full cultivation but lays the willow rods in a single furrow. The success of this lay flat planter would be compromised by surface debris. Both machines are tractor mounted and carry a planting team of two people. Neither machine can operate satisfactorily or safely on rough terrain or on steeply sloping ground.

Site selection

The search for potential growers began in advance of the project start date with an awareness campaign promoted through farmer meetings, agricultural events and the farming press. Following this initial campaign and expressions of interest, a meeting was organised at IBERS to provide further details about the project aims and objectives and the level of commitment required from project growers.

The uncertainties surrounding the qualification of SRC for Single Farm Payment were responsible for a lack of interest amongst farmers in 2004. This period of CAP reform resulted in farmers being reluctant to change activities for fear of compromising their entitlements.

Thirty farms were visited to assess their suitability. Many were rejected as being too small, too sloping, too wet, or having a high habitat value. Very few dairy farmers were interested in the project, despite a very poor milk price at the time. Without the recognition of SRC as habitat they felt that establishing an area of willow would hinder their chance of entering either Tir Cynnal or Tir Gofal schemes.

Several organic farmers expressed an interest. Because of the lack of time ahead of planting in 2004 and hence of lack of time to establish stale seed beds, none was chosen.

There were a significant number of non-farming land owners and smallholders that expressed an interest in joining the project. Because of the key target of assessing the impact of SRC on the whole agricultural business, in terms of labour requirements (for example), and the demands that we felt involvement in the project would place on producers, these were also rejected.

Site selection also considered the geographic spread of the sites across a range of areas (N and S Wales), different altitudes, contrasting soil conditions and a range of farm types.

Details of the sites that were selected for the project are contained in Appendix 1.

Plantings in 2004

As a result of a delayed start to the project, we were only able to plant three of the eight farms in 2004. Concerns of farmers over the Single Farm Payment and cross-compliance were a major difficulty in the identification of farms. One farmer withdrew at a late stage in 2004 despite assurances that both SRC willow and Miscanthus are multi-annual energy crops eligible for energy aid and the Single Farm Payment (EC Council Regulation Nos. 1782/2003 and 795/2004). Time was also taken up with obtaining environmental consents and processing of the first applications for Woodland Grant Applications relating to SRC willow.

In contrast to the advice from Defra (2003), spraying off the areas for planting was carried out in the spring rather than starting in the previous autumn. This actually fits better with the need of livestock farmers for winter grazing. An area of 4.77 ha was planted at Bodorgan in Anglesey, and two areas planted in Pembrokeshire of 10.00 and 5.86 ha at Narberth and a contrasting wetter site at Hayscastle, near

Haverfordwest, respectively. The site at Narberth was near the Bluestone holiday village development in which a biomass boiler became operative in 2008. The area in Anglesey had been in long-term set-aside with a significant amount of creeping thistle, dock, mare's tail and rushes. The three sites were sprayed with glyphosate @5l/ha in early May. At Bodorgan, excess vegetation was burnt off. At Narberth, a wetter area and an area of archaeological interest were excluded.

Competitive quotations for cuttings and planting were obtained in order to meet EU Procurement legislation. Equal quantities of willow rods were obtained of willow rods of Tora, Tordis and Sven from Agrobransle via Renewable Fuels Ltd and Ashton Stott and Resolution from Murray Carter Ltd in order to plant 20 ha of intimate mixtures of five varieties. Varieties were chosen on the basis of limited evidence on past performance and genetic diversity. Farmers did not wish to gamble with unproven varieties.

A major and stressful complication was that cuttings have to be taken before bud break and stored at $-3^{o}C$. This of course needed early as possible decisions on areas to be planted and which varieties and suppliers to use. In order to lessen costs and simplify movement of cuttings, we hired two refrigerated containers for a two month period. It was very difficult, however, to handle pallets in these containers. The length of the rods on pallets is too long to manoeuvre pallets in sideways and pallets were extremely difficult to handle lengthways. Normal containers are too low for fork lifts to enter and we were unable to stack pallets using pallet handlers.

Renewable Fuels Ltd planted the two sites in Pembrokeshire in mid-May. Coppice Resources Ltd planted the Anglesey site in late May. Individual farmers were responsible for all cultivations and sprays with advice from the project. It is clear that planting at a distance is not only more difficult to co-ordinate but carries additional costs of transport and subsistence, let alone the costs of weather delays. This emphasises the need for local investment.

Planting was generally successful at Narberth and Hayscastle, with 1.7 m to 2 m growth of trees by mid-August 2004. We were advised that cutback was not necessary at Narberth as trees had 3-4 good stems, but in retrospect cutback in 2005 would have allowed control of thistles and hastened canopy closure. The site was cutback in 1st February 2006 as a demonstration of willow harvesting using a modified header on a self-propelled Jaguar forage harvester, an event which attracted over 50 local contractors and machinery specialists. The harvested material was sheeted (with a chimney for ventilation) to protect the chip and encourage drying. The chip progressed through a phase of producing white mould and had reached a moisture content of 29% from its initial starting point of around 50% by 6 July 2006. This material was actually used as mulch at Bluestone project, following planning delays in the development of the project. Such non-energy use would not have been possible if this site was claiming Single Farm Payment and Energy Aid, though now we gather that from 2009, energy aid or contracts will not be necessary in order to claim Single Farm Payment.

Weed levels were high at Bodorgan, and to a lesser extent, Hayscastle. Spraying the Bodorgan site with clopyralid @ 1 l/ha in June 2005 to remove spear thistle resulted in herbicide damage to the willow. There was a clear pattern of damage in 6 m strips up and down the field, with intensity increasing across the field. It was deduced that blockages in the spray lines caused high rates of delivery on the central 6 m of the 12 m boom width. The outer 3m of each boom in turn received reduced levels of spray and weed competition was therefore unchecked resulting in poor crop performance. Actual plant mortality was low – new growth has emerged from the scorched/twisted stems. The result was that affected plants averaged only 0.5 m in height as opposed to unaffected plants at over 1.2 m in September. It was felt that the crop was too underdeveloped to be cut back in 2005, although a small strip cut with a disc mower showed a good response in terms of producing more stems and better canopy structure. There was still a significant weed burden at this site in 2005. The site was cutback with a drum mower in February 2006 and sprayed with amitrole (10 l/ha) in late March 2006.

Figure 1.4

Willow crop at Hayscastle three years after cutback

This site on Anglesey was fairly patchy due to poor soils and drainage and the top end of the field suffered from heavy couch grass problems. The site had massive variation: both in terms of crop performance and crop structure. We originally intended to harvest this site in March 2008, but this was prevented by wet weather. There was standing water in many areas of the field. Once harvested, it will be possible to excavate and find out if willow roots have been responsible for blocking drains. A 60 cm deep open field ditch removed some standing water and further ditches were dug in order to harvest this site in winter 2008-09.

At Hayscastle, mob stocking with ewes in late December 2004 and mid January 2005 was used to reduce the volume of grass weed with no damage to the willow. The whole crop was sprayed with a mixture of graminicides in early February 2005. Control was fairly effective but weeds recovered to necessitate cutback in February 2006 and spraying with amitrole in late March 2006.

Plantings in 2005 and 2006

Four further sites were planted in 2005. In order to simplify planting, only one supplier and planting team was used. On the basis of results of replicated trials (see Chapter 3 and Hinton-Jones and Valentine, 2008), cultivars Stott and Resolution were replaced by Inger and Torhild in the mixture of varieties planted. It was hoped to plant earlier in 2005 but a series of delays created logistical difficulties that would be difficult for individual growers to cope with. The last revision included the news that the expected six row planter would not be available and that each site should have a tractor with 88 inch wheel spacings available to use with the four row planter.

An area of 4.4 ha was planted at Glynlliffon College, Caernarvon in mid-May 2005. This followed a forage maize crop in 2004. Crop growth was good in its first year although there were areas of the site that had significant grass weed cover. The crop was cutback in February 2006 and treated with amitrole to control the grass a week later. Two upland sites in Denbighshire – Cernefed, Cyffylliog (350 m) and Cilgoed, Derwen (300 m) of 3 ha each were planted on mid-May 2005. Both followed improved grassland. Crop growth was generally good at both sites. Crops were cutback in spring 2006 and sprayed with amitrole in April 2006.

An area of 3.3 ha was planted at Brigam, near Bridgend. This also followed improved grassland and was the only site where rabbit-proof fencing was judged necessary. Wet soils after planting prevented rolling. Spraying of a residual herbicide 10 days after planting on a hot day followed by a cold night and three weeks of no rain significantly damaged the emerging crop. This spray damage coupled with rapidly drying soils meant a crop survival of less than 20%. This necessitated re-planting in late April 2006. Following growing and grazing of turnip rape and autumn and spring cultivations, the site was relatively weed free without the use of sprays. A mixture of Torhild, Tora, Tordis, Inger and Goodrun was planted in late April 2006 using a two row planter from John Turton in Eastbourne. The planting machine produced a series of problems and an establishment success of only around 60% due to poor placement or cutting damage by the machine. About 0.8 ha was planted by hand, with a 90% establishment rate. Over the winter 4.0 man days were spent filling in gaps (‘gapping up’).

These four sites were due to be harvested in autumn 2008 but exceptionally wet summer and autumn conditions prevented harvest before the end of the project at the end of December 2008. (The original end of the project was 28 February 2009 but WEFO requested that this be brought forward in order that the paperwork associated with Objective 1 funding can be put together). The final yields achieved at the sites will be posted on the Willow4Wales web site.

Whilst maize growers were able to secure a derogation allowing them to harvest in poor conditions, there could be no such allowance for willow harvest. The standing willow crop was left until soil conditions improved so that cross-compliance regulations that govern the protection of soil quality and soil structure were not breached.

Since the project officially finished in December, this necessitated transfer project monies under contracts to the two Machinery Rings in Wales (Pembrokeshire Machinery Ring and Cadwyn Cymru/Link Wales) so that they could finance contractors to harvest crops when ground conditions improved. This process was also complicated by the fact that harvesting machinery has to be transported from England and be supplemented with locally sourced tractors and trailers. Quotes had to be obtained from harvesting companies and for the use of local tractors and trailers. Contingency funding was allocated to protect against delays due to breakdowns or adverse weather conditions.

Herbicides

Given the very high importance of achieving adequate weed control, one member of the project team (Chris Duller) undertook BASIS training. A synopsis of chemical weed control is given in Appendix 2.

Harvesting, drying and storage

The current standard method of harvesting SRC willow is by using a self-propelled forage harvester with a specialised cutting head produced by modifying a maize header (see www.claas.com and www.coppiceresources.com) that can cope with stems as large as 10cm diameter. This advantages of the method are that it uses existing technology to harvest with a high work-rate (1-2 ha/hr) and produces a uniform chip that can be easily handled, stored and transported to suit to a variety of end users. The modifications required to the standard maize header cost around £20K. Such investment can only be justified by a significant area of willow. Accordingly, there are only a few harvesting machines in the UK and none in Wales. All of the machines are currently linked to companies like Coppice Resources and Renewable Fuels Limited.

While machines can be hired to harvest anywhere in the UK, the lack of local machinery is seen as a major barrier to Welsh growers. Transport of machinery adds significantly to harvest costs and adds logistical difficulties and inflexibility. If a major end-user is looking to source energy crop material from Wales, it will have to look at ways to address harvesting and the procurement of machinery.

The disadvantages of the forage harvester with a modified maize header are its inability to cope with slopes and wet soils and the practical difficulties of operating the machine and associated tractors and trailers in small fields. There are other machinery options in existence, including a reaper/bundler machine that harvests whole rods, and a modified sugar-cane harvesters that produces short billets (see Smart and Cameron, 2008, for instance). These machines are very scarce, and do not represent the long-term harvesting option in the UK. It was felt in this project that there was little benefit to be had by using a machine that was unlikely to be available for future harvests.

In February 2006, a forage harvester with a modified maize header from Renewable Fuels Ltd was used to harvest the crop at Narberth. The event was used to demonstrate the machinery to local contractors and machinery dealers. It took two days to harvest the 10 ha site and provided an early opportunity to assess work rates and logistics.

Figure 1.5

Harvesting at Narberth in 2006 with a modified maize header

Two of the project sites were located on the edge of a large afforested area in North Wales, the Clocaennog. With a combination of slopes and wet soils making harvesting with a maize harvester impractical, it was decided to investigate the potential of utilising local forestry machinery to harvest willow. In November 2008, a standard forestry header was used at Cilgoed to cut and stack the willow stems, the stems were then baled using a forestry brash baler and extracted road-side with a forwarder (a standard forestry machine used to extract timber to the roadside. The work rate of the header was incredibly slow compared to a maize harvester, averaging less than 0.4 ha/day. To prevent uprooting the stools, the harvester has to grab and cut each stool individually, before presenting the material in a way to facilitate easy baling. The baler was able to work at a faster rate, 1.5 ha/day. The costs and time of such operations make it impractical for economic harvesting of SRC. In addition, there would be significant potential for soil damage with the repeated trafficking of harvester, baler and forwarder despite the machinery being designed to operate in marginal areas of slopes and wet conditions. It should be noted that cross-compliance does not apply to forestry.

Figure 1.6

Harvesting at Cilgoed site with forestry harvester

The Cernyfed site was cut by hand (with chainsaws and clearing saws) and presented for the baler. A team of two men (one chainsaw, one labourer) was able to cut 0.2 ha/day. The harvesting costs were less than by machine, and there was no machinery damage to the soils. However with the upland sites producing relatively low yields, the costs of using such a harvesting system can only be justified with longer rotation and a greater yield/ ha. The practical issues associated with harvesting by hand would be important to investigate given the interest from the rapidly developing domestic chip boilers. Many landowners are keen to grow small areas of willow for their own use, in areas too small to justify mechanised harvesting.

Figure 1.7

Baling willow with forestry baler

It can be seen that there is a need to develop machinery that is better suited to marginal areas and small fields than the maize harvester and more economic than forestry machinery. The project team had discussions with a small firm of machinery manufacturers, Richard Smalley International, about developing a tracked machine designed to cope with marginal areas. Whilst we thoroughly applauded the concept of a tracked machine that can cope with harvesting sloping sites, we perceived issues with creating a machine with enough throughput capacity and harvesting speed to make it economic.

Harvesting with the modified maize header costs over £450/ha (including tractors and trailers) to harvest material worth around £1000/ha (25odt x £40/t). Any tracked machine would need to be able to harvest at least 1 ha per day to present a breakeven economic option without taking the establishment and other costs into account.

Following the experience with the forestry header and baler, there would appear to be scope to develop a tractor mounted machine to cut and present the willow in a more ergonomic manner than either the harvesting head or by hand. The practical difficulties are to cut the stems so that they fall away from the standing crop, and to cut in a manner so that the roots are not damaged or pulled.

The reliance on specialist machinery for harvesting, and the potential for soil damage and compaction from winter harvesting with harvester and trailers is a significant barrier to potential growers. For many, there would appear to be significant benefits in growing Miscanthus as opposed to willow, with harvesting being carried out with standard mowers and balers that are common place on most farms. If the recent wet autumns and winters are to become more commonplace, then mechanised willow harvesting may be one of the largest obstacles to widespread uptake of SRC willow.

Willow harvested after leaf-fall has a dry matter of between 50% and 55%, with some variability existing between varieties. This water content presents problems in terms of transport costs and energy conversion efficiencies and high water content chip will be unsuitable for many end-users. The storage of woodchip will generate significant heat which can reduce moisture contents towards the target of 35%. There remains little information as to best practice for storage to produce a dry, mould free chip whilst minimising dry matter loss.

The chip harvested from Narberth in 2006 was stored under plastic sheeting (with ventilation to allow moisture to be driven off). Initially there were concerns about the young material being of high green wood: white wood ratio, leading to heating and mould development. In the event, the concerns appeared unjustified. After 16 weeks storage, the chip had dried to below 40% moisture, though drying was not uniform throughout the heap. Because of the developments at the Narberth site, the heap was moved and re-sited. This process caused further heating. Whilst creating a more uniform dry matter, there was evidence that a composting process was beginning to occur. More work in this area is needed.

Forced drying of the chip in grain stores has been suggested as a solution to producing a more acceptable feedstock. With a small arable sector, Wales is poorly serviced with dryers and the only realistic forced drying option would be the development of purpose built handling facilities.

Monitoring of yields

In the mid 1990's, a large number of SRC trials were established across the UK in an attempt to provide information on the interactions between site conditions and the growth rates of a range of willow and poplar varieties. Seven sites were established in Wales. In order to compare the productivity of the sites used in the Willow for Wales programme with these earlier experiments, small plots were established following the experimental design devised as part of the earlier work. Data was collected from these trials and used to estimate annual productivity.

<u>Experiment design and management</u>

Three willow varieties were planted in each research area;

Jorunn	*Salix viminalis* x *Salix viminalis*
Germany	*Salix burjatica*
Q83	*Salix triandra* x *Salix viminalis*

Although these varieties are likely to be less vigorous than the more modern clones used in the main demonstration plantations, they will enable direct comparisons of annual yield to be made with results from the network of site/clone interaction trials previously managed by FR.

A randomised block design was used at all sites established. Each variety was planted in 3 monoclonal plots at each site. Plots were marked out with labelled stakes. The planting design followed the 'twin row' system used in commercial SRC plantations. Each plot contained 10 rows planted with 10 cuttings. Spacing between rows was alternately 1.5 m and 0.75 m with 0.9 m between cuttings within the row, giving 9875 cuttings per hectare. Assessments were carried out on the innermost 36 stools of each plot, ignoring the two outermost rows, to eliminate edge effects.

The planting density was low compared to that currently used commercially but conformed to that used by FR at previous SRC trials designed to test site/clone interactions and give yield information. Planting material was taken from a well established SRC trial at Talybont near Brecon, (2 year old shoots on 9 year old stools), just before bud burst. Cutting length was approximately 25 cm and minimum cutting diameter was 10mm. Cuttings were cold stored prior to planting by hand.

The experiment sites underwent the same ground preparation, weed and pest control operations as the main demonstration plantations. Unlike the demonstration areas, cuttings were not rolled in following planting. As willow cuttings are very sensitive to weed competition in the planting year, additional chemical and manual weed control operations were carried out after planting to provide as near to weed free conditions as possible. Chemicals used included:

Propyzamide – 'Kerb'	– used to control grasses.
Propaquizafop – 'Falcon'	– used to control grasses.
Clopyralid – 'Dow Shield'	– used to control annual broad leaved weeds.

On a commercial scale, it is likely to prove too costly to maintain weed free conditions. Instead a trade off between financial input and reduced growth in the first year has to be made. It is likely that the sites used in this programme have a very large seed bank as most had been left uncultivated for a number of years. Fences were erected around the experimental plots to keep sheep, hares and other browsing mammals out. Some of the best chemical weed control was seen at Brigam and is shown in Figure 1.8.

After the first growing season ended, any shoots taller than 50 cm were cutback to 10 cm above ground level to encourage coppicing and early canopy closure. Dead cuttings were removed and replaced with two new cuttings. The coppice was then left to grow on for the remainder of the trial period.

Figure 1.8

Excellent weed control at Brigam, August 2005

At the end of each growing season two assessments were carried out in the trial plots. The first assessment measured the diameter at 1m above ground level of each shoot on each of the 36 assessment stools in each plot at each site. This measurement, referred to as 'D100', was used as an explanatory variable of yield. This measurement point was chosen as it can be conveniently recorded in the field, is non-destructive and has been successfully used in previous yield estimation projects. Data was collected using digital callipers equipped with software designed for the plot layout used here (see Figure 1.9). The second assessment was less intensive and aimed to provide data that could be used to investigate the relationship between D100 and shoot dry weight. This entailed measuring D100 on 10 shoots of a chosen site/variety combination. These shoots were then cut from the stools, comminuted and oven dried at 100^{O}C until a constant weight was achieved. This destructive assessment was carried out using shoots selected from the guard rows of the chosen site/variety combination. At the end of the first growing season following cutback, dry weight data was recorded from samples collected at Narberth, Bodorgan and Hayscastle. Samples from one willow variety were measured on each site (Jorunn, Q83 and Germany respectively). Ten dry weight and D100 observations were taken on each site/variety combination. In subsequent years destructive samples were taken from other site/variety combinations. Both assessments were based on a methodology developed by Forest Research under previous contracts.

Figure 1.9

Masser Digital callipers used to collect shoot diameter measurements

The full protocol for biomass assessment of short rotation willow coppice plantations and methods used for model development and translation of stem diameter measurements (D100) to stem dry weight are shown in Appendix 3.

Results from the yield estimation exercise are presented in Tables 1 – 4. Productivity varied considerably between sites and varieties. Germany was not productive at any of the sites in the first year but recovered at Brigam to produce yields equivalent to around 8 odt /ha / year by the end of the third growing season. Germany was the least suitable variety tested: the five least productive sites and variety combinations included this variety. Jorunn was the most versatile variety tested, by the end of the third growing season, it had produced yields equivalent to 8 odt/ha at Glynllifon, and Cilgoed and 13 odt/ha/year at Brigam. This site and variety combination was the most productive tested. Q83 was very productive in the first year of growth following cutback at Hayscastle but did not sustain this in subsequent years.

The most productive sites were Brigam in South Wales and Glynllifon in the North West. Both sites were at low altitude, Brigam being 65m above sea level and Glynllifon 150 m above sea level. Brigam had been used as sheep pasture prior to establishment and has been amended with paper waste before SRC was established. The site at Glynllifon had been used to produce forage maize prior to establishment with SRC and was anticipated to produce good willow yields despite the relatively high stone content of the soil and problems with competitive weeds in the first year. In practice, each of the varieties tested produced between 7 and 8 odt/ha/year at Glynllifon, suggesting that this was perhaps the most suitable site tested for SRC production in this project. The two most marginal sites tested, Cernyfed (350 m above sea level) and Cilgoed (300 m above sea level) were surprisingly productive. Q83 produced around 5 odt/ha by the end of the third year at both sites whilst Jorunn produced around 8 odt/ha at Cilgoed and 5 odt/ha/year at Cernyfed. No results were available for Narberth Farm in the 3rd year as those plots were damaged by the road servicing the Bluestone project.

The sites at Narberth, Hayscastle and Anglesey were all capable of producing yields of around 5 or 6 oven dry tonnes per hectare per year by the end of the third growing season. At the end of the fourth growing season, this had increased to around 7.7 oven dry tonnes per hectare per year for Q83 at Bodorgan and Hayscastle and for Jorunn at Narberth Road. This suggests that yield in the second rotation is likely to be higher than achieved in the first. This trend has been widely observed in previous studies and in commercial plantations.

As the D100 diameter assessment only records shoots taller than 1m, data from this assessment can be used to estimate survival. From Table 2, it can be seen that at least 85% of Jorunn stools were producing shoots over 1m tall at all sites in all years and that at least 89% of Q83 stools were performing to the same standard. Germany stools were not as reliable as the other varieties tested. There was no large variation between sites.

Tables 3 and 4 show that Q83 and Jorunn produced similar numbers of shoots per stool at most sites and that both varieties produced more shoots per stool than Germany. At most sites, Germany produced shoots that were of smaller diameter than those produced by the other varieties tested. This is also reflected in the lower yields achieved by Germany.

Table 1.1. Summary of yield after cutback (oven dry tonnes per hectare) for each site and variety tested.

Site	Germany				Jorunn				Q83			
	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year
Bodorgan	3.3	6.1	10.8	22.4	4.6	8.9	12.6	26.5	6.6	12.0	16.2	33.9
Hayscastle	3.0	6.5	10.7	21.2	8.4	9.8	13.7	21.5	10.7	13.8	16.8	30.8
Narberth. Farm	2.1	2.4			10.9	9.1			8.8	10.4		
Narberth. Road	4.5	4.4	7.4	20.1	12.6	11.4	17.9	30.6	8.6	12.1	18.1	22.4
Brigam	2.4	7.8	25.4	N/A	9.5	26.4	39.1	N/A	8.1	22.2	22.3	N/A
Glynllifon	2.1	9.4	20.7	N/A	3.9	12.4	24.0	N/A	2.9	10.5	21.8	N/A
Cernyfed	1.4	0.8	4.6	N/A	3.9	9.8	15.2	N/A	2.3	3.6	14.0	N/A
Cilgoed	0.6	1.2	10.0	N/A	3.0	11.5	24.1	N/A	1.8	7.2	15.0	N/A

Table 1.2. Percentage of stools producing shoots over 1m tall for each site and variety tested.

Site	Germany				Jorunn				Q83			
	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year
Bodorgan	93	83	86	88	96	88	91	89	100	97	100	100
Hayscastle	87	65	73	78	98	90	94	92	100	97	100	99
Narberth. Farm	88	76	N/A	N/A	97	85	N/A	N/A	99	96	N/A	N/A
Narberth. Road	99	87	91	93	100	95	98	99	98	95	98	98
Brigam	86	94	93	N/A	97	100	100	N/A	94	97	97	N/A
Glynllifon	91	99	99	N/A	97	100	99	N/A	97	100	100	N/A
Cernyfed	78	88	91	N/A	96	100	100	N/A	94	100	100	N/A
Cilgoed	79	98	98	N/A	97	100	100	N/A	89	93	93	N/A

Table 1.3. Summary of shoot diameter (mm) at 1 metre above ground level for each site and variety tested.

Site	Germany				Jorunn				Q83			
	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year
Bodorgan	9.0	12.0	15.0	18.2	10.1	13.6	14.8	17.6	8.4	12.5	15.4	18.5
Hayscastle	9.0	12.2	16.3	20.3	10.5	11.9	13.1	14.6	9.4	12.5	14.7	17.1
Narberth. Farm	7.9	10.4	N/A	N/A	10.4	10.6	N/A	N/A	8.6	10.2	N/A	N/A
Narberth. Road	8.5	8.6	12.8	18.1	10.4	11.3	12.7	14.8	8.7	10.9	14.9	15.1
Brigam	7.8	12.7	19.1	N/A	10.1	13.9	15.8	N/A	7.8	15.6	15.1	N/A
Glynllifon	7.6	13.3	17.0	N/A	8.9	12.5	15.0	N/A	7.0	12.7	15.9	N/A
Cernyfed	6.3	9.3	11.4	N/A	7.3	8.5	9.8	N/A	5.1	8.0	12.1	N/A
Cilgoed	5.4	9.7	14.4	N/A	7.6	11.2	14.0	N/A	5.1	12.5	15.0	N/A

Table 1.4. Summary of numbers of shoots per stool for each site and variety tested.

Site	Germany				Jorunn				Q83			
	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year	1st Year	2nd Year	3rd Year	4th Year
Bodorgan	6.9	7.8	7.3	9.8	5.1	13.4	5.5	7.8	8.6	12.5	9.3	12.0
Hayscastle	7.4	7.2	7.1	8.6	8.1	11.9	7.7	9.4	12.1	12.5	11.1	13.6
Narberth. Farm	7.4	6.7	N/A	N/A	10.5	11.3	N/A	N/A	11.5	10.9	N/A	N/A
Narberth. Road	9.2	7.9	7.5	8.4	11.0	10.5	10.3	12.1	11.0	10.2	11.7	14.1
Brigam	8.2	7.7	9.6	N/A	12.4	13.1	11.5	N/A	13.6	12.9	14.2	N/A
Glynllifon	7.6	7.7	9.2	N/A	7.6	9.2	7.4	N/A	10.2	10.3	11.6	N/A
Cernyfed	7.0	7.0	7.2	N/A	14.0	16.6	15.0	N/A	9.3	10.7	15.7	N/A
Cilgoed	3.8	5.0	10.1	N/A	9.5	10.8	5.0	N/A	7.3	8.1	10.1	N/A

Comparison with results from previous trials

Figures 1.10 –1.18 show standing biomass estimates for each site/variety/age combination tested in the project compared to sites established under a previous study funded by the Forestry Commission, Defra and the DTI. In all cases, the variation in yield between sites, varieties and years observed during both projects is similar. No results were available for Narberth Farm in the 3rd year as those plots were damaged by the road servicing the Bluestone project.

Yields for Germany at Cilgoed in year one were lower than the least productive site containing this variety in the previous study (Figure 1.10). Q83 extended the range of yield estimates in both directions in the first year (Figure 1.12). At the third year, Germany at Cernyfed was the least productive site/variety tested in both projects (Figure 1.16). Jorunn at Brigam was the most productive site/variety combination tested in the third year (Figure 1.17). The range of yield estimates for Q83 was not increased by results from sites established during this project (Figure 1.18).

These results illustrate the importance of site and genotype in determining yields of biomass. It should be borne in mind that older varieties were used in this part of the project to monitor yields in relation to a known set of trials.

Figure 1.10 Standing biomass (odt per ha) Germany, year 1

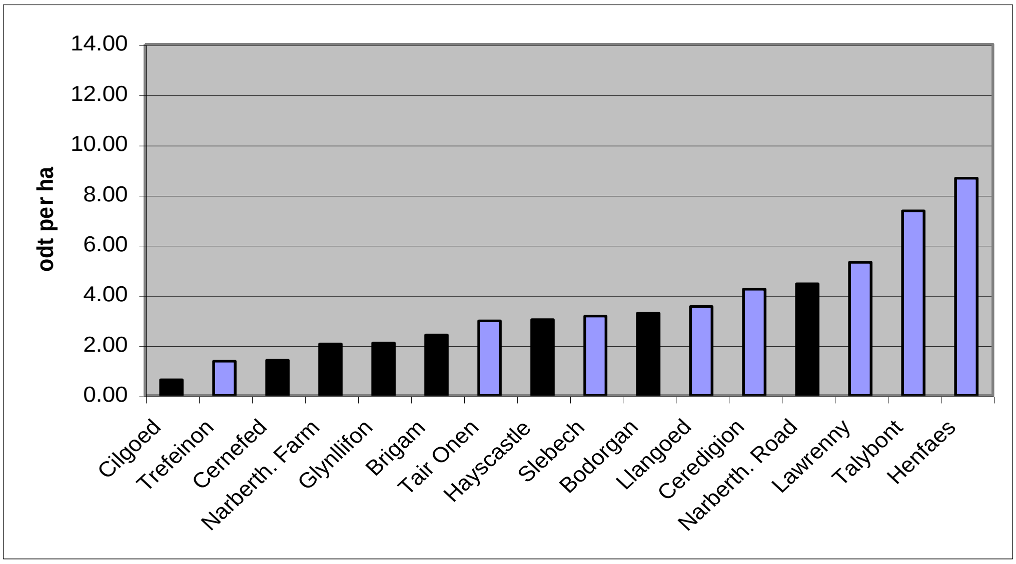


Figure 1.11 Standing biomass (odt per ha) Jorunn, year 1

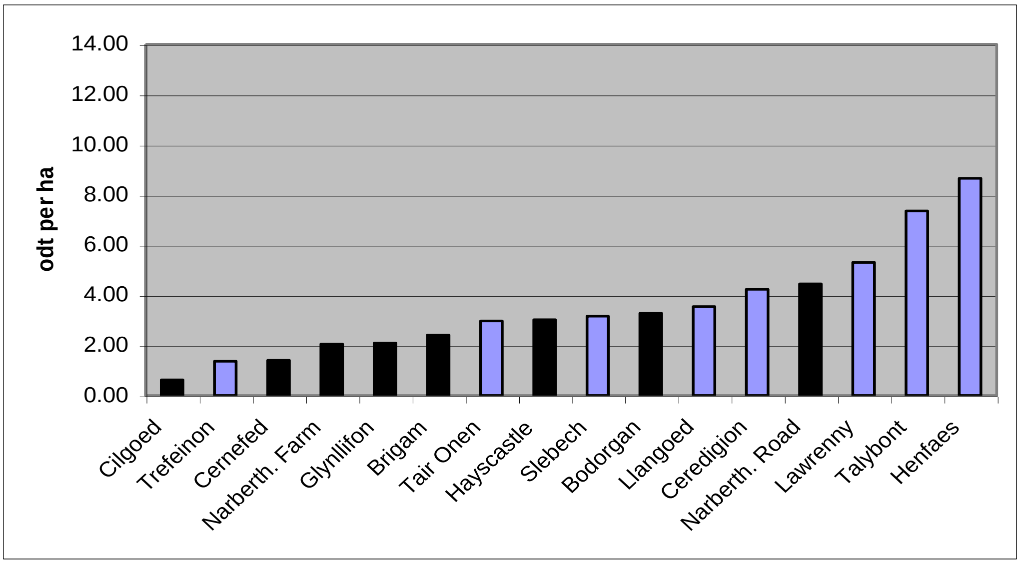


Figure 1.12 Standing biomass (odt per ha) Q83, year 1

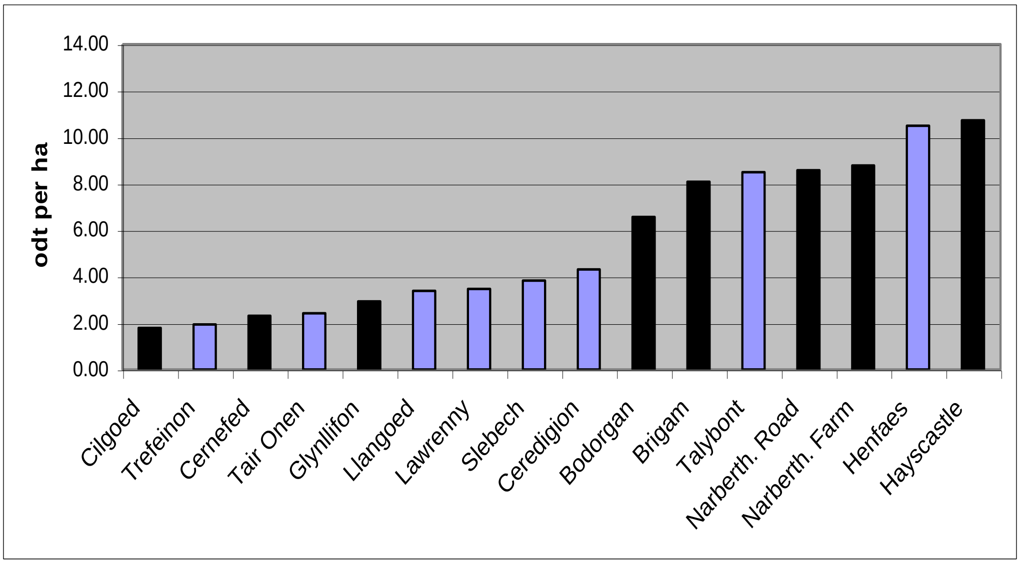


Figure 1.13 Standing biomass (odt per ha) Germany, year 2

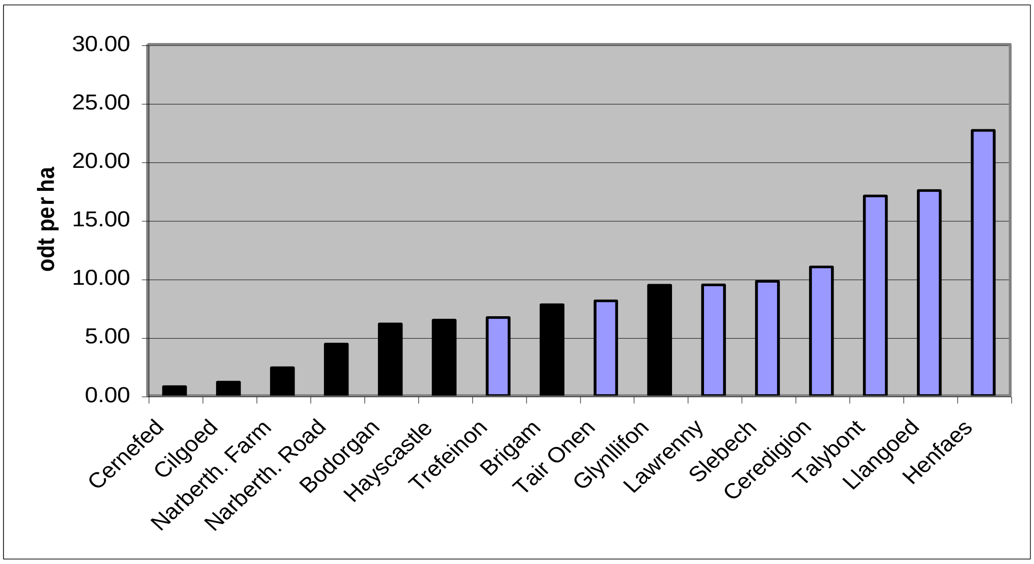


Figure 1.14 Standing biomass (odt per ha) Jorunn, year 2

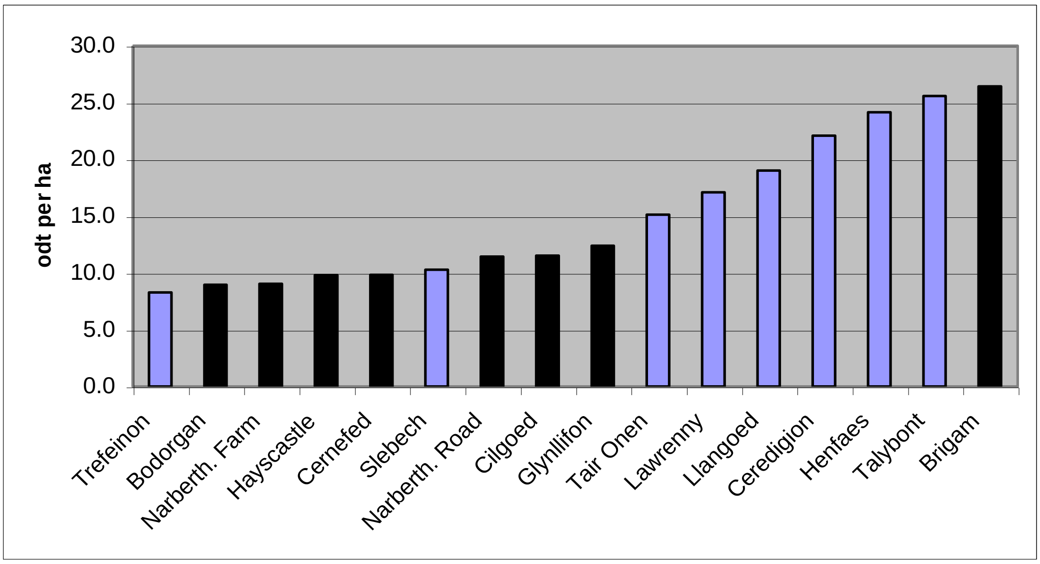


Figure 1.15 Standing biomass (odt per ha) Q83, year 2

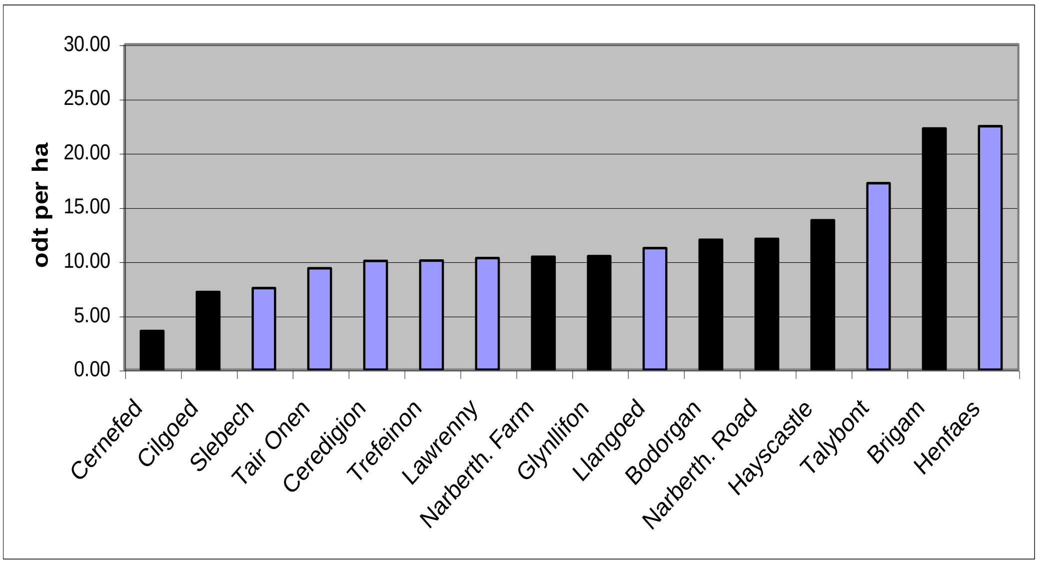


Figure 1.16 Standing biomass (odt per ha) Germany, year 3

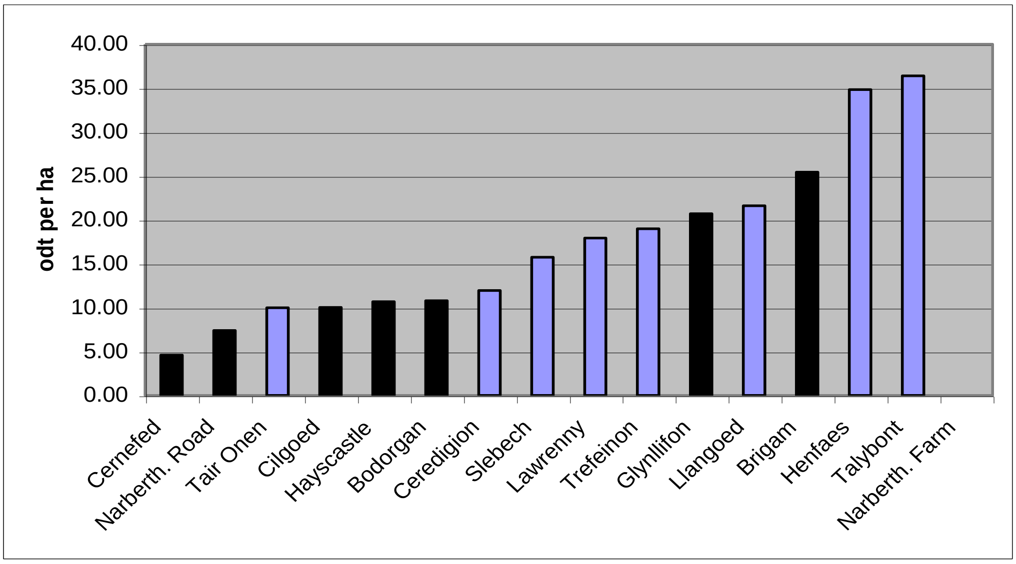


Figure 1.17 Standing biomass (odt per ha) Jorunn, year 3

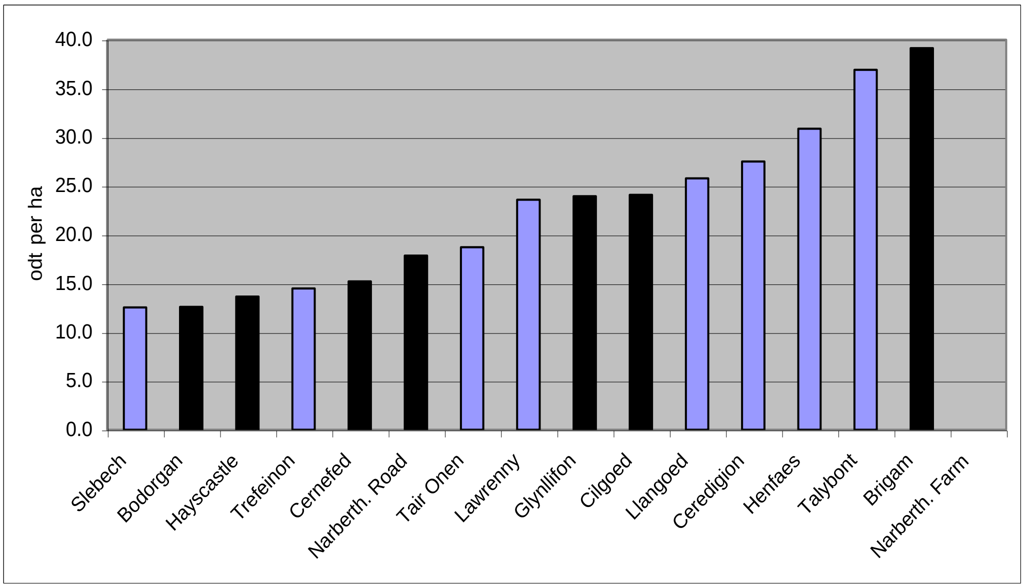
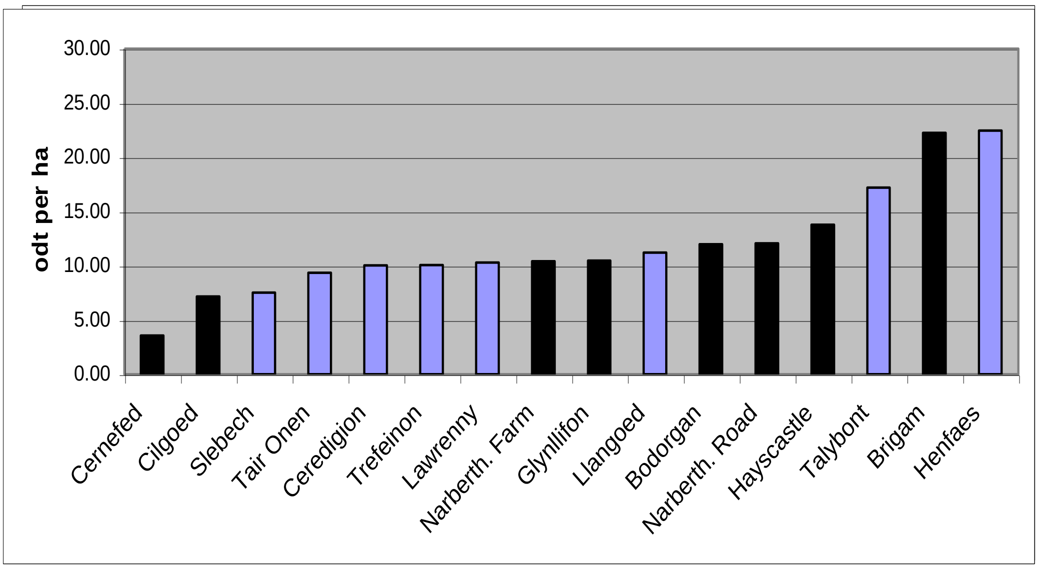


Figure 1.18 Standing biomass (odt per ha) Q83, year 3



Yield estimations from the 'Demonstration' plantations

A protocol was devised during the project for estimating standing biomass in large areas of SRC. The data collection protocol is described in Appendix 3 and the yield modelling methodology is based on that described in the 'Model Development' section of this report. If a relatively quick and easy method of estimating yield in a standing crop of SRC can be devised, growers may be able to make more informed decisions about when to harvest and what possible income from the harvest would be generated. Table 5 summarises the results of this exercise. Results from this exercise suggest that by the end of the third growing season, Hayscastle, and Glynlliffon were the most productive sites assessed and Bodorgan the least productive.

Table 1.5. Summary of yield estimates for 'Demonstration' areas.

	Standing biomass (oven dry tonnes per hectare)		
Site	1st Year	2nd Year	3rd Year
Bodorgan	4.4	4.6	9.2
Hayscastle	7.5		13.6
Cilgoed		2.8	
Glynllifon		4.7	12.5
Narberth Road			11.7

Non-energy uses of SRC

Current EU legislation has prevented the use of energy crops for non-energy use. Such use would lead to the loss of the rights to Energy Aid Payments and more significantly the loss of Single Farm Payments. This ruling restricts farmers from entering into markets such as bedding, or even producing chip for the horticulture industry. As mentioned earlier, the claiming of energy aid or contracts will not be necessary in order to claim Single Farm Payment from 2009.

Multi-functional benefits include providing shelter for free-range poultry, game or ruminants. In the current project, we noted the use of the Bodorgan site for game cover. The estate carries a significant number of pheasant which winter in the crop. The large number of snipe that use the site for cover is even more significant. The crop's linear structure is very well suited to the creation of shooting 'drives'.

The headlands of the crops also provide scope for agricultural activity. The site at Glynlliffon established a wild-bird cover crop on the headlands whilst others mowed the headlands for silage. Some of the farmers attempted to integrate sheep and willow. Whilst short term mob-stocking was useful as a means of reducing the cover of grass weeds, any long-term occupation of the crop resulted in significant damage to the trees. Whilst bark-stripping and shoot damage were apparent, the greatest damage was caused by ewes physically breaking off stems from the stools by trying to move through the crop.

Provision of local employment

Whilst the SRC willow is promoted as low input and low labour, the crop does provide significant local employment opportunities. Harvesting is a winter activity, providing work for contactors in a normally quiet period. Transport, drying and processing of the willow then adds further potential for local employment. Wood chip boilers like that at the Bluestone Project at Narberth require a regular supply of chip as well as requiring the services of local engineers.

With a growing willow industry in Wales, there would be potential to develop local cutting suppliers and planting teams as well as a requirement for the services of local agronomists.

Farmer Questionnaire

In order to gauge participating farmers' views on SRC willow and involvement in the Willow for Wales project, we constructed a short questionnaire shown below. All responses were anonymous.

HELYG I GYMRU - WILLOW FOR WALES

FARMER QUESTIONNAIRE

1. How useful did you find involvement in the project?

Very useful ☐

Useful ☐

Of some use ☐

Not useful ☐

2. Do you intend to maintain the willows planted on your farm?

Highly likely ☐

Likely ☐

Unlikely ☐

3. Would you increase your involvement with energy crops with the necessary support? (NB No commitment implied)

Highly likely ☐

Likely ☐

Unlikely ☐

4. Please rank what you consider are the main attractions of growing willow –

Reduction in workload ☐

Financial reward ☐

Environmental value ☐

Provision of game cover ☐

Other (Please specify) ☐

……………………………………………………………………………………………………..…

5. Please rank what you consider are the main drawbacks of growing willow –

High workload ☐

Ties up land for long period ☐

Low financial return ☐

Less interesting than keeping livestock ☐

Other (Please specify) ☐

………………………………………………………………………………………………………..…

6. Are you happy for your farm to be used for occasional demonstration of willow production?

Yes ☐ No ☐

Table 1.6.

Question	**Very useful**	**Useful**	**Of some use**	**Not useful**
1. How useful did you find involvement in the project?	**4**	**1**	**1**	**0**
	Yes	**No**	**Maybe**	
2. Do you intend to maintain the willows planted on your farm?	**4**	**0**	**2**	
3. Would you increase your involvement with energy crops with the necessary support? (NB No commitment implied)	**4**	**1**	**1**	
… 6. Are you happy for your farm to be used for occasional demonstration of willow production?	**4**	**0**	**2**	

Results

Of the seven questionnaires sent out, six were returned and are summarised in the following tables.

Table 1.7

Question 4	1	2	3	4	5	6
Please rank what you consider are the main attractions of growing willow						
Reduction in workload	*			Y		2
Financial reward	Y				Y	1
Environmental value	Y	Y	Y	Y		3
Provision of game cover	Y**				Y	4
Home energy use	***	Y	Y	Y		5
Other (please specify)						

* Not sure if there has been any
** Popular with snipe (wet) and pheasants
*** We do not yet use woodchip/pellets but who knows

Table1.8

Question 5	1	2	3	4	5	6
Please rank what you consider are the main drawbacks of growing willow						
High workload	Y					4
Difficulties with Single Farm Payment	Y	Y	Y	Y	Y	1
Ties up land for long period	Y					3
Low financial return	Y	Y*	Y			2
Less interesting than keeping livestock						5
Lack of local market	Y				Y?	6
Problems with machinery availability	Y			Y	Y	7
Other (please specify)			**			

* Possibly

** Disappointing lack of interest from Government

The tables show that most of the respondents

- found involvement in the project very useful
- intended to maintain the willows planted on their farms
- would increase their involvement with energy crops if there were a planting grant and technical support
- would be willing to act as a demonstration site in the future.

Most of the respondents saw environmental value as the main attraction of growing willow, even though this is not rewarded by current agri-environmental schemes. Three of the six respondents saw home energy use as an attraction.

All respondents considered difficulties with Single Farm Payment as a drawback of growing willow, even though such difficulties should not exist. Four of the six respondents considered low financial returns, while three respondents also considered machinery availability, as drawbacks. One respondent identified a disappointing lack of interest from Government as a drawback.

CHAPTER 2

Environmental impacts of production of SRC in Wales

Reduction of carbon emissions

The primary reason for using biomass as a renewable energy source is to reduce carbon emissions. Agriculture is the second largest IPCC source category for the emissions of greenhouse gases (1.50 Mt C equivalent) after Energy (11.55 Mt C equivalent) in Wales (AEA 2008). It is estimated that the carbon saved will be 4-6 t/ha through the substitution of fossil fuels and another 0.5-1.0 t/ha from the sequestration of atmospheric carbon in the soil. Energy ratios from technologies using SRC wood chips are much higher than those obtained for biofuels from annual crops (Elsayad, 2003).

It is of course not tenable for biomass crops to replace natural and semi-natural habitats such as woodland, wet meadows and unimproved grassland having high habitat value and already acting as carbon sinks. It is estimated that 60,000 ha of energy crops in Wales would save 0.27–0.42 Mt/year. This represents between 16-25% of total emissions from Welsh agriculture and 2–3% of total Welsh emissions. This does not take into account the substitution of methane from animals (42% of total agricultural emissions).

Full life cycle analyses of changes in land use have been undertaken by St Clair et al, (2008). Converting grassland to oilseed rape results in increased emissions of 691 kg carbon equivalents / ha after one year and 3457 kg carbon equivalents / ha after five years. In contrast, converting grassland to short-rotation coppice or Miscanthus for bioenergy results in savings of 361-379 kg carbon equivalents / ha after one year and 2257-2300 kg carbon equivalents / ha after five years.

From these figures, it can be calculated that 0.461-0.646 Mt of C equivalents, about 30-40% of the total emissions from Welsh agriculture, would be saved per 100,000 ha of energy crops in Wales. This does not take into account the substitution of methane from animals (about 40% of total agricultural emissions).

Visual impact

Rowe et al (2007) point out that the visual appearance of SRC (and Miscanthus) contrasts significantly from traditional crops. The main concerns are the obscuring of landscape features, obstruction of views, impacts on scenic quality and rapid changes in appearance caused by harvesting. Investigations in Sweden and UK have concluded that visual impact can be limited by adjusting scale and shape of plantations to blend into the dominant landscape features and by complementary planting of shrubs or native trees. The Forestry Commission has published guidelines to the sensitive planting of SRC. Regulations require an assessment of visual impact. In the Willow for Wales project, no comments about adverse visual impact have been received.

Figure 2.1

Visual appearance of SRC willow

Water quality

In the first and second year of establishment, the consensus of opinion is that there may be high levels of nitrate leaching, but levels of leaching thereafter are very low. The crops could effectively be used to reduce nitrogen runoff, particularly if plantations are used as buffer strips along watercourses. Soil erosion is also significantly reduced. The use of energy crops (particularly willow) in phytoremediation of contaminated soil and water is an important environmental benefit. Manures and sewage sludge should not of course be applied near water courses.

As we note in the harvest section, wet weather is a limitation to harvest and there is a risk of soil erosion and compaction which would break cross-compliance regulations.

Impacts of SRC on biodiversity

In the context of Wales, SRC impacts biodiversity in 2 main ways:

- At establishment it creates a pseudo-arable environment for weeds in a predominantly pastoral landscape.

- It creates and maintains early succession woodland conditions on a rotational basis.

When pasture was ploughed for SRC establishment there was a change from a flora dominated (99%) by a few long lived perennials to one with more even numbers of species of annuals (34%), short lived perennials (39%) and long lived perennials (35%). By the second year after planting the ground flora was again dominated by long lived perennials such as Creeping Buttercup *(Ranunculus repens)* and Yorkshire Fog *(Holcus lanatus)* an effect accentuated by weed control measures.

At Narberth (Oakwood) one section of SRC was rotovated between rows after first cutback in 2005 to try to stimulate annual weed growth but it was unsuccessful and by the end of the growing season no differences in flora were found between the rotovated and untreated areas.

Annual weeds in particular are important to birds, both in terms of dietary seed production and a source of insect food.

Figure 2.2

Arable weeds in young coppice at Cilgoed, Denbighshire 2005

Table 2.1 Importance of seed of weed genera in bird diets adapted from Marshall *et al*. 2003.

Level of Importance	**Weed General**
Very Important	*Chenopodium*
	Polygonum
	Stellaria
Important	*Cerastium*
	Poa
	Rumex
	Senecio
	Sinapsis
	Viola
Present	*Capsella*
	Cirsium
	Fumaria
	Sonchus
Nominally present	*Galeopsis*
	Galium
	Geranium
	Matricaria

Table 2.2 Insect species associated with various weeds.

Weed Species	Number of insect species
Polygonum aviculare	61
Rumex obtusifolius	79
Stellaria media	71
Cirsium arvense	53
Poa annua	46
Senecio vulgaris	50
Cerastium fontanum	22
Chenopodium album	31
Persicaria maculosa	20
Sinapsis arvensis	37
Anagallis arvensis	3
Capsella bursa-pastoris	13
Fumaria officinalis	3
Galeopsis tetrahit	13
Solanum nigrum	7
Viola arvensis	2

Annual weed seed production varied from site to site. Hayscastle produced an average of 0.28 kg of seed per m^2 with unshed seed peaking in October and ground (shed) seed peaking in November.

Figure 2.3

Arable weeds in young coppice on the Bodorgan Estate, Anglesey 2005

Glynllifon produced the same temporal pattern but produced 0.39 kg/m^2 whereas at Narberth peak seeding was in September. In energy terms seed from Glynllifon produced an average of 7.15 MJ/m^2, Hayscastle 5.13 MJ/$m^2$and Narberth 0.37 MJ/m^2. Winter usage of SRC sites by birds followed the pattern of seed production.

Table 2.3 Calorific values of seeds collected from four SRC fields across Wales

Species	Mean energy content (MJ/kg) of seed	Range of energy content (MJ/kg) of seed
Cirsium spp.	19.82	19.73 – 20.79
Chenopodium album	18.85	18.33 – 19.31
Rumex spp.	17.50	16.99 – 18.03
Alopecurus geniculatus	17.23	16.94 – 17.58
Persicaria hydropiper	16.72	15.01 – 18.06
Persicaria maculosa	16.60	15.21 – 17.56

Table 2.4 Winter bird species recorded at the six sites

	Bodorgan	Hayscastle	Oakwood	Glynllifon	Cernyfed	Cilgoed
No. of species	16	22	22	19	13	19
No. of granivorous species	13	15	15	11	10	14
% of granivorous species	81%	68%	68%	58%	77%	74%

Cirsium (thistle) species were associated with the presence of Chaffinches and *Cerastium* (Mouse-eared chickweed) and *Rumex* (dock) species with Redpoll. The small number of field sites limited the number of weed and bird species that could be analysed. In the field, it was observed that goldfinches were particularly associated with standing *Cirsium* species, feeding on the seeds directly from the plant. Once the plants started to die back and collapse, ground foragers such as Blackbird, Redwing and other thrushes then utilized them.

Nets over the vegetation to specifically exclude birds showed significantly more seed on the ground within the nets confirming that birds are the main utilizers of this resource. This is reflected in the fact that visible fat in the birds increased during the period of seed shed. In more mature SRC plantations seed resources are scarce but the habitat is utilized for breeding and foraging for invertebrate food. Standard Breeding Bird Surveys (BBS) were conducted at seven sites in the first year after planting and repeated in subsequent years where possible. Winter bird surveys were also undertaken at these sites with two visits between October and January.

Figure 2.4

Exclusion nets at Oakwood

Using an SRC site in the second year of its second rotation, weekly mist netting for birds took place between March 2005 and April 2006 to determine the pattern of bird usage over time.

Figure 2.5

Mist net

Table 2.5 Bird species caught or recorded in the surveys during the breeding season (April – September), winter (October – March) and both periods

(*Species confirmed to be nesting in the SRC)

Breeding season only (20 species)	Winter season only (15 species)	Caught in both seasons (25 species)
Barn owl	Fieldfare	Blackbird*
Blackcap	Goldcrest	Blue tit
Chiffchaff	Greenfinch	Bullfinch
Curlew	Herring gull	Buzzard
Garden warbler	Lesser spotted woodpecker	Chaffinch
Grasshopper warbler	Linnet	Coal tit
House sparrow	Meadow pipit	Crow
Jackdaw	Redwing	Dunnock
Kestrel	Reed bunting	Goldfinch*
Mistle thrush	Siberian chiffchaff	Great tit
Pied wagtail	Snipe	Great spotted woodpecker
Redstart	Starling	Jay
Sedge warbler	Stonechat	Long-tailed tit
Siskin	Willow tit	Magpie
Skylark*	Woodcock	Marsh tit
Swallow		Nuthatch
Swift		Pheasant
Treecreeper		Redpoll*
Tree pipit		Robin
Whitethroat		Rook
Willow warbler*		Song thrush*
		Sparrowhawk
		Woodpigeon

Although the full range of bird species is shown above, the characteristic groups included 5 species of finch, 5 species of thrush, 4 species of tits and 5 species of warbler. The attraction of SRC to warblers was in part evaluated by radio tagging the most abundant of this group, the Willow Warbler over 3 seasons. The average territory size was less in SRC than the scrub control and territories showed considerable overlap. The birds were faithful to the SRC and associated tree and hedge lines but showed a strong negative association with improved grassland.

Figure 2.6

Redpoll (*Carduelis flammea*) caught at Glynllifon College

As willow warbler populations in the UK are in decline an expansion of SRC could have a positive effect in helping in the recovery of this species and other bird species using this habitat.

In 2003 window traps were used to collect insects along transects into the crop and at canopy and ground level. Probably because the crop was young only low willow beetle abundance was recorded in May/June samples from Hayscastle and these generally near the ground. Overall there were significantly more insects trapped at the edge of the crop compared with the crop centre. In September 2005 at Hayscastle, the abundant spiders' webs in the thick gorse hedge around part of the field contained many hundreds of willow beetles as they left the crop for the winter. They were not seen on visits 2 weeks prior or 2 weeks after this.

For small mammals each site was trapped using Longworth live traps on 7 occasions over 3/4 nights using 40 traps at each site. A line of 10 traps were set in each of, the hedgerow, headland, 5 m into the crop and in the centre of the crop. These were checked twice daily for the survey period. Results from all sites were very similar with Wood mouse dominating within the crop and greatest diversity along the hedgerows.

Figure 2.7

Wood mouse

For illustrative purposes the total results from Narberth for 7 trapping occasions (2 per year) are given below:

Table 2.6 Small mammal combined totals for Narberth (Oakwood) for 7 trapping occasions.

(All 10 traps per location)	Hedgerow	Headland	5m in crop	Crop centre
Bank Vole	16	2	3	0
Common Shrew	5	5	0	0
Pygmy Shrew	4	1	0	1
Short-tailed Vole/Field Vole	10	18	4	2
Wood Mouse	11	54	85	99
Yellow-necked Mouse	2	3	0	1

Larger animals also utilised SRC. At the most upland site, hares were seen on almost every visit with a maximum of 6 at any one time. Hare damage to the young shoots was similar in extent to damage at a non-project site at 365 m in Ceredigion suggesting a possible problem with upland sites.

Figure 2.8

Hare at Cernyfed Farm, Denbighshire

At almost all sites foxes and badgers were recorded, the latter foraging particularly heavily within the SRC in dry spells when grasslands became unproductive for earthworms but under the willow canopy the soil remains comparatively moist.

The biodiversity potential of SRC in Wales has not been recognised for the important resource which it provides. Its richness would justify inclusion in any future agri-stewardship schemes developed by the Welsh Assembly Government.

The case for the inclusion of SRC willow in the next generation of agri-environmental schemes

On the strength of these results, IBERS and the Welsh Biomass Centre have made the case to the Welsh Assembly Government that SRC should be included in the next generation of agri-environmental schemes. The WAG 2020 report itself said that the present agri-environmental schemes may not stand the test of time. New agri-environmental schemes must deliver

- Environmental goods and services such as clean water and air
- Carbon mitigation and sequestration
- Enhanced biodiversity

As the most serious environmental challenge of our time, climate change mitigation should be central to the next generation of agri-environmental schemes. IBERS' views on the vulnerability of Welsh agriculture to regulations aimed at, for instance, making farms low or even net zero carbon and the role of SRC in offsetting existing greenhouse gas emissions have been summarised in its response to the consultation on the 'Review of Land Management Actions under Axis 2 of the Rural Development Plan 2007-2013'.

SRC willow (and Miscanthus) could play a major role in offsetting. In the mitigation of climate change, the use of bioenergy (and energy efficiency) are important 'stabilisation wedges'. While biofuels derived from annual crops have high carbon emissions and directly compete with primary food production, crops are very efficient in terms of reduction of carbon emissions through substitution of fossil fuels and sequestration of carbon in the soil. Furthermore, they can be grown on land which is not suitable for primary food production.

Support could be provided through the provision of a planting grant covering a proportion of establishment costs or through annual agri-environment payments. Support could be used tactically, e.g. capped support in certain areas or for heat applications.

CHAPTER 3

Identifying the best varieties in Wales and the collection of native adapted willows

The main purpose of this part of the project was to assess the adaptability and biomass yield potential of old and new varieties of SRC willow through trialling in Wales. In addition, native willows have been collected as a basis for increasing the adaptation of SRC willows to the special conditions of Wales rather than relying on varieties produced in eastern Britain or in Sweden.

Trialling of existing and potential varieties in order to identify those best adapted to Welsh conditions

Three trials were established in locations within 20 km of Aberystwyth using a total of 25 willow varieties and planted at a stocking rate of 13,333 cuttings per hectare. Table 3.1 shows which varieties were used in each trial.

Trial I was established in 2003 at a single lowland site, IBERS Gogerddan, using 15 Swedish and UK bred varieties.

Figure 3.1

Trial 1 at IBERS Gogerddan. The outer rows are guard plants of a single variety

.
Trial II, established in 2004, incorporated 3 sites at different altitudes (32 m, 228 m and 296 m), using 11 of the varieties from Trial I, and 4 new varieties.

Figure 3.2

Trial 2 Experimental site at 32 m

Figure 3.3

Trial 3 at 228 m

Figure 3.4

Trial 4 at 296 m

All trials were planted in accordance with the design guidelines of the Forestry Commission and plant variety testing practices (Tabbush and Parfitt, 1999). Following the establishment year, all sites within the trials were coppiced to promote growth in the second year. Trial I was harvested on a 2-year rotation (2006 and 2008) and Trial II on a 3-year rotation (2008). Trial III will be harvested on a 3-year rotation in 2010.

Assessments of leaf canopy architecture were implemented at Gogerddan, IBERS in 2007 to study the potential of contrasting varieties to make efficient use in harnessing the light environment to maximise photosynthesis, and hence yield. These effects are likely to be greatest at times of highest radiation. There maybe other more subtle effects from radiation on yield because distribution of CO_2, water vapour and temperature within the crop can be affected.

Data on the percentage of light (more exactly, photosynthetically active radiation) penetration was collected over a two month period (July and August) in 2007, using the SS1 'Sunscan' Canopy analysis system. Sixty-four diode readings are recorded along a metre long probe and measurements were made at 3 set points within the plot (15 varieties x 3 replicate blocks x 3 measurements = 135 measurements/month) Results were expressed as the mean of three measurements from three replicate plots.

Table 3.1. Willow varieties used in trials at IBERS, Aberystwyth

Variety	Breeding programme	Species	Trial
L78183	Swedish	*S. viminalis*	I & II
Ashton Stott	EWBP	*S. viminalis, S. udensis*	I & II
Beagle	EWBP	*S. viminalis*	I & II
Discovery	EWBP	*S. viminalis, S. schwerinii*	I & II
Doris	Swedish	*S. dasyclados*	II & III
Endeavour	EWBP	*S. viminalis, S. schwerinii*	I & II
Endurance	EWBP	*S. rehderiana, S. dasyclados*	I
Gudrun	Swedish	*S. dasyclados*	II & III
Inger	Swedish	*S. triandra, S. viminalis*	I, II & III
Karin	Swedish	*S. dasyclados*	II & III
Nimrod	EWBP	*S. viminalis, S. schwerinii*	II
Olof	Swedish	*S. viminalis, S. schwerinii*	I & III
Resolution	EWBP	*S. viminalis, S. schwerinii*	I & II
Sherwood	Swedish	*S. viminalis, S. schwerinii, S. eriocephala*	I & II
Sven	Swedish	*S. viminalis, S. schwerinii*	I & III
Terra Nova	EWBP	*S. viminalis, S. schwerinii, S. triandra*	I & II
Tora	Swedish	*S. viminalis, S. schwerinii*	I, II & III
Tordis	Swedish	*S. viminalis, S. schwerinii*	I, II & III
Torhild	Swedish	*S. viminalis, S. schwerinii*	I
LA 970217	Rothamsted	*cv. 'Tora' x S. caprea*	III
LA 970282	Rothamsted	*S. viminalis, S. burjatica*	III
LA 980279	Rothamsted	*cv. 'Tora' x S. discolor*	III
960226	EWBP	*S. viminalis, S. schwerinii*	III
970395	EWBP	*cv. 'Jorunn' x S. burjatica*	III
980236	EWBP	*S. viminalis, S. schwerinii, S. triandra*	III

EWBP = European Willow Breeding Programme

LA = Long Ashton Research Station

Results have been summarised in a table (Table 3.2) similar to those of the HGCA Recommended Lists and published by Hinton-Jones and Valentine (2008). Since the results were limited, they do not constitute a Recommended List or even a Descriptive List, but nevertheless serve as an example of what a Recommended List of willow could look like. The table also includes results of some of the physical and chemical properties of willow achieved from tests carried out in a separate 'WERC' Objective 1 project (Steer et al, 2008).

Table 3.2. Variety performance of SRC willow in Wales for yield and other characters 2003-2008

	Tordis	Endurance	Sherwood	Endeavour	Olof	Beagle	Sven	Resolution	Inger	Tora	Ashton Stott	Terra Nova	78183	Torhild	Discovery	Doris	Gudrun	Karin	Nimrod	P Value
Yield (odt/ha per annum)																				
Trial I - 1st rotation	12.2	11.6	10.6	10.1	11.3	11.9	9.8	9.2	9.9	9.1	9.8	8.2	8.7	6.6	6.5					<.001
Trial I - 2nd rotation	14.1	13.2	14.0	14.2	12.8	11.8	13.6	13.6	12.5	13.0	11.9	12.2	11.5	12.2	10.4					n.s.
Mean	**13.2**	**12.4**	**12.3**	**12.2**	**12.1**	**11.9**	**11.7**	**11.4**	**11.2**	**11.1**	**10.9**	**10.2**	**10.1**	**9.4**	**8.5**					
Trial II (32masl) - 1st rotation	9.9		10.2	10.9		11.6		11.6	8.8	10.9	9.9	6.0	8.8		14.6	10.0	10.0	3.2	7.0	
Trial II (228masl) - 1st rotation	4.8		7.1	8.7		6.7		6.5	6.6	7.0	7.0	6.2	6.6		8.2	4.6	4.0	3.1	6.2	
Trial II (296masl) - 1st rotation	4.4		5.8	5.1		6.3		7.2	7.9	7.8	4.7	7.1	4.3		6.6	6.4	6.9	2.0	7.5	
Mean	**6.4**		**7.7**	**8.2**		**8.2**		**8.4**	**7.8**	**8.5**	**7.2**	**6.4**	**6.6**		**9.8**	**7.0**	**7.0**	**2.8**	**6.9**	<.001
Stem number																				
Trial I - 1st rotation	5.0	8.3	4.6	6.8	5.6	9.3	6.6	5.6	8.0	5.5	7.7	8.2	10.4	4.6	4.7					<.001
Trial I - 2nd rotation	9.4	15.1	9.7	14.3	11.5	18.5	15.5	9.2	13.7	17.4	13.2	13.7	18.4	12.7	8.9					<.001
Mean	**7.2**	**11.7**	**7.2**	**10.6**	**8.6**	**13.9**	**11.1**	**7.4**	**10.9**	**11.5**	**10.5**	**11.0**	**14.4**	**8.7**	**6.8**					
Trial II (32masl) - 1st rotation	5.2		6.0	5.3		9.4		5.3	5.4	5.0	9.2	5.9	9.6		5.2	6.2	8.3	7.8	5.2	
Trial II (228masl) - 1st rotation	3.0		3.7	4.7		6.0		3.3	3.8	4.5	5.5	5.3	8.7		4.9	3.5	4.8	5.2	4.9	
Trial II (296masl) - 1st rotation	4.0		4.6	4.1		8.7		3.5	4.6	5.1	6.3	7.1	9.0		5.6	5.1	6.0	5.9	5.6	
Mean	**4.1**		**4.8**	**4.7**		**8.0**		**4.0**	**4.6**	**4.9**	**7.0**	**6.1**	**9.1**		**5.2**	**4.9**	**6.4**	**6.3**	**5.2**	n.s
Stem diameter at 100cm (d100)																				
Trial I - 1st rotation	1.28	1.23	1.09	1.10	1.08	0.97	1.09	1.16	1.12	1.08	1.21	1.00	0.85	1.02	1.09					<.001
Trial I - 2nd rotation	1.50	1.16	1.20	1.15	1.20	0.98	1.20	1.17	1.19	1.38	1.14	1.16	0.89	1.35	1.50					<.001
Mean	**1.39**	**1.20**	**1.15**	**1.13**	**1.14**	**0.98**	**1.15**	**1.17**	**1.16**	**1.23**	**1.18**	**1.08**	**0.87**	**1.19**	**1.30**					
Trial II (32masl) - 1st rotation	1.79		1.74	1.68		1.26		1.61	1.67	1.80	1.61	1.31	1.28		1.97	1.73	1.58	1.17	1.56	
Trial II (228masl) - 1st rotation	1.96		2.03	1.98		1.57		2.05	1.88	2.06	1.69	1.74	1.32		1.77	1.83	1.60	1.32	1.80	
Trial II (296masl) - 1st rotation	1.41		1.27	1.64		1.54		1.60	1.74	1.59	1.41	1.55	1.39		1.51	1.50	1.59	1.34	1.70	
Mean	**1.72**		**1.68**	**1.77**		**1.42**		**1.75**	**1.76**	**1.82**	**1.57**	**1.53**	**1.33**		**1.72**	**1.69**	**1.59**	**1.28**	**1.69**	<.001
Incidence of Leaf Rust (2007 data)																				
Trial I	0.00	0.00	0.46	0.23	0.23	1.18	0.00	0.76	0.18	0.00	0.56	0.00	1.22	0.07	0.03					<.001
Trial II (32masl)	0.11		0.85	0.25		1.28		0.25	0.37	0.00	0.77	0.00	1.75		0.29	0.15	0.00	0.62	0.00	
Trial II (228masl)	0.00		1.22	0.06		2.43		0.29	1.00	0.03	1.24	0.00	2.44		0.03	0.11	0.00	0.47	0.00	
Trial II (296masl)	0.00		2.04	0.10		2.04		0.70	1.14	0.02	2.34	0.00	2.82		0.11	0.18	0.13	0.66	0.00	
Mean	**0.04**		**1.37**	**0.14**		**1.92**		**0.41**	**0.84**	**0.02**	**1.45**	**0.00**	**2.34**		**0.14**	**0.15**	**0.04**	**0.58**	**0.00**	<.001
Leaf damage (2007 data)																				
Trial I	1.69	1.06	1.65	1.40	1.26	1.40	1.27	1.63	1.12	1.55	1.21	2.00	1.16	1.57	1.59					<.001
Trial II (32masl)	1.92		2.08	2.43		2.14		2.18	2.33	2.08	2.13	2.55	1.86		2.21	2.26	1.63	2.66	2.91	
Trial II (228masl)	2.58		2.89	2.20		2.69		1.89	2.57	2.61	2.33	2.27	2.18		2.35	2.71	2.23	2.30	2.30	
Trial II (296masl)	2.17		1.96	2.19		2.00		2.01	2.13	1.96	2.40	1.89	2.09		2.35	1.76	1.33	1.71	1.88	
Mean	**2.22**		**2.31**	**2.27**		**2.28**		**2.03**	**2.34**	**2.22**	**2.29**	**2.24**	**2.04**		**2.30**	**2.24**	**1.73**	**2.22**	**2.36**	<.001
Aphid infestation (2007 data)																				
Trial I	0.69	0.72	0.95	0.75	0.79	0.45	0.85	0.07	1.05	0.87	0.49	0.45	0.58	0.73	0.80					<.001
Trial II (32masl)	0.70		0.70	0.33		0.55		0.43	0.58	0.30	1.63	0.45	0.50		0.43	0.98	0.63	0.45	0.10	
Trial II (228masl)	0.53		0.88	0.25		0.53		0.25	0.48	0.60	0.63	0.25	0.40		0.13	0.22	0.58	0.38	0.15	
Trial II (296masl)	0.00		0.00	0.00		0.18		0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	
Mean	**0.41**		**0.53**	**0.19**		**0.42**		**0.23**	**0.35**	**0.30**	**0.75**	**0.23**	**0.30**		**0.19**	**0.40**	**0.40**	**0.28**	**0.08**	<.001
Chemical properties (from Trial 1 - 1st rotation woodchip samples)																				
Trial I - Gross CV (MJ/kg)	17.7	18.3	17.7	18.6	17.7	17.7	16.9	16.8	16.6	16.8	17.7	18.4	17.3	17.6	16.7					n.s.
Trial I - Lignin (%)	20.6	21.6	19.3	19.4	18.5	19.7	20.7	16.1	17.0	21.3	21.0	23.3	16.7	19.4	18.7					<.001
Trial I - Cellulose (%)	46.1	47.7	50.2	48.8	49.0	44.9	47.0	52.9	48.6	47.4	50.2	43.8	53.9	51.1	49.5					<.001
Trial I - Hemi-cellulose (%)	12.6	9.7	12.9	13.7	14.5	15.1	11.2	11.6	12.3	9.4	10.3	9.6	12.4	10.4	9.8					<.001
Physical properties																				
Trial I - Bulk density (Kg/m³)	138	172	162	179	161	157	184	161	176	171	172	170	176	169	173					<.001

In Trial I, 6 varieties produced yields in excess of 10 odt/ha/yr in the first harvest rotation, followed by all 15 varieties in the second harvest rotation. Yield data from *Trial I* suggests that to a certain extent some conclusions can be drawn as to which varieties perform best in Wales, as yield assessments should have at least 2 harvest cycles before any variety recommendations are made (Larsson, 1998). As expected, variety yields were generally greater in the second harvest rotation compared to the first, probably attributed to an overall increase in stem numbers (100%) and stem diameter (11%) between harvest years. Interestingly, the highest yielding variety *Tordis* had the lowest mean stem number and the highest mean stem diameter; whereas, one of the lowest yielding varieties *L78183* had the highest mean stem number and lowest mean stem diameter.

Commercial growers are encouraged to grow 4-6 varieties in mixtures based on their yielding capacity and resistance to rust (McCracken et al., 2001). In that respect, the yields of the five highest yielding varieties in these trials was 11% greater than the overall mean for both harvest rotations. Many of the newer varieties have good rust resistance (Lindegaard et al, 2001) and this was confirmed in Trial I, as the incidence of rust was generally very low in the pre-harvest year. *L78183* and *Beagle* had the highest incidence, but this was considered light, and five varieties had no incidence. Leaf damage and the incidence of aphids are also critical assessments and can have a profound impact on yields. Aphids remove sugars from the stems.

An infestation of giant black aphids (*Pterochlorus viminalis*) was experienced in 2005 (see Figure 1.3) Differences in the severity of attack were noted between different varieties. In one plot of Discovery, the combination of a susceptible variety and prolonged waterlogging led to plant death.

We would have expected biological control, such as a rise in ladybirds or an influx of birds to have happened. This did not occur, possibly in the case of ladybirds due to isolation of the plots, and in the case of birds, possibly due to distastefulness of the aphids.

It was noted that the levels of rust was higher and the incidence of aphids lower at higher altitudes.

Varieties of willow should produce woodchips that meet European Wood fuel Standards (CEN 355). All varieties assessed in Trial I through the 'WERC' project, produced woodchips that came under the G100 standard for particle size. The amount of clean white wood in a sample of wood chip for each variety ranged from 84.9% for *Discovery* to 68.1% for *Tordis*, but due to large variation between samples, there were no significant differences between varieties. Bulk densities of short rotation coppice woodchips are typically around 170 kg/m^3. Results from the trial show a range from 138.2 kg/m^3 for *Tordis* to 183.7 kg/m^3 for *Sven*, although nine of the 15 varieties did have values that surpassed 170 kg/m^3. This could be a vital statistic economically, as bulk density will impact on transport costs from source to end-user.

The proportions of the three main cell wall components of plant biomass, cellulose, hemicellulose and lignin, are expected to affect the Gross Calorific Value (heating value) and the kinetics of devolatilisation. Willow chips have been shown to have a slightly better Gross CV than other energy crops (Steer et al., 2008), due to its high lignin content. Lignin content ranged from 16.1% to 23.3% for varieties in this trial.

The ratio of lignin to hemicellulose contained within the material can be used as an indicator of its heating value (Demirbas, 1997). Terra Nova had the highest concentration of lignin and the lowest hemicellulose to lignin ratio and as expected this variety had one of the highest Gross CV's. *Resolution* and *L78183* had the highest hemi-cellulose to lignin ratio, distinctly higher than that of the other varieties. Cellulose and lignin content has been found to be an important parameter affecting pyrolysis. High cellulose content has been shown to increase pyrolysis rate, whereas higher lignin content gives a slower rate. Cellulose contents ranged from 43.8% for Terra Nova to 53.9% for *L78183*, and there were highly significant (P<.001) differences between varieties. The results suggest that all varieties would present reasonable quality feedstock for the combustion process.

In Trial II, biomass production was highest (9.5 odt/ha/yr overall) at the low altitude site (32 m) and lowest (6.0 odt/ha/yr) at the highest altitude site (296 m). As outlined in Chapter 1, these differences are to be expected and probably reflect differences in wind exposure rather than altitude *per se*. Site, variety and variety x site differences were highly significant (P<.001). Across all sites, cv. Discovery was the best yielder (9.8 odt/ha p.a.) and Karin the worst (2.8 odt/ha p.a.). All but two varieties produced their best yields at the low altitude site. The two exceptions were Nimrod and Terra Nova which produced their best yields at the highest altitude site (7.5 odt/ha p.a. and 7.1 odt/ha p.a. respectively).

At the lowland site, eight varieties produced yields in excess of 10 odt/ha/year, and three produced yields greater than *Tora*. It has been suggested that 6 odt/ha/yr may be a more realistic yield in the uplands (Heaton et al., 2001). In that case, eleven varieties surpassed 6 odt/ha/yr at 228 m and nine varieties, including *Nimrod* and *Terra Nova*, at 296 m. The reason for this could have been less aphid infestation, as described later, at higher altitudes.

Varieties at 32 m produced significantly more stems and significantly less at 228 m. Varieties at 228 m had significantly greater stem diameters. CV. *L78183* had the greatest mean stem number across sites and *Resolution* the lowest. *Tora* had the greatest stem diameter across sites and *Karin* the lowest. It is difficult at this stage to make any assumption about potential future yields or harvesting problems associated with increased stem number and stem diameter for *Trial II*.

The incidence of rust was generally low at all three sites, but was greatest at 296 m and lowest at 32 m. Similarly to Trial *I*, *L78183* had the highest incidence of rust at all 3 sites, whereas cvs.*Gudrun, Nimrod, Terra Nova, Tora* and *Tordis* showed virtually no incidence.

Leaf damage assessed as percentage green leaf area lost caused by unspecified insects and wind was generally low and differences between varieties small. Damage was greatest at the 228 m site and lowest at the 296 m site.

The incidence of aphids was generally low but greatest at 32 m and lowest at 296 m. *Nimrod* had particularly low aphid infestation.

Results of the assessments of percentage light penetration of the leaf canopies of willow varieties in Trial I are shown in Table 3.

Table 3.3. % light penetration through leaf canopies in Trial I

Varieties	% light penetration of canopy (July)	Ranking July	% light penetration of canopy (August)	Ranking August	Variety Mean	Overall rank
78183	0.92	13	1.06	14	0.99	14
Stott	0.83	14	1.83	9	1.33	13
Beagle	3.70	7	3.83	2	3.77	3
Endeavour	2.79	10	1.78	10	2.28	11
Discovery	4.23	2	2.52	5	3.37	4
Terra Nova	2.27	12	2.42	6	2.35	10
Resolution	4.45	1	3.17	3	3.81	2
Endurance	0.21	15	0.45	15	0.33	15
Tora	2.54	11	1.59	12	2.06	12
Torhild	3.73	6	2.89	4	3.31	5
Sven	3.85	4	1.63	11	2.74	8
Olof	3.53	9	1.86	8	2.69	9
Tordis	3.62	8	2.29	7	2.96	6
Sherwood	3.82	5	9.08	1	6.45	1
Inger	4.06	3	1.48	13	2.77	7
Mean	2.97		2.53		2.75	
s.e.d of the mean					0.86***	

There were no significant differences between the light penetration in July (3.0%) compared to August (2.5%). Sherwood (6.5%) had the greatest light penetration overall (thus the least light intercepted) and Endurance the lowest (0.3%), and this was consistent in both July and August. These differences could be visually observed. Endurance has large ovate leaves as a result of having no *S. viminalis*, which has long narrow leaves, in its pedigree. This resulted in it being clearly ‘dark’ under the Endurance canopy with very little weed growth.

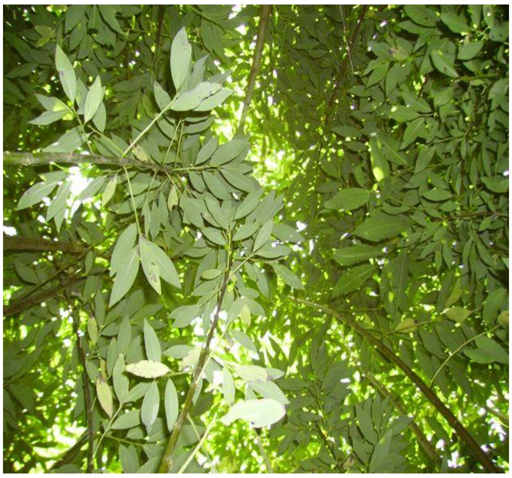


Figure 3.5

Examples of canopy cover of two varieties of willow. Photographs clearly show the best light-intercepting cv. Endurance with dense foliage compared to the less dense and narrow-leaved cv. Sherwood

Values are generally very low, indicating that light interception by the leaf canopies of willow varieties at this site was highly efficient. The willow crop at this site was in its 4th year, and the canopy cover represented 18 months of growth since the last harvest in 2006, with a significant increase in stem number, which probably accounts for the greater canopy cover.

Results of the assessments of % light penetration of the leaf canopies of willow varieties at the altitudinal sites of Trial II are shown in Table 3.4.

Differences between Varieties, Sites, Months and the interactions between Varieties x Sites, Varieties x Months and Varieties x Sites x Months, were highly significant (P<.001).

In both months, % light penetration was greatest at the highest altitude site (20.8% July, 18.3% August) and lowest at the lowest altitude site (4.6% July, 7.2% August). Karin had the greatest overall % light penetration for both months across the 3 sites (24.6% July, 54.9% August) and Terra Nova the lowest (4.1% July, 3.4% August.

While the canopies developed in the growth conditions found at above 200 m did not generally intercept as much light as under lowland growth conditions, the relatively high levels of light intercepted by Nimrod and Terra Nova at 228 and 296 m may be critical to the development of willow for upland areas of Wales if this was judged desirable.

The crop was in its third year, and the canopy cover represented 30 months of growth since first cutback in 2005.

The trials conducted at IBERS have highlighted the potential of SRC willow varieties to produce high yields in lowland and upland areas that compare well with those achieved through trialling in other regions of the UK, e.g. Lindegaard *et al*. (2001).

Table 3.4 % light penetration through leaf canopies at the altitudinal sites of Trial II

JULY

Varieties/Genotypes	32 m site	228 m site	296 m site	Variety Mean	Overall ranking
78183	0.76	9.58	27.41	12.58	9
Sherwood	4.87	20.26	26.92	17.35	3
Inger	11.85	12.21	16.56	13.54	7
Doris	3.38	17.34	14.40	11.71	11
Gudrun	2.76	9.20	15.27	9.08	13
Karin	10.93	10.38	52.58	24.63	1
Tora	6.67	16.03	20.69	14.46	5
Tordis	5.23	24.06	25.33	18.21	2
Ashton	1.57	7.83	18.29	9.23	12
Beagle	1.83	16.54	18.02	12.13	10
Discovery	6.91	16.45	16.78	13.38	8
Nimrod	2.85	4.50	9.28	5.54	14
Terra Nova	1.98	3.62	6.62	4.07	15
Endeavour	4.68	10.88	25.48	13.68	6
Resolution	3.17	22.90	18.25	14.77	4
Mean	4.63	13.45	20.8	12.96	

AUGUST

Varieties/Genotypes	32 m site	228 m site	296 m site	Variety Mean	Overall ranking
78183	4.11	7.86	19.99	10.65	11
Sherwood	6.07	17.75	25.81	16.54	3
Inger	4.01	16.95	14.74	11.90	8=
Doris	1.23	21.48	17.62	13.44	5
Gudrun	1.96	12.30	10.85	8.37	12
Karin	54.14	61.71	48.99	54.95	1
Tora	3.84	13.72	26.75	14.77	4
Tordis	8.05	25.24	16.58	16.62	2
Ashton	1.84	9.95	22.83	11.54	10
Beagle	2.49	21.17	15.34	13.00	6
Discovery	6.61	15.09	13.99	11.90	8=
Nimrod	2.62	4.28	4.86	3.92	14
Terra Nova	3.41	2.52	4.21	3.38	15
Endeavour	2.02	4.84	17.05	7.97	13
Resolution	5.05	16.12	15.33	12.17	7
Mean	7.2	16.7	18.3	14.07	

Fasciation

Figure 3.6

Fasciated shoot

A small percentage of fasciated shoots were observed in the trial in August 2004. Fasciation is a condition in which the stem is distorted and flattened. It is a condition that may randomly affect a diverse range of plants. True fasciation is the product of a single, normally dome-shaped growing point that has become abnormally broadened and flattened. Any side shoots usually remain small and undeveloped.

The cause of fasciation in willow is not known. In other species, it is said to be caused by random genetic disruption, infection by a bacterium, or by stress such as frost or insects. Plants commonly affected: delphiniums, euphorbias, forsythia, foxgloves, lilies, primulas. Fasciated or Fantail willow (*S. udensis 'Sekka'; formerly S. sachalinensis 'Sekka'*), originally from Northern Japan and NE Asia is an unexplained abnormality that is not harmful to the plant and prized by florists; stems used frequently in Ikebana arranging.

In our trial, the varieties affected were Beagle (0.02%), Discovery (0.1%), Torhild (0.04%), Sherwood (0.04%), Inger (0.04%).

Figure 3.7

A flower arrangement involving fasciated stems of willow in the Melia White House Hotel in London in 2004

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Native willow collections

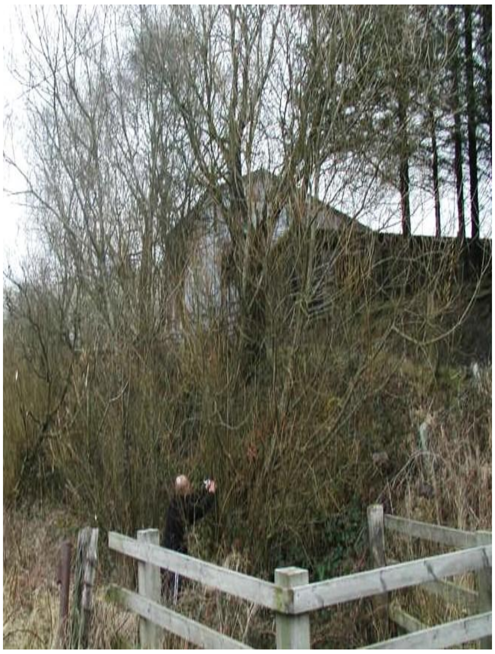
Another aspect of the Willow for Wales project has been to collect native willow clones from various altitudes to test the hypothesis that possible adaptation to cold, wet, windy and marginal conditions exist. This opens the possibility of developing breeding populations for selection for greater adaptation to Welsh conditions, in partnership with an existing willow breeder. In collecting clones, we have observed that 300 m is the limit for *Salix viminalis* (osier willow). However, this may be due to its preference for river banks where the water is slow moving rather than being limited by altitude. *S. viminalis* types form the genetic backbone of most biomass willow varieties. Some *S. cinerea* (sallow) and *S. caprea* (goat willow) can be found above 500 m. Degree of wind exposure rather than altitude *per se* is probably more important. It would be worth investigating the scope for direct use of clones in upland areas. In addition, both species can be hybridised with *S. viminalis* in a genetic improvement programmes, though this is a long-term approach.

Figure 3.8

Google Earth view of Wales showing where willows were collected

Figure 3.9

Collecting native SRC willow (*S. viminalis* 'types') at Llangurig (left) at 289 m and Llanbadarn, nr. Aberystwyth (right) at 40 m in 2006. During the early stages of assessments, both genotypes have shown significant potential compared to the established control variety *Tora*



Twenty seven collections were made in 2006 from within a 50 mile radius of Aberystwyth, Ceredigion. Managements include first year cutback in 2007 and measurements of primary stem length and stem number per stool. Collected accessions were assessed for pests and diseases in 2007 and 2008, as rust or aphid incidence 0 = no incidence to 5 very severe and leaf damage (% green leaf tissue lost) 0 = 0-5%; 1 = 6-10%; 2 = 10-20%; 3 = 20-40%; 4 = 40-65%; 5 = 65-100%.

Ten genotypes had a greater primary stem length than *Tora*, and all but 2 genotypes had greater stem numbers. Eleven genotypes showed no incidence of rust in 2007 but only 2 in 2008. Eight genotypes had greater combined primary stem lengths and stem numbers than Tora.

Eighteen collections were made in 2007, having extended the previous radius to 80 miles from Aberystwyth. Managements include first year cutback in early 2008 and measurements of primary stem length and stem number per stool. Collected accessions were assessed for pests and diseases in 2008. None of the collected genotypes produced primary stem lengths greater than cv.*Tora*. Thirteen genotypes did produce more stems than cv. Tora. Only two genotypes showed no incidence of rust.

Eighteen collections were made in 2008 from South East Wales (Monmouthshire, Breconshire), South West Wales (Pembrokeshire) and North West Wales (Vale of Clwyd & Trawsfynydd). First cutback will be made in 2009. Collected accessions were assessed for pests and diseases in 2008. All genotypes showed an incidence of rust in 2008, although for six genotypes incidence was low.

Many genotypes are showing great potential compared to the control, and would hope that breeding programmes within the UK will recognise their potential in the future. A full list of collected genotypes and preliminary data are presented in Appendix 4.

CHAPTER 4

Making the Supply Chain Work

Economics of SRC willow

The economics of SRC willow is crucial to all the potential participants in the biomass supply chain. A new model has been developed based on levels of actual inputs obtained in the Willow for Wales project costed at 2007 levels (Valentine et al., 2008). Average costs were estimated at £1338/ha). These compare favourably with estimates of £1663/ ha determined for England (Defra, 2006) based on a standard cost of £1273/ha (Cambridge/ SAC, 2005) adjusted for additional costs of herbicides, rabbit fencing and gapping up. (It should be noted that consent from the breeder should be sought for gapping up). The costs of planting material (£750/ha) was the largest item, followed by the costs of planting (£170/ha), pre-emergence sprays (£95/ha, with a range of £58-152/ha), post cutback sprays (£94/ha, range £46-148) and gapping up (£39/ha). The Rural Development Plan for England 2007-13 allows for a planting grant to cover up to 40% of the actual costs of establishment. This is justified on the basis that both the value of carbon savings in climate change mitigation and the opportunity for farmers to diversify are not reflected in the market price of energy crops. Accordingly, there is likely to be very little planting without intervention, given the high initial costs of establishment: a classical market failure. No scheme exists in Wales (the Woodland Grant was withdrawn by the Forestry Commission Wales in 2006) but it was assumed that a 40% grant will become available, either from the Welsh Assembly Government or dealt with below, through Industry.

The effects of varying yields and ex-farm prices on returns to farmers expressed as Net Present Value (Cumulative Gross Margin, discounted at 6% over 5 crop rotations, 16 years) are shown in the following Table 4.1.

Table 4.1 The effect of varying yields and prices on Net Present Values

Price per odt (£)	£35	£45	£60	£75
8 odt in all rotations	-209	263	972	1681
8 odt in rotation 1 10odt in rotation 2-5	-126	441	1291	2141
8 odt in rotation 1 12 odt in rotation 2-5	-44	618	1610	2602
10 odt in rotation 1 15 odt in rotation 2-5	101	928	2168	3048

Results demonstrated that at lower prices (£35-45/ ha) and yields (8-10 odt/ha), it will be difficult to match the returns from growing wheat or even lowland sheep. At higher yields (10-15 odt/ha) and more realistic prices (£60-75/t) that take into account inherent energy value, high competition for the resource and climate change mitigation (substitution of fossil carbon and sequestration of carbon in the soil), attractive returns from SRC willow can be obtained as long as local markets are available which keep down transport costs.

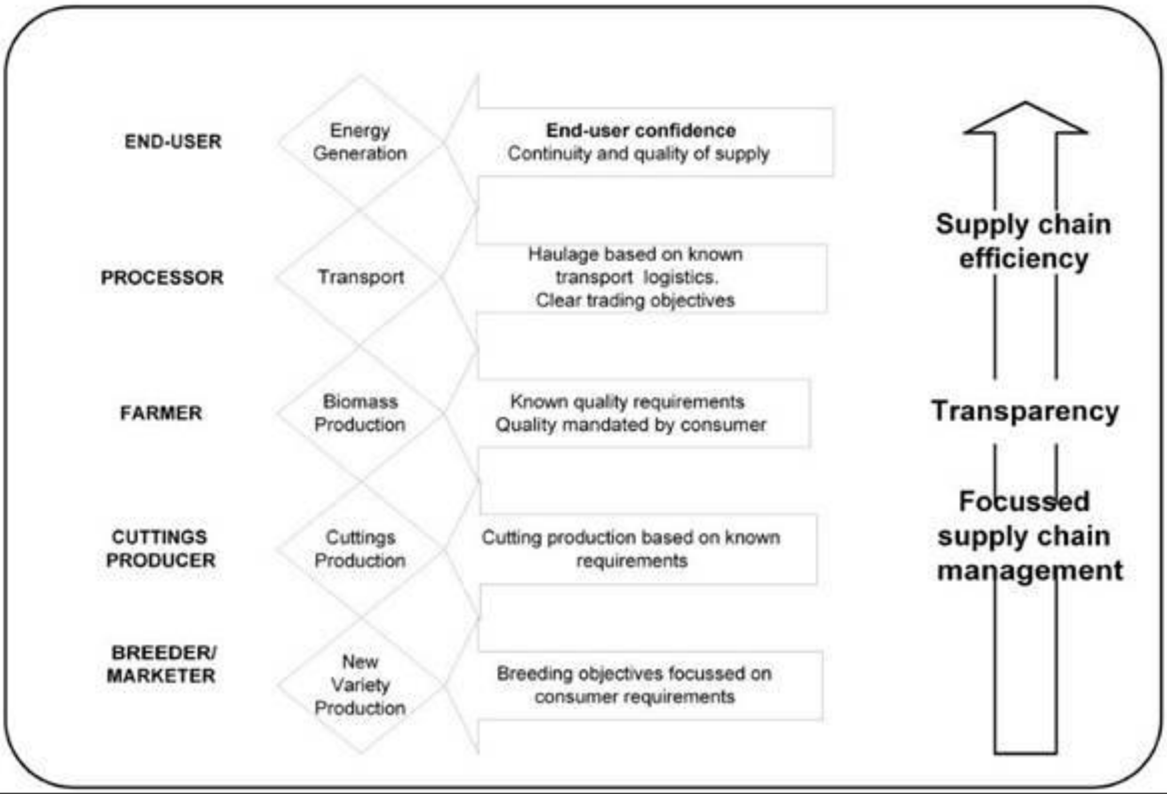
For the scenario of £665/ha planting grant, a price of £45/odt and yields of 8 odt in the first rotation and 12 odt/ ha in subsequent rotations, values of £22/odt for production costs and £232/ha for gross margin for SRC willow can be derived. This assessment of the economics of willow is far more positive than that given in 'Sustaining the Land. A review of Land Management Actions under Axis 2 of the Rural Development Plan'. published in September 2008.

The additional payment for energy crops obtained from differentiated levels of Renewable Obligation Certificates from 2009 could enable electricity generators to pay higher prices for energy crops.

Following initial kick-start, one would expect economies of scale and local availability to result in savings for further planting and for farmers, having confidence of their technical ability and an assured market (through contracts), to invest in further plantings themselves.

It is worth noting that Bical is currently in negotiation with RWE npower to agree terms for the supply of significant quantities of the energy crop Miscanthus. The price of the crop is under discussion but it is likely to be towards the upper end of the price scenarios investigated by Valentine et al., (2008). IBERS believes SRC willow woodchip could potentially be worth more in the light of its higher calorific value and less slagging and fouling than chip from Miscanthus.

Making the supply chain work



A commercially viable SRC supply chain needs to be developed for Wales. Such a chain should ensure that those engaged have adequate returns for their investment, risks and for the value that they add.

Given a price sufficiently competitive to allow willow chips to compete with other raw materials, the major question becomes one of how the supply chain is structured and managed.

In considering the supply chain for SRC willow, we drew on our knowledge of a supply chain recently investigated within the AFENO project[2] in relation to stimulating the commercial production of naked oats for the poultry industry. It in turn drew on the example of Barilla, the largest pasta manufacturer in Europe, the expertise of Gerald Mason of the Home-Grown Cereals Authority and flour miller, and the experience of Graham Lacey, the Trading Director of Centaur Grain (a farmer-owned marketing company covering most of England and handling approximately 1.5 m t of grain annually).

Most raw materials for compound mills are purchased on a traded basis, allowing buyers maximum flexibility to change constituents as commodity prices alter. Other industries have preferred to exercise more purchasing control over supplies through supply contracts, even though this may incur additional costs.

The AFENO project, which engaged industries across the supply chain (similar to Willow for Wales), recommended that grower contracts were necessary in order to stimulate supply.

An extract from the AFENO report is worth quoting:

> *'Production contracts decouple price from physical supply and results in stability of long term supply. In so doing they provide a security to both grower and user. Growers and users feel confident that the needs of both parties are being considered. Production contracts should ideally be fair to all parties, recognising each sector's part in the supply chain. The producer feels part of a partnership and the user is able to demonstrate active support and fairness. Production contracts which seek to distribute value fairly results in continuity and predictability of supply, the opportunity to specify quality standards, known costs, short chains and logistic efficiency. Working in a dynamic way helps create a shared partnership with the net result being a "win - win".*
>
> *Continuity and security of supply is essential especially, where there is a requirement for high investments or where non established markets exists where there is a limited alternative feed stock. This is the case for the biomass market. The specific requirements of biomass production therefore align it to being a contract-led market, and one where values can be shared'*.

A biomass supply chain needs to integrate various players. The links can be summarised as follows:

[2] Maunsell C M, Macloed M G, Wade A P, Nute G, Valentine J, Nixey C, Waller A H, Easdon S, Green, C G, Mason, R M.2004. Avian Feed Efficiency from Naked Oats (AFENO) October 2000 – September 2003. Final report of DEFRA Project Number LS3623.

The plant breeder

Plant breeders can be deemed to represent the first link in the chain. Their contribution is to continually improve the performance of varieties. This activity is a long-term investment and, in immature markets, is highly speculative. Plant breeding demands significant and continued investment over a long period of time. Market failure and risks are high and this is particular true in non established markets such as willows for biomass production. For a new crop to be successful, it requires to be adaptable to the farming system delivering a proven performance, an enthusiastic and supportive consumer and an appropriate profit which can be shared within the value chain.

It is accepted that developing new varieties is costly with at least ten years of annual breeding costs followed by a period of evaluation prior to any commercialisation, and that propagation or multiplication costs are also high. These two factors combine so that the planting material (cuttings) and therefore establishment costs are high relative to other crops. Plant breeding is specialized, high risk and does not attract new market entrants.

Traditionally plant breeders recoup their investment through royalties on the sales of varieties covered by Intellectual Property Rights which is attached to the first point of sale of seed or propagation material. In established markets such as cereals and oilseeds royalties are collected annually with a short recovery period for the breeder in that royalty is returned to the breeder within months of crop establishment. Royalties are declared and are transparent so growers have an understanding to that cost element and its relationship to the commodity price. Breeders working in established markets have the benefit of an accepted track record and can relate royalties to crop price, output and functionality. This is much more difficult in the case of perennial energy crops. In establishing the level of royalty for willows, a new perennial crop, the royalty was initially simplistically assessed in Sweden by Svalof-Weibull AB on the grounds that as the crop would be in the ground for at least twelve years, then the royalty should equate to twelve years cereal royalty. This is neither dynamic nor does it bear a direct relationship to the added value being delivered.

Another weakness with the current system is the regulation of the supply of varieties and material is open to mis-use and abuse. It has been known that cheap inferior and unproven willows have been introduced and planted in the UK which not only puts at risk growers' profitability but jeopardizes the financial stability of this emerging market. There are of course wider implications such as plant health which needs to be considered particularly in light of the fact that willows, as perennials are expected to have a viable life of ten years plus.

Despite the EU regulations forbidding the use of planting farm saved cuttings from plant protected varieties of willows, it is apparent that there is already abuse in the market place. This unlawful action denies the breeder and developer of the variety much needed income to sustain their programmes which puts at risk the long term viability of this fledgling market.

A new approach on royalties has been put forward by Senova Ltd. It proposes to replace the existing royalty method with one which is based on the area established. At present royalty is paid as a one off payment at the time of planting or purchase of clones. Under a Royalty Area Collection (RAC) approach the royalty can be drawn down over an extended period of time. Furthermore the royalty payment can be made to coincide with growers' harvest income. In this model, the grower would buy the protected clones in much the same manner as today. However as a condition of sale a contractual agreement would be entered into whereby growers would agree to pay royalty on the established area at each harvest. In this way the royalty is spread over an agreed term which in practice could be four or five harvests or annual over the life of the variety on that farm.

Crop developer and cuttings supplier

The next link in the chain is the crop developer who in essence, will, through their judgment of market prospects, build up propagation stock to take cuttings to market (grower). Their role is not only one of supplying planting material but of building confidence in the market and varieties on offer. Concept and propositional selling is important especially in crops that are undergoing development. Often this requires field trials to establish best practice advice and identify the suitability of varieties to specific regional or environmental requirement. Marketing and promotion are key elements as is the provision of sound, and reliable advice. Their leadership in this market is enhanced when there is a structured market pull (contract) from the consumer or end user.

Currently, the supply of cutting is highly speculative due to the perennial nature of the crop, need for varietial mixtures, and above all the lack of an existing market.

One of the principal difficulties faced by both the plant breeder and the cutting providers is that of producing sufficient but not excess material to satisfy the demand and market needs. Currently cutting providers are often undertaking the production without knowing the demand and inevitability this leads to waste position which of course becomes a cost. Organizations cannot afford to produce crops 'on a hope'. The cost of market failure is prohibitive. So predictive planning is essential. This will help ensure a sustainable production system and reduce costs and risks. Local production in Wales should bring cost and security of supply benefits. Senova has proposed to redress this with a tri-partite agreement engaging plant breeders, growers and end users.

Using a licensed nursery approach, a model could be developed whereby the breeder supplies the nursery with material to be trialed, assessed with the best candidate clones being brought forward for controlled production under the nursery's supervision. Such a model creates a more dynamic relationship with the key operators within a supply chain and can ensure that the value share is more fairly distributed taking into account the investment and risks of each party. Local trials and production ensures that the optimum clones are advanced taking in the specific demands for that region or customer.

Such a model provides benefits along the chain; the plant breeder would benefit from having a greater income per hectare, albeit that it is extended over a longer period; the grower would have the benefit of a lower initial charge, better advice with the optimal clones to grow therefore improving performance and profitability. The end user would have the security of a local network supplying and offering access to the most appropriate clones for that area. Such a scheme delivers benefits to all and facilitates the means by which government aid could be directed thereby stimulating efficiencies and provided much needed local trial base information which is so sadly lacking today.

Government support could be used to provide a capital allowance for specialist equipment required by nurseries and perhaps go further by providing or encouraging an assured production or certification system. One could imagine that with local or regional success there could then be developed a cluster of nurseries which could exchange information and even be encouraged by benchmark performance and share risk production. Working in a more regional basis and in a more integral way will allow for better production planning and commercialization.

Growers

Growing SRC willows will mean that farmers have replaced an arable or livestock activity. Farmers have to have confidence that biomass will be economically viable and sustainable and that they will be able to receive the necessary technical advice. In livestock areas, many will be unfamiliar with cultivations and spraying of herbicides to control weeds. In this situation, as well as with arable growers, the use of an experienced contractor is essential.

The costs of planting are currently high. The absence of planting grants in Wales remains a major barrier to the uptake of energy crops by farmers.

Contractors

Specialized planting needs to be undertaken using dedicated planters such as step planters. There are very few of these in the country and none in Wales. Contractors can ill afford to buy such specialized machinery when a market does not exist. We may therefore have to be reliant in the short term upon the few established contractors that there are to establish SRC in Wales, but need to bear in mind that when and where the market grows, there will be considerable pressure on availability.

An effective supply chain will demand attention to the needs of equipment with decisions being taken on whether to purchase and manage, or contract. A four row planter will do less than 10 ha per day. Allowing for travel, down time and weather, the area that a planter can do in a season is not large.

The “Woodfuel Industry”

From field to fuel there can be different options. In some instances, such as small scale CHP units the consumer may be willing to buy directly from local growers or buy wood chips openly in the market. However, large scale users will require a more dedicated supply chain and may prefer to contract their supply needs to others. The activity is complex and multi-facetted. Effective logistics and guaranteed consistency of product are essential. Contract production will greatly assist in planned transportation and supply.

End-user

Production is for consumption, so there must be willing buyers and users of wood chips. The future of the supply chain probably depends on the development of the marketplace and not the ability to grow crops. Barriers to the development of a healthy and dynamic marketplace need to be removed.

Investments being made by power generating companies into using energy crops and specifically SRC willows chips will demand that there is viable, reliable and continually supply of raw material for the life of that investment. To secure this, a supply chain requires to be well structured with a degree of transparency but at the same time needs to be dynamic to take into account unforeseen situations.

Co-firing is viewed as an important means of kick-starting the biomass industry. It is seen as a stepping stone to dedicated electricity generation. Both are eligible for Renewable Obligation, a significant degree of subsidy. Heat generation receives no such support. While the RCEP and others have argued for ROCs for heat, there are practical difficulties in implementation.

Others influencing the supply chain

Government

Governments intervene in order to meet policy objectives and obligations (global, European & national) particularly where there are costs and benefits that would not be realized by current market participants. In this case, the aim is to deliver a vision for clean energy production including renewable energy generation largely to meet targets of reducing CO_2 emissions, meeting the needs of the needs of society and sustainable development. Support can be in the form of commissioning R&D, some form of financial grant or advice. Sir Ben Gill has highlighted the fragmented nature of government approaches.

Research and Development

Research and Development has an important role in finding creating new scenarios. Breeding of new varieties is seen as very important in increasing primary production, from say an average of 8 odt/ha now to 10-12 t/ha using recently developed varieties to 14-16t/ha using varieties currently in the pipeline.

Growing energy crops for biomass is basically a means of converting solar energy, through the process of photosynthesis, to biomass which can then be converted to electricity and heat (compare photovoltaics). Current yields of biomass are well below theoretical potential, and improving yield through plant breeding and the selection of adapted varieties will greatly improve the economics of the biomass supply chain. For instance, selecting varieties of willow that are more branched would intercept more solar energy which can be converted to biomass. More rapidly growing crops would also enhance the option of harvesting every two years rather than every three years.

Currently, willow breeding is undertaken by Agrobransle in Sweden and by Rothamsted Research. As Wales has different conditions, the Willow for Wales project assessed new and unreleased potential varieties from these programmes at different altitudes. There was also a need to assess the yields of new varieties in standard protocol trials. There is some evidence that varieties bred in Sweden or in the south-east of England may not be fully adapted to Welsh conditions, so that the further testing and breeding of varieties for Welsh conditions (beyond the life of Willow for Wales) would be justified.

Research is also needed to quantify other benefits of biomass e.g., carbon credits, environmental benefits, application for bioremediation, to improve conversion technologies and to model supply chain issues in different currencies.

The way forward

Growers' confidence would be greatly improved by the introduction of transparent and fair contracts. Each participant of the supply chain needs to add rather than extract value from the product. There is much to be gained by sharing knowledge especially in respect to market confidences and prospects so that better informed decisions can be taken.

Prices need to be fair and sustainable. The shorter the supply chain the better.

Tactical support from WAG as justified above, would help kick start the supply chain.

Continuity in the Renewables Obligation would help to minimize uncertainty in investments for end-users and reflect the long term nature of purpose grown energy crops.

In summary, commercially viable and sustainable SRC supply chains in Wales need to be developed. Those engaged at each stage of the chain need to have adequate returns for their investment, taking account risks and added value. Fair transparent medium- to long-term production contracts will provide security to breeders, crop developers, cutting suppliers and planting contractors in order that they can make the necessary long-term investments.

CHAPTER 5

Industry's need for energy crops and SRC willow

Co-firing for electricity generation at Aberthaw, South Wales

RWE npower, a division of the RWE Group, is a leading integrated UK energy company. They supply gas and electricity to around 6.6 million customer accounts through their retail business, npower and operate and manage a portfolio of flexible low-cost coal, oil and gas-fired power stations, with the capacity to generate over 10.3 GW (gigawatts) of electricity. They currently operate three coal-fired power stations and one oil-fired power station that are co-firing solid and liquid biomass. The graph below illustrates the amount of electricity generated from co-firing operations across the portfolio between 2003 and 2007.

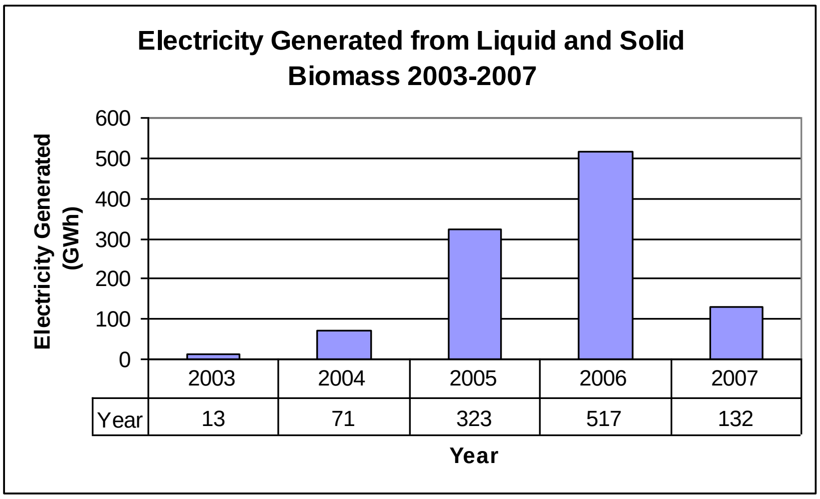


Figure 5.1

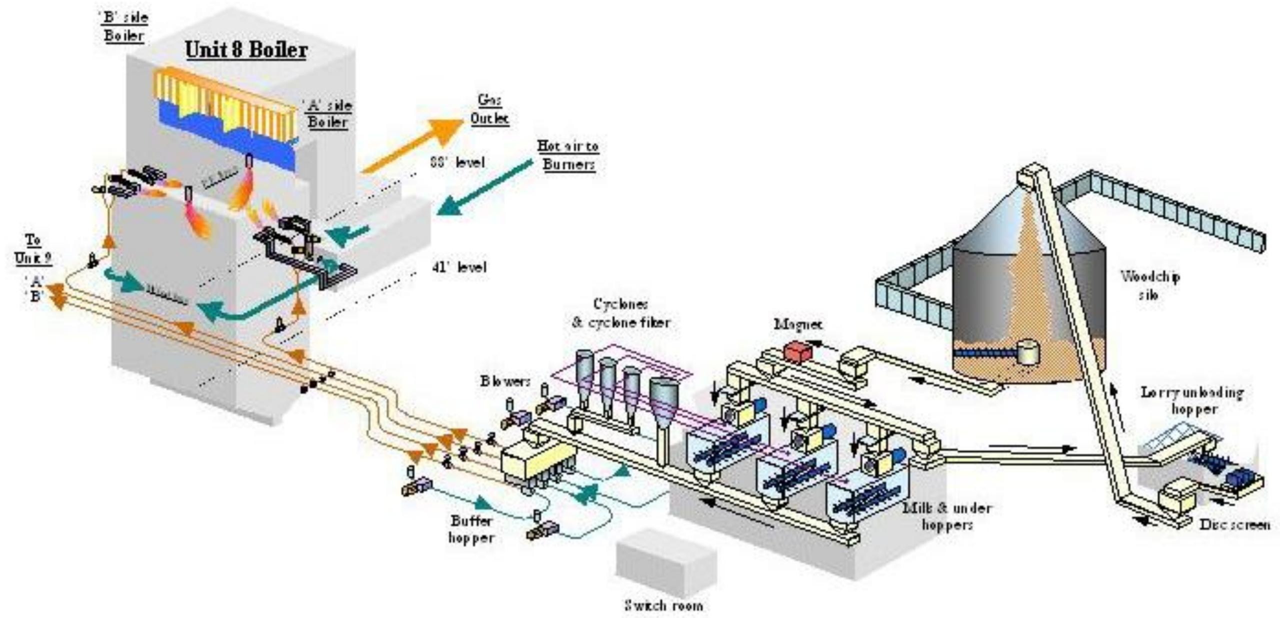
Electricity generated by RWE npower through co-firing of biomass

Source: Corporate Responsibility Reports, RWE npower (GWh = gigawatt hours)

RWE npower's decision to co-fire reflects one of its core business objectives, to minimise carbon dioxide emissions across its portfolio by one third from 2000 levels by 2015. The company has made a commitment to increasing the amount of electricity that it generates from renewable sources and helping the UK government to meet its climate change targets. The company supported the introduction of the Renewables Obligation (RO), which requires electricity suppliers to supply an increasing proportion of their electricity from renewable sources or to pay a buy-out price. Stimulated by the RO, RWE npower have invested in developing renewable energy projects which are eligible for Renewable Obligation Certificates (ROCs) which can then be submitted against their obligation. In 2007 131,892 ROCs were generated from co-firing operations across the portfolio.

At RWE npower's coal-fired power station in South Wales, Aberthaw, several schemes have been developed to enable co-firing of both solid and liquid biomass. And in 2007 just over 14,000 tonnes of solid biomass was co-fired. The power station has a total capacity of 1,500 MWe, equipped with three main units and three gas turbines and provides enough electricity to meet the needs of approximately 1.5 million people. It has been in operation since 1971 and employs around 290 people. A processing plant for sawdust on one of the main units became operational at the end of 2005. And in 2007 the final stage of a £10 million investment in a solid biomass processing plant for the other two main units was completed. This will result in carbon dioxide emissions being cut by over 200,000 tonnes per annum by reducing the amount of coal combusted. Planning permission was required for the construction of the solid biomass processing plant under the Town and Country Planning Act 1990. In addition, authorisation to co-fire was required from the Environment Agency under the Environmental Protection Act 1990, now replaced by the Environmental Permitting Regulations 2007 and associated Environmental Permit. The investment is made up of woodchip reception and storage, silo storage, milling, dust collection, weighing, batching and conveying equipment. The schematic below shows how the plant works in simple terms.

Figure 5.2 Schematic of solid biomass processing plant



Up to four days worth of woodchip can be stored in the silo and reception area (approximately 4000 tonnes), ideally sized 9cm^3 or less with a moisture content of 50% or less. Woodchip is transferred to the infeed by a horizontal auger where an electromagnet separator removes ferrous metals before the material is fed by a conveyor and slide valves to three hammer mills. Once milled material is transferred to a bulk hopper and passed by weigh belt feeders to either one of the main units. Pneumatic conveyors then pass the material along pipelines to the boiler where four injection devices are situated to control the flow of material into the boiler.

In the first half of 2008, operation of facility was reduced due to delays in the commissioning of the Flue Gas Desulphurisation (FGD) on the main units. This led to an overload of woodchip onsite and problems with storage. Prolonged storage of woodchip caused further issues in operation of the biomass plant, affecting the performance of the mills. In the second half of 2008 operation of the facility improved but was constrained by fine tuning of the FGD process and securing biomass supplies.

Figure 5.3

Solid biomass processing plant

Feedstocks for the plant currently consist of virgin wood from forestry primarily sourced locally, however trials have been conducted using Miscanthus and willow in an effort to increase the diversity of the fuel mix. In support of expanding feedstocks for the plant, RWE npower are currently engaged in negotiations with Bical, a developer and supplier of Miscanthus. The negotiations aim to agree terms for the procurement of significant quantities of Miscanthus per annum, subject to establishing technical feasibility. (Bical Website, 2008). In support of the negotiations, Bical are approaching farmers in South West England to grow Miscanthus, where planting grants are available. The grants are available from Natural England and aimed at offsetting some of the growers' establishment costs, subject to its environmental criteria, which helps to make the crop more profitable.

Research undertaken in a separate Objective 1 project (Steer et al, 2008a,b) has helped to demonstrate that willow and Miscanthus provide economic and sustainable sources of biomass with suitable combustion quality for co-firing at Aberthaw. As indicated above, a supply chain exists in South West England for Miscanthus but not for willow, which gives Miscanthus the edge at the present time.

Electricity generation through co-firing at Welsh Power's Uskmouth plant and in a dedicated power station near Newport, South Wales.

Welsh Power is undertaking co-firing of biomass in its Uskmouth plant and has a dedicated biomass power station at the planning stage. At present, they are using shea meal, olive residues and wood pellets as the biomass resource, but wish, in line with the policies of the UK and Welsh Assembly Governments, to use as much locally grown energy crops, as possible for reasons of sustainability and security of resources. While energy crops can be sourced abroad or in England, they consider it very important that as high a proportion as possible be sourced around Newport in order to reduce transport costs and carbon footprint and to offer development opportunities within Wales.

In conjunction with Lantmannen Renewable Fuels, we believe that 4000 ha of energy crops in a 50 km radius of Newport would be a reasonable target. This represents approximately 1/20th of the land suitable for energy crops in the area based on WAG GIS figures. We are satisfied that this land use will assist diversification rather than result in competition with primary food production, that there will be positive effects on biodiversity and ecosystem quality, and that there will be positive carbon benefits resulting from substitution of fossil fuels and sequestration as long as only improved grassland and arable areas are used.

The development of biomass heating systems by EGNI and others

EGNI has been involved in 50kW to 1MW heating systems throughout rural and urban Wales and is now involved in the proposed 17.5 MWe biomass power station in Rassau Ebbw Vale and a pelleting plant at Rhymney, Gwent. It perceives a biomass requirement of 270,000 t for both plants, of which 30,000 t will be from energy crops (Jones, 2007).

More details of EGNI's activities in Wales are as follows;

- The Rhymney pellet plant is progressing steadily and should be on track to commence full production by Q4 2009 (130,000t raw material required)

- Ebbw Vale power station (17.5MWe) is still in the planning process, due commissioning date Q4 2010

- Completed feasibility work on Anglesey/Gwynedd power station (8 – 12MWe), the work carried out on the w4w project played a significant part in deciding on the proposed fuel mix for this proposal.

- The feasibility of a much larger power station on the Holyhead site that could provide power for Anglesey Aluminium is being investigated

- EGNI ESCo was launched in early September. This will offer Energy Supply Contracts based on renewable energy across the UK. It is proposed to include energy crops as a feed source for this business.

The Bluestone development has led to the formation in 2004 of the PBE Bioenergy as a producer co-operative to grow, market and supply biomass and develop 'Fuel to Flame' supply chains. It too is finding recruitment of farmers difficult.

One of the farmers involved in the Willow for Wales project (Bridgend) has installed a biomass boiler. The availability of their own secure source of biomass helps to justify investment in both demand and supply.

It has been estimated that by 2010, there will be a demand for 130MWe and 285MWh, requiring 1.5 m t of biomass, rising to 230MWe and 500MWh requiring 2.5 m t of biomass in 2020 (Jones, 2007). These amounts cannot be met by forestry and recycled timber alone and will either have to be imported or grown on Welsh farms.

The effects of competition on the availability of biomass

A recent assessment of the Welsh wood fuel industry's views on the current market concluded that "although currently there doesn't tend to be a problem sourcing fuel for the small dispersed heat projects, the larger power stations are beginning to find that, unless long term contracts are in place, they may be bidding against each other for the same materials" and that "competition between energy customers for biomass materials is beginning to take place" (Horne & MacDermott, 2007).

This assessment strongly suggests that energy crops will be needed, as suggested in the INTRODUCTION.

CHAPTER 6

Technology transfer, presentations and consultations

Appendix 5 contains a summary of the projects extension and dissemination activities

Farms have been used for real 'touch–and–see' demonstration events to inform farmers and others on the role of renewable energy sources in mitigating CO_2 emissions, how to grow willow, likely returns, end-uses and benefits to biodiversity. The balance of attendees at Open Days switched from being dominated by people with a general interest in green energy when we held events in 2004 to later being dominated by land owners.

IBERS demonstrated the use of SRC willow for heat and power at shows and other events, and given interviews to press and radio.

Together with Rothamsted Research, John Valentine, together with Iain Donnison and John Clifton-Brown met with Sir Ben Gill at Rothamsted Research to present their views to the Biomass Task Force. John Valentine was also invited to a meeting in London to discuss tentative conclusions of the Biomass Task Force.

John Valentine presented written[3] and oral[4] evidence to the House of Commons Welsh Affairs Committee Inquiry into Energy in Wales. The report[5] quoted John Valentine's description of biomass as 'the sleeping giant of renewables' and his conclusion that confidence inducing measures and setting targets were essential to kick-start the biomass industry. It welcomed the investment that has been put in to research projects such as the Willow for Wales and looked to the Government to provide a strategic framework in which energy crops in Wales can become a commercial reality.

John Valentine and John Clifton-Brown gave written and oral evidence to the National Assembly's Environment Planning and Countryside Committee's in relation to biofuels and bioenergy on 23rd March 2006.

John Valentine, Fred Slater and Victoria Davies served on the Woodland Development and Biomass Steering Group 2006-2007 and assisted with the drafting of the CONSULTATION ON A BIOENERGY STRATEGY FOR WALES in 2007.

Valentine J, Duller C, Hinton-Jones M, Evans B, Slater F, Fry D; Tubby I, Jones C, Wilson E, Jones E, Sanders J, .Oldridge A, Green C G, Larsson S, Heaton R and Perkins G gave a visual presentation in the 14th Biomass Conference in Paris in 2005.

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[3] John Valentine, John Clifton-Brown and Iain Donnison House of Commons Welsh Affairs Committee. Energy in Wales. Third report of Session 2005-06 Volume II Ev 86- Ev 87.

[4] John Valentine House of Commons Welsh Affairs Committee. Energy in Wales. Third report of Session 2005-06 Volume I, 108pp.

[5] House of Commons Welsh Affairs Committee. Energy in Wales. Third report of Session 2005-06 Volume II Ev 87- Ev 90.

John Valentine, Chris Duller and Maurice Hinton-Jones gave a presentation on Willow for Wales – Making the Bioenergy Supply Chain Work at the Energy Crops in the Atlantic Space conference at Evora, Portugal in December, 2007.

John Valentine gave a presentation at the CAT conference on 'Zero-Carbon Land Use' in March 2008.

John Valentine, Peter Randerson, Rebecca Heaton and Chris Duller presented a poster on the economics of SRC in the UK at the 16th European Biomass Conference in Valencia in June 2008.

Chris Duller gave the presentation on behalf of himself and John Valentine at the AAB Biomass and Energy Crops III conference at York in December 2008.

Maurice Hinton-Jones presented a poster on behalf of himself and John Valentine at the AAB Biomass and Energy Crops III conference at York in December 2008.

Danielle Fry made a well-received presentation at the Welsh Ornithological Conference on 'The birds of short-rotation willow' in November 2008.

Danielle Fry and Fred Slater presented a paper at the AAB Biomass and Energy Crops III conference at York in December 2008.

Edward Jones gave a presentation on 'The Demand for Biomass Energy in Wales – A Developer's View' at the Welsh Assembly's Biomass Energy Conference at Llandrindod in March 2007.

IBERS also participated in a number of consultations.

In 2007, IBERS made comments in relation to the EU Common Agricultural Policy: 2008 Health Check Q2 regarding the rate of compulsory modulation and what aspects of RDP activity might benefit from increasing compulsory modulation.

In 2008, IBERS responded to the request for feedback from the Innovation Partnership Wales Strategy Group in relation to the Renewable Energy Route Map for Wales. In putting forward the case for diversification, IBERS recognises that livestock farming will remain the focus of Welsh agriculture, but there are risks associated with ignoring the need for change and 'putting all one's eggs in one basket'. In relation to biodiversity, IBERS pointed out that the Wales Biomass Centre had produced a considerable body of evidence of enhanced biodiversity from short rotation coppice willow for energy.

IBERS also took the opportunity to respond to the Review of Land Management Actions under Axis 2 of the Rural Development Plan 2007-2013. IBERS's view was that climate change mitigation should be central to a new strategy. It is the most serious environmental challenge of our time. IBERS calculated that 0.461-0.646 Mt of C equivalents, about 30-40% of the total emissions from Welsh agriculture, would be saved per 100,000 ha of energy crops in Wales. This does not take into account the substitution of methane from animals (about 40% of total agricultural emissions).

CHAPTER 7

Conclusions

Commercial scale blocks of SRC willow were successfully established on seven farms in Wales. They have been used to demonstrate production to interested farmers and others. We have quantified the actual inputs in the seven blocks costed at 2007 levels. Results compared favourably with estimates obtained in England (Defra, 2006). Given yields of 10-15 odt /ha and realistic prices (£60-75/ t) that take into account inherent energy value, high competition for resource and climate change mitigation, attractive returns can be obtained.

The sites have also shown the high value of SRC and associated interfaces with other habitats to be valuable for bird and insect biodiversity.

The project has also acted as a focus for discussions with end-users and other participants of biomass supply chains. It should be borne in mind that unlike the petrochemical supply chain, biomass supply chains are at an early stage of development.

The project has however raised a number of issues that act as barriers to take-up by farmers and the development of robust supply chains.

First, there were considerable difficulties in relation to Single Farm Payments. Separate arrangements exist for Wales. Hopefully initial teething problems have now been ironed out and farmers and those responsible for administering the Scheme in Wales are aware that SRC willow is eligible and the conditions for eligibility.

Secondly, there is no planting scheme for Wales which would cover part of the establishment costs. It is understood that the initiation of a planting scheme will be the subject of a wide consultation on biomass in Wales, but even if accepted, it would be ready too late to support planting in 2009. Alternatively the differential levels of Renewal Obligation Certificates give electricity generators the opportunity to support SRC. We have also made the case that SRC could be supported in the next generation of agri-environmental schemes. In the absence of planting grants in Wales, it is likely that the energy crops as part of the biomass mix will come from outside Wales or will be imported.

Thirdly, despite past research and development that has resulted in published guidelines, there are a number of technical issues that would be difficult for individual farmers to deal with. Weeds presented a major problem. More research would seem to be justified on herbicide choice and non-herbicide methods of control, such as planting into nurse crops that suppress weeds but offer little competition to the willow crop or the use of mulches. Good drainage and/or better harvesting methods are also essential to allow harvesting to take place without severe damage to soil structure.

Lastly, this project has provided not only useful experiences but importantly has highlighted some of the commercial weaknesses which will need to be addressed if the crop is to have a sustainable future. In order for this to be achieved, it will be essential that there is greater integration between those involved in value and supply chain delivering greater transparency and assured quality both in terms of cutting and technical advice. Potential new growers are at a loss to have qualified and independent advice and there is a need to better improve the technology transfer and commercially sound advice to those who are eager to engage in this new enterprise. Commercially viable and sustainable SRC supply chains in Wales need to be developed. Those engaged at each stage of the chain need to have adequate returns for their investment, taking account risks and added value. Fair transparent production contracts need to be put in place that will provide security to participants of the supply chains so that they can make long-term investments.

We have examined ways of taking the project further. Unfortunately the new Convergence programme does not support the primary production of energy crops. This would need to be supported by the Rural Development Plan.

There is good scope however for industry to develop supply chains and for supply chain participants, such as a willow developer, to seek Convergence or government support of planting and harvesting machinery and infrastructure.

The high potential for job creation upstream of primary production of biomass suggests that policy makers need to take account not only the needs for greater diversification of agriculture in Wales but also the needs of the whole economy in terms of renewable energy and sustainable rural and urban development. Wholehearted support of the development of energy crops is required to meet current and future Industry needs and policy objectives.

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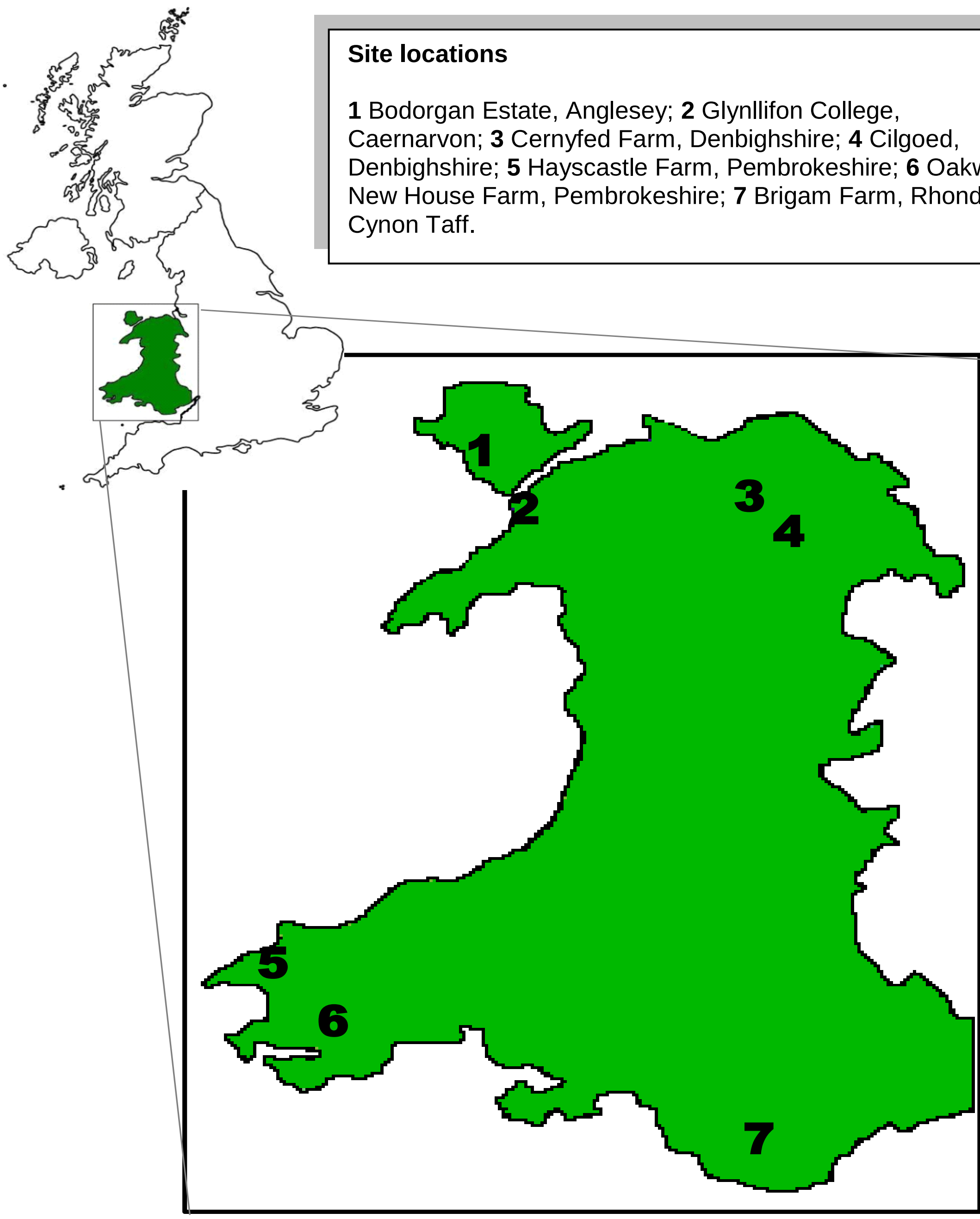
APPENDIX 1

Willow for Wales: The sites

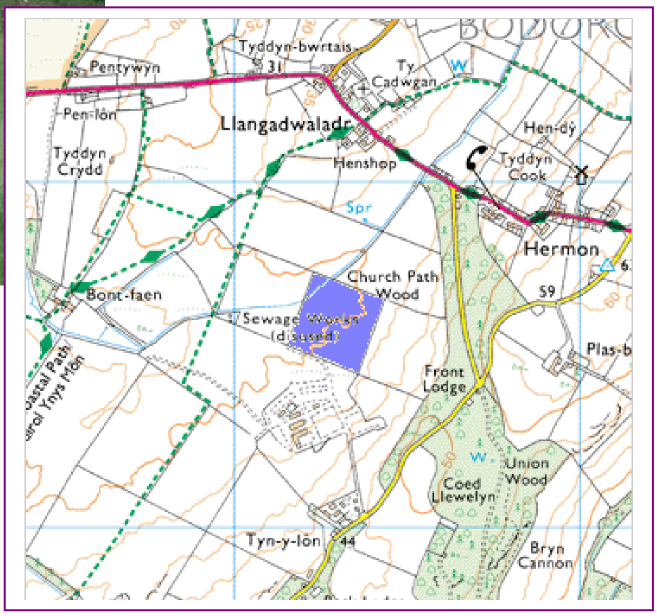
The Willow for Wales project planted seven sites across Wales. All were located on farms that consisted predominantly of improved grassland habitat but at a range of altitudes and soil types representing a cross section of the Welsh environment. Due to this variation, ground preparation and planting varied between the sites according to the cropping history and site-specific practicalities. The main difference in management practice between sites was in herbicide application. The area planted at each site ranged from 3 to 10 ha with a mean of 5.1 ha. Planting material was a mixture of five willow varieties: Tora, Tordis, Sven, Ashton Stott and Resolution. All of these varieties are *Salix viminalis* hybrids and therefore have similar characteristics. In addition, the varieties were planted as an intimate mixture rather than discrete blocks giving each site the same overall structure.

Site locations

1 Bodorgan Estate, Anglesey; **2** Glynllifon College, Caernarvon; **3** Cernyfed Farm, Denbighshire; **4** Cilgoed, Denbighshire; **5** Hayscastle Farm, Pembrokeshire; **6** Oakwood, New House Farm, Pembrokeshire; **7** Brigam Farm, Rhondda Cynon Taff.

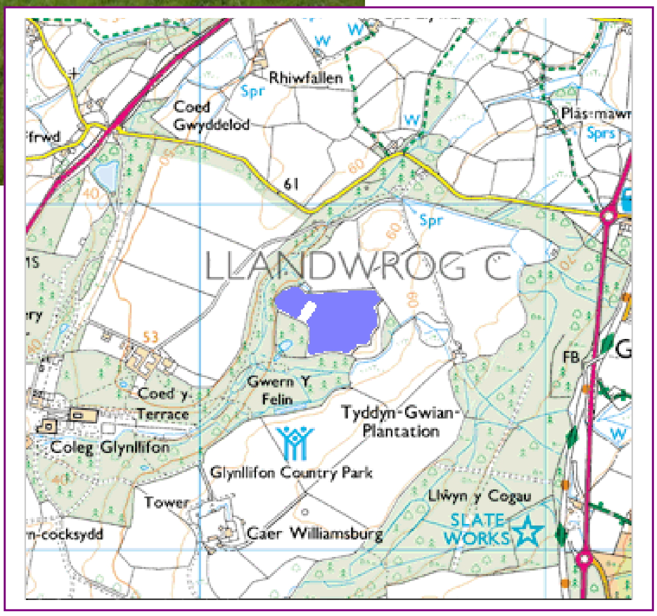


Bodorgan Estate, Anglesey, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



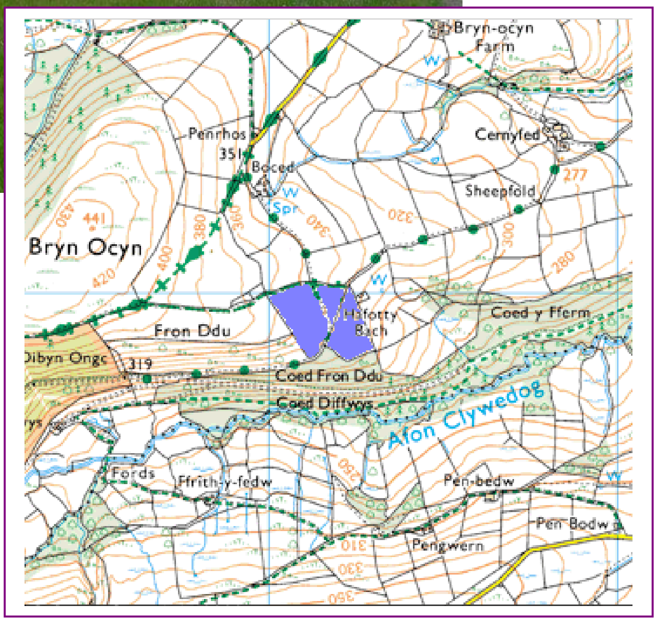
Grid Reference:	SH 383 685
Planted area:	4.77 ha
Altitude:	50m above sea level
Slope:	-
Aspect:	-
Soil:	Silty loam/silty clay loam with medium stones to 25cm
Drainage:	Moderate, slightly impeded drainage
History:	Long term set aside for past 10 years – cereals previously
Bordering vegetation:	Mixed arable, grassland – mature alder trees on W and NE boundary
Landscape:	Woodland belt to SE of site, mixed conifer/deciduous woodland block to N and farm buildings to W. Hamlet 1km to east on ridge

Glynllifon College, Caernarfon, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



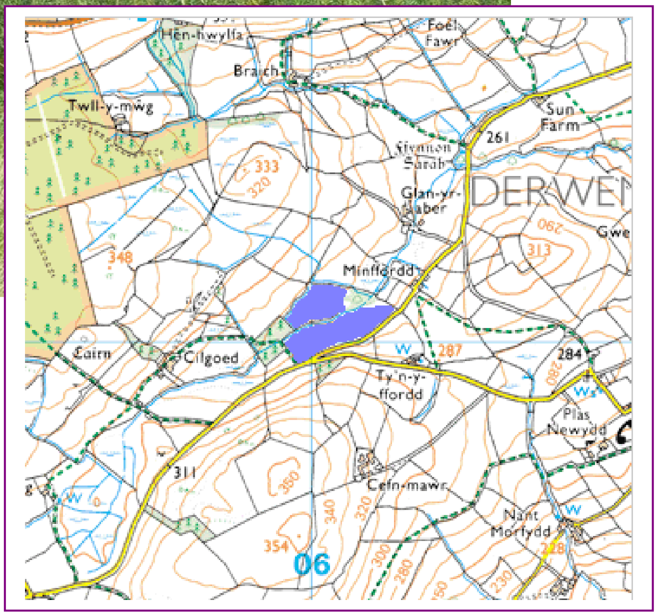
Grid Reference:	SH 464 557
Planted area:	4.36 ha (from 4.76)
Altitude:	50m above sea level
Slope:	-
Aspect:	-
Soil:	Silty clay loam
Drainage:	Free draining
History:	Maize in recent years
Bordering vegetation:	Permanent pasture and mature woodland
Landscape:	No dwellings overlooking site

Cernyfed Farm, Denbighshire, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



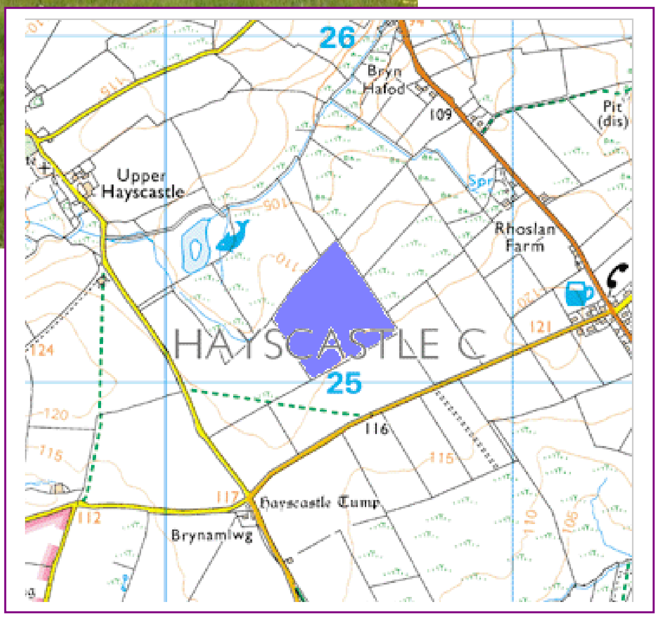
Grid Reference:	SJ 033 579
Planted area:	3 ha
Altitude:	300m above sea level
Slope:	Up to 12%
Aspect:	SE
Soil:	Brown earth – Denbigh series – over laying shale
Drainage:	Free draining soils
History:	Long term permanent pasture – sheep grazing
Bordering vegetation:	Cleared forestry on southern boundary (scrub) perm pasture elsewhere. Split by old field boundary (hawthorn and blackthorn)
Landscape:	Concerns over proximity of small holiday cottage compromised the planting area slightly

Cilgoed, Denbighshire, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



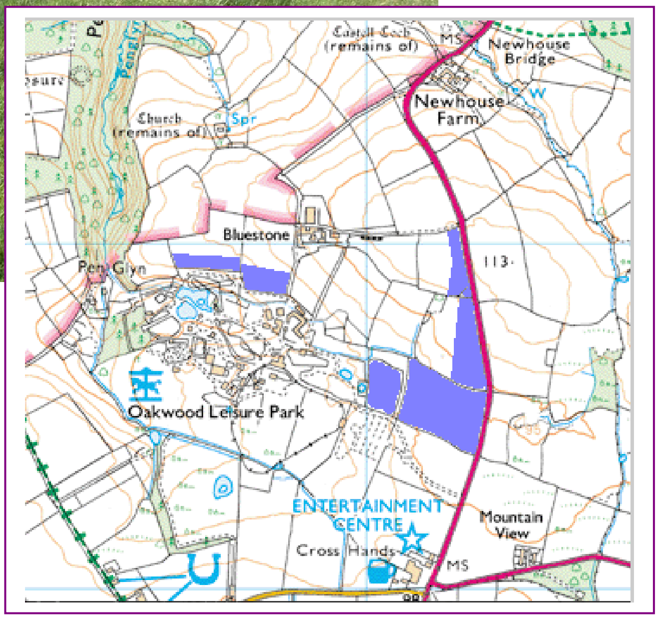
Grid Reference:	SJ 061 510
Planted area:	4.2 ha (from 4.6)
Altitude:	300m above sea level
Slope:	3%
Aspect:	NNW
Soil:	Silty clay loam – stony below 15cm
Drainage:	Steam bed bisecting fields – under drained. Some wetter areas
History:	Grassland – ploughed and reseeded in 2001
Bordering vegetation:	Mixed species hedge to S and E, streamside corridor on northern edge (willow, hazel, and ash). Adjoining fields are perm pasture – area of wet grassland habitat on NW boundary
Landscape:	No dwellings overlooking site

Hayscastle Farm, Pembrokeshire, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



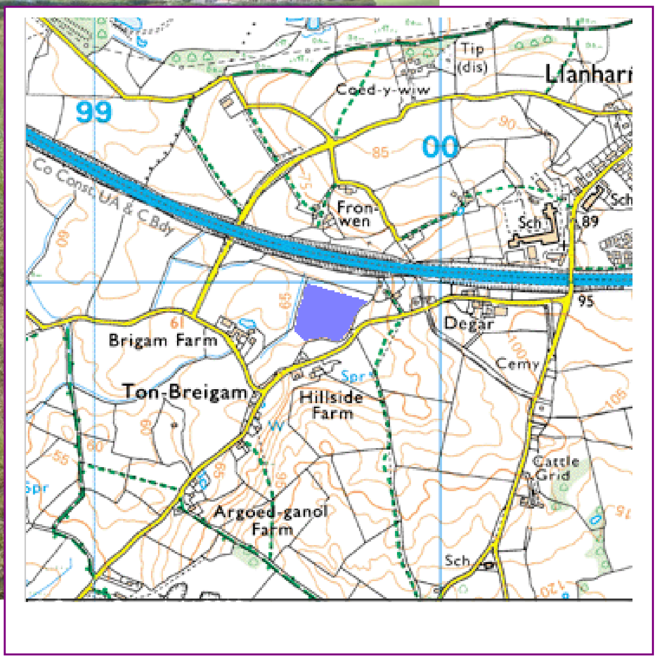
Grid Reference:	SM 904 255
Planted area:	5.86 ha
Altitude:	110m above sea level
Slope:	1%
Aspect:	SW
Soil:	Peaty loam (6-9 inches) above semi permeable clay
Drainage:	Old drains in place but not effective – some temporary surface water logging
History:	Reseeded as permanent pasture within the last 20yrs – previously cereal crops
Bordering vegetation:	Permanent pasture
Landscape:	No overlooking dwellings – low gradients restrict any visual impact

Oakwood, New House Farm, Pembrokeshire, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



Grid Reference:	SN 072 126
Planted area:	10 ha
Altitude:	100m above sea level
Slope:	-
Aspect:	-
Soil:	Silty clay loam
Drainage:	Well drained – 2 fields with ditch to north
History:	Permanent pasture – reseeded within last 15 years
Bordering vegetation:	Fields bordered by mixed species hedges including some mature oak, ash and willow. Adjoining fields of permanent pasture. Leisure park on SW side
Landscape:	Minimal impact – low gradients – no dwellings

Brigam Farm, Rhondda Cynon Taff, site description and surrounding landscape. The area planted with SRC is highlighted in purple on the map.



Grid Reference:	SS 997 799
Planted area:	3.3 ha
Altitude:	60m above sea level
Slope:	-
Aspect:	-
Soil:	Silty clay loam
Drainage:	Well drained
History:	Permanent pasture
Bordering vegetation:	M4 runs along the northern edge, remainder is permanent pasture
Landscape:	Minimal impact – low gradients – Farm house and buildings to SW

APPENDIX 2

A synopsis of chemical weed control

Note: This synopsis does not constitute an endorsement or recommendation of herbicides that can be used in SRC willow. An advisor certified by BASIS (the registration, standards and certification scheme for pesticides and fertilisers) will be able to advise individuals on the most suitable type of herbicide for your situation and on when best to apply it. The Pesticides Safety Directorate: Code of practice for using plant protection products (England and Wales) http://www.pesticides.gov.uk/safe_use.asp?id=64 and Scottish Government: Code of practice for using plant protection products in Scotland http://www.scotland.gov.uk/Publications/2006/12/19110050/0 must be consulted in relation to the statutory obligations associated with the application of pesticides.

Pre- planting

The use of a non-selective, broad spectrum herbicide like glyphosate is strongly recommended in the autumn prior to establishment. Following spring cultivation a second application will control any flush of new weed growth. In this project, we applied glyphosate in the spring partly as a result of limited time between identifying farms and getting permissions and partly as a result of the desire of livestock farmers to retain their winter grazing.

Once the willow is planted the choice of recognised herbicides is limited and relatively expensive. Few sprays have full label approval for use on willow, though some have specific off-label approval (SOLA). This limited choice of herbicides highlights the importance of pre-establishment weed control.

Pre- emergence

Immediately after planting residual herbicides should be applied to the seed bed to control emerging weeds.

Early SRC plantings in the UK and most of Central Europe and Scandinavia were based around the use of the Atrazine and Simazine that had been used widely in the forestry sector. With their withdrawal from Annex I of Directive 91/414/EEC due to concerns over transfer to aquatic environments, growers have had to look to other effective residuals. Final expiry of essential use was Dec 2007.

Pendimethalin (Stomp 400) is currently seen as the strongest contender as an industry recognised replacement. Applied immediately post planting at 4l/ha it provides good control of annual grasses and some broad leaved weeds. In the first of the Willow for Wales farm plantings the residual programme included isoxaben (Flexidor) at 1l/ha in addition to pendimethalin to increase control of broad leaved weeds. This amide herbicide also has a recognised increased persistency (with a soil half life of 100 days). However at a cost of over £70/,l its economic worth has been questioned. Diflufenican (Hurricane @0.25l/ha) has been used in conjunction with pendimethalin by some growers to increase control of broad leaved weeds under off label approval.

The efficacy of residuals is dramatically reduced in very dry soils and in soils with organic matter contents above 6%. Whilst pendimethalin has proven suitable in arable/setaside conditions, its use in soils coming out of long-term grassland (with high OM%) is less assured.

Post emergence

There is a range of sprays approved for the control of both grass and broad-leaved weeds in farm forestry. Current practices include; grass control using cycloxydim (e.g. Laser @1l/ha +adj), propaquizafop (e.g. Falcon @1.5l/ha) or fluazifop (e.g. Fusilade Max @3l/ha) and broad leaved weeds control using clopyralid (Dowshield @1l/ha).
Propaquizafop is generally preferred for black grass control whilst cycloxydim is recognised as a better means for couch control.

For weeds like spear thistle, it is recommended that clopyralid is applied in two applications, to sensitize the target. The second application is applied as the target shows significant signs resulting from the first spraying – normally between two and three weeks. This practice also reduces the risks of crop damage from double dosing strips.

Metsulfuron-methyl (Ally SX @42g/ha) has been trialled for control of annual broad leaved weeds but with variable levels of crop damage. Other actives that have been trialled by growers trying to find cheaper alternatives to recognised chemicals include MCPA, Mecoprop-P and 2-4.D – all with damaging results.

The sensitivity of the crop to a range of actives emphasises the care needed to ensure that there is no contamination of spraying equipment. Most problems with damaging tank residues have been experienced on predominantly grassland farms where operators are less familiar with equipment and do little spraying.

Post cutback

One of the key factors dictating product choice is weather conditions. Many growers to avoid creating wheel markings will look to access their crops during dry conditions, which invariably are associated with high atmospheric pressure and cold temperatures. In such conditions, propyzamide (Kerb @ 3.75l/ha) has been used effectively against existing grass weeds (particularly couch) and providing protection against emerging annual broad-leaved weeds. However, its residual activity will be compromised by mild weather conditions. It is less effective where there is a large amount of organic material and where possible we have advised grazing (mob stocking) with sheep ahead of cutback to reduce this bulk. With an imminent cutback, there is little risk of sheep-browsing damaging the crop.

In warmer conditions, non-selective contact herbicides have been used effectively. Glufosinate-ammonium (Harvest 4l/ha) provides good control of grass weeds, although its control of large spear thistle has been less convincing. Amitrole (Weedazol) applied at forestry volumes (10l/ha) has proven a valuable tool in crops contenting with grassland weeds (thistles, dock and grasses). This can be used even when the crop is starting to sprout with only moderate crop check. In exposed sites it is recommended that it is mixed with Codacide oil (9l Weedazol + 1l adj) to improve target contact and prevent drift.

APPENDIX 3

Protocols for biomass assessment of short rotation willow coppice plantations

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This protocol is to allow willow grown in Short Rotation Coppice to be measured in order to gain an estimate of the total standing volume of the crop. The diameter of all the stems on a stool at 1 m perpendicular to the ground will be measured for a 0.5% semi-systematic sample of the stools within the crop. The sampling plan to be used for the site will be to select every 20th row of the block and every 10th stool within each selected row.

The sampling procedure will be:

1. For each block a corner is selected to start from.

2. A random number, N, between 1 and 20 is noted on the data form, and the first row of the block to be sampled will be the Nth row in from the corner, followed by every 20th row after the first sampled row. When the last row has been identified, count the number or remaining rows in the crop and note this on the data form.

3. For each row to be sampled, another random number between 1 and 10 will be noted on the data form. The Nth stool along the row will be the first stool sampled, followed by every 10th stool after that along the row.

4. The number of live and dead stools within the sample row will be counted and noted.

5. For each stool in the sample, the number of stems of height greater than 1 m will be measured for its D100 value. Shoots that are less than 1 m tall are deemed not measurable and are not counted or recorded.

[NB If the planting pattern of the crop is very regular so that dead or missing stools are easy to identify, dead or vacant stools will be included in the selection procedure, otherwise they will be ignored and only live and productive stools will be counted and selected for the sample. In these circumstances missing stools will be classified as dead under note 4 above.]

Measurements and observations will also be taken on the area occupied by each block or plot to obtain its stocking rate. Before sampling each block, its dimensions and shape will be measured and recorded from which the total land area occupied by crop in the block can be estimated. Measurements can be made using tapes, GPS or GIS. Please make a note of which method was used when recording the area. From these observations a stocking rate for the block and the total number of stools in the block can be estimated.

D100 measurements will be made with the use of Masser digital callipers supplied by Forest Research (Masser, Oy, Finland). Shoot diameter should be measured 1 m vertically from ground level. These callipers record each diameter measurement to the nearest millimetre. The digital callipers are set up to electronically record the calliper reading and other records that identify the stem being measured. The procedure used for recording data on these instruments is described below under 'Instructions for use of Masser digital callipers'. Before taking any measurements on shoots, the dead leaves should be removed, to ensure that assessments can be taken without interference from foliage.

Model development

A straightforward approach was used to estimate standing biomass at the trial sites at the end of each growing season. The data collected during the destructive field assessment was used to establish relationships between D100 and shoot dry weight. The established relationships were applied to the D100 measurements recorded during the non-destructive assessment. Plot dry weights were calculated and transformed into a more meaningful 'oven dry tonnes per hectare' measure. The following description refers to the methodology used at the end of the first growing season following cutback at sites planted in 2004. A similar approach was used in subsequent years.

Translation of stem diameter measurements (D100) to stem dry weight

The object of this exercise was to find a mathematical function which described the relationship between stem dry weight and shoot diameter at 1m above ground level (D100).

Three forms of relationship between dry weight and D100 were fitted and investigated. Denoting dry weight as w, these were:

1. Polynomial

These relationships are of the form;

$$w = a + b_1 D100 + b_2 (D100)^2 + b_3 (D100)^3 + \varepsilon$$

Considering the dimensionality of the variates, where dry weight of the stem would most likely be closely proportional to stem volume, it was assumed that polynomial functions up to order 3 may be necessary to represent the relationship.

Statistical analyses (using Genstat®) showed that differences between the fitted curves for each variety were statistically significant. It was therefore decided on the basis of this to fit separate polynomials for each variety, and to assess the order of polynomial required to represent the relationship within each variety. Based on the statistical significance of fitted polynomial coefficients, it was found that a cubic polynomial was required for Jorunn, a linear model was sufficient for Q83, while a quadratic model was required for Germany.

2. log-log

The form of these relationships are;

$$\ln(w) = a + b * \ln(D100) + \varepsilon$$

The functional form of this on the dry weight scale is;

$$w = a(D100)^b$$

Error terms are assumed to be homoscedastic[6] on the transformed log scale, which proved to be a more accurate assumption than the assumption of constant variance

[6] = similar variances. This is also known as homogeneity of variance.

on the original scale, which showed evidence of increasing variance with increasing value of dry weight.

Statistical analysis again showed differences in the relationships fitted to the data for each variety and therefore separate relationships were assumed.

3. Exponential

These relationships are of the form;

$$\ln(w) = a + b * D100 + \varepsilon$$

Errors are again assumed constant on the log scale for *w* and the functional relationship for *w* is of the form;

$$w = c * \exp(b * D100)$$

where *c* = exp(*a*)

In this case, there were no significant differences between the gradients (*b*) fitted to each variety, but there were differences between the intercepts (*a*), resulting in parallel lines representing the relationships for each variety.

The choice between the 3 forms of relationship was mainly based upon the relative values of R^2 expressing the percentage variance of dry weight explained by the model. Of the 3 forms of model, the polynomial equations gave the highest R^2 value of 98.3% across the data for all 3 varieties, whilst the values for the other forms were around 93%. The exponential model involved the least parameterization, and because of this, and the better modelled error structure, would generally provide a better structural representation of the relationship between dry weight and D100 than the polynomial models. However, given the purpose of the models to translate and interpolate D100 measurements into estimated dry weights, the higher R^2 of the polynomial models was preferred and these were accordingly selected for use on the D100 measurements collected at the experiments.

In applying these models to the D100 data, a problem was identified on their range of application. The lower end of the range of data on D100 values was higher than some observations taken in the main experiments. Extrapolation of the fitted models to these lower values resulted in negative estimates of dry weight for the Q83 variety, and increasing dry weight with decreasing D100 values for the other two varieties. Since the fitted models evidently could not be extrapolated beyond the D100 range on which they were fitted, they were replaced for low values of D100 with interpolation between the origin (with a D100 of zero equated with zero dry weight) and the fitted value at the minimum of the range of the fitted curve.

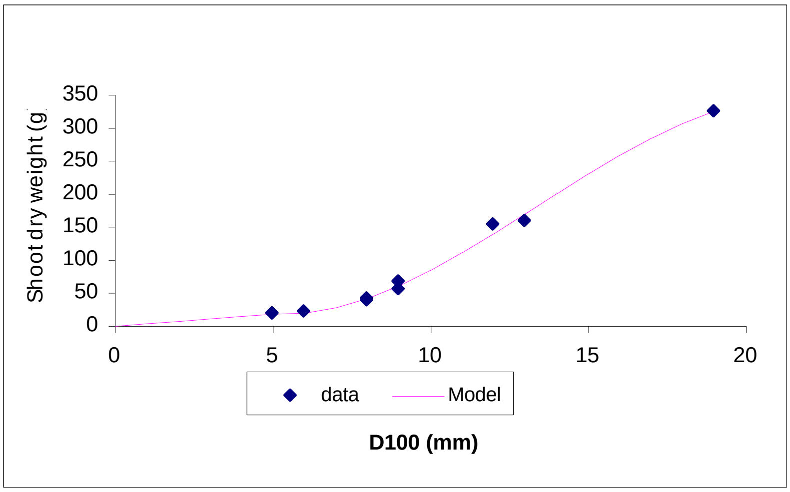
The fitted relationship for each variety was:

Jorunn: $w = 149.4 - 53.7 * D100 + 6.29 * (D100)^2 - 0.1566 * (D100)^3$

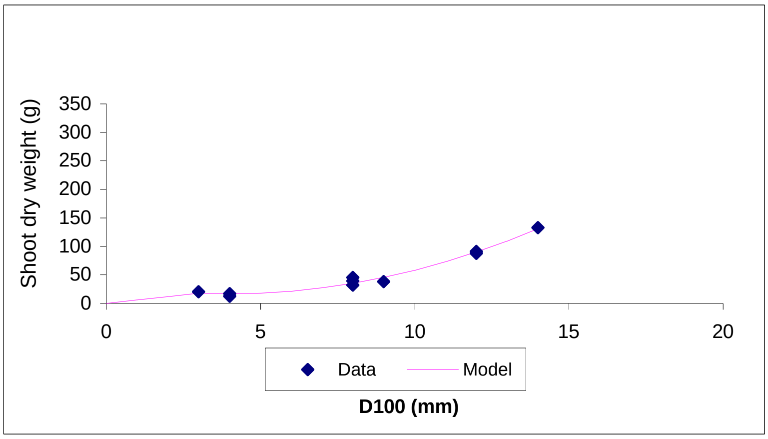
Q83: $w = -45.9 + 14.55 * D100$

Germany: $w = 34.58 - 9.02 * D100 + 1.137 * (D100)^2$

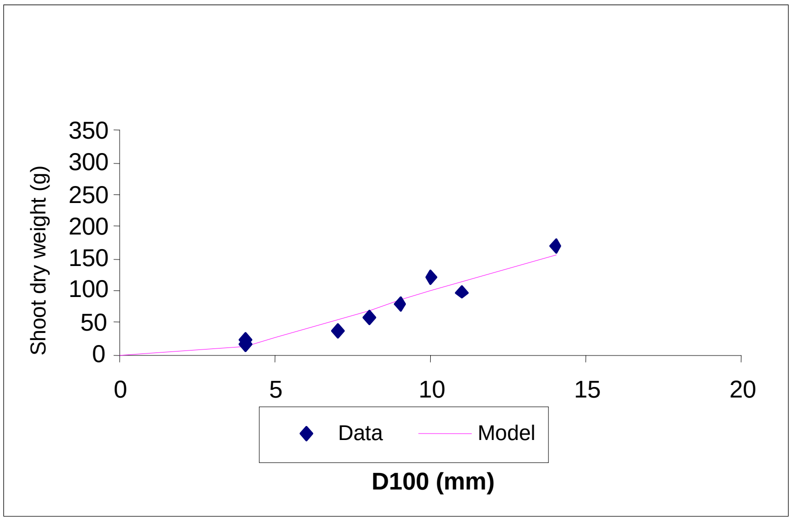
These fitted relationships are shown with the original data and the interpolation at low D100 values in Appendix Figures 1- 3.



Appendix 3 Figure 1. Jorunn model



Appendix 3 Figure 2. Germany model



Appendix 3 Figure 3. Q83 model

APPENDIX 4

A full list of native SRC willow genotypes collected in Wales between 2006-2008

							1st year cutback		2007			2008		
Accession number	Collection year	Species type	Origin	Latitude	Longitude	Altitude (masl)	Primary stem length (m)	Stem number	Rust	Leaf damage	Aphids	Rust	Leaf damage	Aphids
Tora	2006		CONTROL				2.09	2.6	0	3	0	0	2	0
Sa 28	2006	*S. viminalis*	Borth, on 'Animalarium' road near entrance to old tip	52.4884	-4.0507	10	1.92	2.8	1	2	0	2	3	0
Sa 29	2006	*S. viminalis*	Ty Mawr caravan site. 1.5kw W of Llancynfelyn	52.5093	-3.9976	18	2.23	3.6	2	1	0	1	2	0
Sa 30	2006	*Salix x sericans (S. caprea x viminalis)*	Ty Mawr caravan site. 1.5kw W of Llancynfelyn	52.5093	-3.9976	18	1.70	4.9	1	1	0	1	2	0
Sa 31	2006	*S. viminalis*	1km SE of Tywyn, off road to Aberdyfi near power generator	52.5875	-4.0889	25	2.24	3.8	0	2	1	2	3	0
Sa 32	2006	*S. viminalis*	2km SW of Arthog off A493 Dolgellau to Towyn Road	52.7113	-4.0086	5	1.38	2.7	1	2	1	2	3	2
Sa 34	2006	*S. viminalis*	Pen-y-Garn, Bow Street, access to stream.	52.4406	-4.0265	30	2.07	4.0	3	3	0	1	3	0
Sa 35	2006	*S. viminalis*	Glanyrafon Ind.Estate by waterworks, 1km south east of Llanbadarn Fawr	52.4064	-4.0592	40	2.49	2.5	0	3	0	2	2	0
Sa 36	2006	*S. fragilis*	Blaendolau playing fields, 0.5km S of Llanbadarn Fawr	52.4064	-4.0592	10	1.44	4.3						
Sa 37	2006	*S. viminalis*	Park Anenue Car Park, Aberystwyth	52.4150	-4.0804	10	2.11	3.3	0	3	1	0	3	0
Sa 38	2006	*S. viminalis*	1km west of Llangurig, roadside by brook	52.4051	-3.6021	289	2.30	2.3	0	2	0	2	2	0
Sa 39	2006	*S. cinerea*	By stream in grazed paddock on Builth Road	52.1710	-3.4212	150	1.27	3.2	1	3	0	0	1	0
Sa 40	2006	*S. fragilis*	Builth Wells, on Llanelwedd side of river upstream from bridge	52.1496	-3.4024	140	1.55	3.0						
Sa 41	2006	*S. fragilis / S. cinerea (*2 types)*	Aberduhonow, 2km E of Builth Wells *serrated leaf/hairless and wide leaf type	52.1496	-3.4024	130	1.72	3.3						
Sa 42	2006	*S. fragilis*	500m NW of Llyswen on riverbank downsream of road bridge to Boughrood	52.0324	-3.2667	90	1.30	3.4						
Sa 43	2006	*S. fragilis*	1km NW of Talgarth below Bronllys Castle	51.9975	-3.2320	110	1.57	3.1						
Sa 44	2006	*S. viminalis*	Llandeilo	51.8890	-3.9865	26	1.66	4.3	0	3	0	1	2	0
Sa 45	2006	*S. viminalis*	NW side of Tynygraig village	52.3044	-3.9202	196	2.80	3.0	0	2	0	2	3	0
Sa 46	2006	*S. viminalis*	Llanerchyrfa, 3km NW of Abergwesyn	52.1618	-3.6741	320	1.91	4.0	0	3	0	1	3	0
Sa 47	2006	*S. viminalis*	2km SW of Tregaron	52.2180	-3.9343	160	2.19	4.0	2	3	2	2	3	0
Sa 48	2006	*S. viminalis*	Ffarmers	52.0845	-3.9705	160	1.71	4.1	0	2	1	2	3	0
Sa 49	2006	*S. purpurea*	Edwinsford, 3km SE of Llansawel (Excellent basketry potential)	51.9971	-4.0006	100	1.98	5.6						
Sa 50	2006	*S. alba (Var: vitellina)*	500m E of Talyllychau	51.9787	-3.9978	110	1.95	3.0						
Sa 51	2006	*S. viminalis*	Llansawel	52.0083	-4.0170	150	2.32	3.1	2	2	0	2	3	0
Sa 52	2006	*S. viminalis*	Newcastle Emlyn, back of rugby field on riverbank	52.0403	-4.4670	30	1.90	3.8	0	1	0	1	2	1
Sa 53	2006	*S. purpurea*	On the bank of a stream in horse paddock Dre-fach	52.0913	-4.1845	130	2.22	3.1	0	1	1	1	2	0
Sa 54	2006	*S. alba*	Flooded plain near Lampeter RFC field	52.1107	-4.0764	130	2.18	3.1						
Sa 55	2006	*S. viminalis*	Ty Mawr caravan site. 1.5kw W of Llancynfelyn	52.5093	-3.9976	18	1.80	3.5	0	0	1	2	3	0
Tora	2007		CONTROL				1.71	2.1				0	2	0
Sa 56	2007	*S. caprea*	2km N of St Dogmaels. E side of B4546 opp house 'Maes yr Hedydd'	52.1005	-4.6908	7	1.00	4.0				2	3	0
Sa 57	2007	*S. viminalis*	0.5km SW of Moylgrove. On back road to Newport	52.0657	-4.7543	120	1.66	3.4				2	3	0
Sa 58	2007	*S. caprea*	Llanychaer bridge, in village opposite pub	51.9805	-4.9326	54	1.15	3.5				1	2	0
Sa 59	2007	*S. caprea*	2km SW of Dinas Cross on N side of A487	52.0024	-4.9180	72	1.09	2.0				4	3	0
Sa 60	2007	*S. viminalis hybrid*	Dinas island (Brynhenllan). 200m E of Ship Inn	52.0216	-4.9076	1	1.35	3.3				4	3	0
Sa 61	2007	*S. viminalis hybrid*	2km S of Gwbert. On E side of B4548 near turning to Waungelod	52.1018	-4.6733	8	1.27	2.0				3	3	0
Sa 62	2007	*S. viminalis*	Porthmadog. Old quarry near footpath over 'sluice' gate	52.9249	-4.1257	9	1.51	2.1				2	2	0
Sa 63	2007	*S. caprea*	1km E of Ffestiniog, on N side of B4391 near entrance to golf club	52.9626	-3.9146	277	0.38	1.5				0	3	3
Sa 64	2007	*S. caprea*	1km SE of Pentrefoelas, on minor road to Rhyd-lydan	53.0445	-3.6721	218	0.62	2.2				0	2	0
Sa 65	2007	*S. viminalis*	1km E of Pentrefoelas. Ty'n-y-garreg Farm below A5 on S side of river.	53.0491	-3.6663	233	1.18	2.6				3	3	0
Sa 66	2007	*S. viminalis*	1km E of Pentrefoelas. Ty'n-y-garreg Farm below A5 on S side of river.	53.0491	-3.6663	233	1.23	2.2				3	3	0
Sa 67	2007	*S. viminalis*	1.5km E of Cerrigydrudion, on S side of A5 opposite entrance to fish-farm	53.0313	-3.5821	270	1.34	2.8				3	2	0
Sa 68	2007	*S. viminalis*	7km SW of Cerrigydrudion, on N side of B4501 (Llechwedd Figyn farm)	52.9879	-3.6058	337	1.06	2.2				4	3	0
Sa 69	2007	*S. fragilis*	Newtown, south bank of river by main bridge	52.5168	-3.3159	113	1.02	2.8						
Sa 70	2007	*S. fragilis*	Newtown, under main bridge	52.5167	-3.3174	113	1.49	3.6						
Sa 71	2007	*S. viminalis*	2km NW of Four Crosses, on B4393 to Llansantffraid ym Mechain	52.7688	-3.1101	69	1.46	1.6				1	3	0
Sa 72	2007	*S. fragilis*	Aberriw. In village on N side of B4390 opposite Red Lion Hotel	52.5989	-3.2018	88	1.20	3.3						
Sa 73	2007	*S. fragilis*	Aberriw. In centre of village on N bank of Afon Rhiw E side of bridge	52.5998	-3.2003	95	1.37	4.1						
Tora	2008		CONTROL									0	1	0
Sa 74	2008	*S. caprea*	2km SW of Llandymog on roadside	53.1789	-3.3340	56						1	2	0
Sa 75	2008	*S. viminalis*	1.5km S of Llandymog on riverside	53.1789	-3.3340	56						2	1	0
Sa 76	2008	*S. viminalis*	1.5km S of Llanelwy (St Asaph) in hedgerow	53.2577	-3.4424	15						3	1	0
Sa 77	2008	*S. viminalis*	By bridge south of Trawsfynydd, Gwynedd	52.9035	-3.9261	200						1	2	0
Sa 78	2008	*S. viminalis*	By bridge south of Trawsfynydd, Gwynedd	52.9035	-3.9261	200						1	2	0
Sa 79	2008	*S. viminalis*	Back of castle on riverbank by weir, Skenfrith, Monmouthshire	51.8764	-2.7933	43						2	3	1
Sa 80	2008	*S. viminalis*	On roadside between wall and river Rockfield, Monmouthshire	51.8268	-2.7500	32						1	2	0
Sa 81	2008	*S. viminalis*	By old bridge on riverbank, very small tree Trefynwy, Monmouth	51.8157	-2.7132	17						2	3	0
Sa 82	2008	*S. viminalis*	Brynbuga (Usk), Monmouthshire. Across the road from rugby field	51.7049	-2.9022	16						1	2	0
Sa 83	2008	*S. viminalis*	Chain Bridge on riverbank by pub, 1.5km E of Nant-y-Derry, Monmouthshire	51.7485	-2.9643	28						3	1	0
Sa 84	2008	*S. viminalis*	Crughywel, Powys. On isolated small bank in river by old bridge	51.8561	-3.1342	67						2	1	0
Sa 85	2008	*S. viminalis*	2km SE of Talybont-on-Usk, Powys in hedgerow on roadside	51.8953	-3.2901	130						2	1	0
Sa 86	2008	*S. viminalis*	Aberhonddu (Brecon), Powys recreation park on riverbank	51.9470	-3.3922	133						2	1	0
Sa 87	2008	*S. viminalis hybrid*	On a bank on off-road track near Trefin, Pembrkeshire	51.9482	-5.1456	33						3	1	0
Sa 88	2008	*S. viminalis hybrid*	On roadside, partially cut near Porthgain, Pembrokeshire	51.9466	-5.1812	26						3	0	0
Sa 89	2008	*S. caprea*	Broad Haven, Pembrokeshire. Large-leaved in wooded area near public car-park	51.7838	-5.0973	11						3	1	0
Sa 90	2008	*S. viminalis*	2km N of Bosherston, Pembrkeshire down an off-road track	51.6159	-4.9432	57						2	2	0
Sa 91	2008	*S. viminalis*	Whitehall. 1.5km NE of Carew, Pembrokeshire, in hedgerow by garage	51.6986	-4.8251	51						1	1	0

APPENDIX 5

Summary of extension activities

Date	Venue	Activity
Dec 2003	IGER Aberystwyth	Awareness event to identify potential growers
Dec 2003	Welsh Winter fair	Poster display to promote the project
Jan-March 05	30 farms across Wales	Site visits to potential growers
May 2004		GWLAD article to promote project
July 2004	Royal Welsh Show	Stand display to promote project
Aug 2004	IGER Aberystwyth	Cropping Options Open Day
Aug 2004	Pembrokeshire Show	Stand display to promote project
Oct 2004	Narberth	Open day
Oct 2004	IGER Aberystwyth	Field visit with Grassland Society Members
Nov 2004	Hayscastle	Open day
Nov 2004	Hirwaun	Meeting with Tower Colliery to discuss willow for remediation work
Nov 2004	Carmarthen	Evening workshop to discuss energy crops
Dec 2004	Royal Welsh Show	Stand display to promote project
Apr 2005	Nat Botanic gardens	Bioenergy awareness event
May 2005	Bridgend	Planting Open day
July 2005	IGER Aberystwyth	Meet with AM Elin Jones to discuss Energy Crops
July 2005	Royal Welsh Show	Stand display to promote project
Aug 2005	Pembrokeshire Show	Stand display to promote project
Aug 2005	IGER Aberystwyth	Meet with Merion Evans, Woodfuels Ltd to discuss energy crop supply
Aug 2005	Hayscastle	Open day
Aug 2005		Radio interview with BBC Radio Wales
Sep 2005	ADAS Pwllpeirian	Biomass info day
Oct 2005	IGER Aberystwyth	Meet with AM Glyn Davies to discuss Energy Crops
Nov 2005	IGER Aberystwyth	Training session with ADAS consultants on energy crops
Nov 2005	Clawdd Newydd	Biomass awareness event including site visits (Cilgoed and Cernyfed)
Dec 2004	Winter Fair	Stand display to promote project
Feb 2006	Narberth	Harvesting Demo day
Feb 2006	Narberth	S4C filming
Apr 2006	IGER Aberystwyth	Meet with Sir Ben Gill to discuss W4W activities
May 2006	IGER Aberystwyth	Meet with Peter Kendal NFU to discuss W4W activities
July 2006	Royal Welsh Show	Stand display to promote project
July 2006	IGER Aberystwyth	Open day
Aug 2006	Pembrokeshire Show	Stand display to promote project
Sep 2006	IGER Aberystwyth	BEGIN stakeholders meeting
Sep 2006	Worcester	Present at Wood Energy event
Sep 2006	Corwen and Ruthin	Open days
Oct 2006	Caernarfon	Open day
Oct 2006	Carmarthen	Bio energy event at Gelli Aur
Dec 2006	Usk	Bio energy event
Dec 2006	Winter Fair	Stand display to promote project
Jan 2007	Newtown	Bio energy event
Feb 2006	IGER Aberystwyth	S4C filming
Feb 2006	Nat Botanic gardens	Bioenergy awareness event
Feb 2006	Hayscastle	FUW visit Hayscastle
March 2007	Caernarfon	Open day
May 2007	Wrexham	Visit Smalley international re machinery
June 2007	Leyburn	Visit Metcalfes re machinery
July 2007	Anglesey	Open day
July 2007	Royal Welsh Show	Stand display to promote project
July 2007	Bishops Castle	Stand display to promote project
Oct 2007	Carmarthen	Meet with Trinity College to discuss energy crops
Oct 2007	Anglesey	Meet with Anglesey aluminium to discuss energy crops
Oct 2007	Cardigan	Presentation to grass soc

APPENDIX 5 Summary of extension activities (Contd)

Date	Venue	Activity
Oct 2007	IGER Aberystwyth	Filming for biomass programme
Dec 2007	Bridgend	Open day
Jan 2008	Builth Wells	Presentation to grass soc
Feb 2008	Bridgend	Energy awareness event
Feb 2008	Narberth	Open day
July 2008	Barnsley	Meet to discuss Newport Biomass project
Oct 2008	Narberth	Energy event
Oct 2008	IGER Aberystwyth	Open day
Nov 2008	Corwen and Ruthin	Open days
Nov 2008	Pembrokeshire	Energy event
Dec 2008	Winter Fair	Stand display to promote project
Dec2008	York	Presentation to AAB