Addressing the land use issues for non-food crops, in response to increasing fuel and energy generation opportunities.

Issued by:
John Kilpatrick
Senior Renewable Energy Consultant
ADAS Rosemaund
Hereford
UK
HR1 3PG

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Contributors to this report include John Kilpatrick, Catherine Heywood, Claire Smith, Lucy Wilson, Chris Procter and John Spink of ADAS. Sections 4.2, 5.3.1 and Appendices 1-XI were provided by Forest Research: Ian Tubby, Robert Matthews, Ewan Mackie, Geoff Hogan and Tim Randle

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1. Executive Summary

One of the roles of the NNFCC is to develop markets for UK renewable feedstocks. One of these, biomass, has the potential to supply energy for heating, electricity production and as a liquid transport fuel. This report establishes the current scale and location of biomass production in the UK and assesses the potential for increasing biomass production in the future. This report was commissioned by the National Non-Food Crops Centre (NNFCC) on behalf of the Department for Environment, Food and Rural Affairs (Defra)

1.1 UK Land use

Total land area of the UK is 24.25 million ha of which 17.4 million ha is farmed and 2.8 million ha is forest, the remainder being mainly urban land. There is a trend towards decreasing the agricultural area. Agricultural land use has a history of responding quickly to market forces. For example, cereal production rose from 3 million ha in the 1890s to 3.4 million ha in WWI, falling to 2 million ha during the 1930's Depression. Production rose again to 3.4 million ha in WWII and peaked at 4 million ha in the 1980s, falling back to a current level of 3 million ha. Oilseed rape has also demonstrated an elastic response to market forces rising from 4,000 ha in 1970 to 682,000 ha in 2007.

1.2 Energy crop production

Energy crop production established under the Energy Crop Scheme is currently limited to approximately 5,000ha of Miscanthus and 1,500ha of SRC with an additional 1,500ha of SRC established in association with the ARBRE scheme in the North East. Annual production is estimated at 64,000 odt for Miscanthus and 23,000 odt for SRC.

Market pull for energy crops has been limited and prices offered have not encouraged growers to make the long term commitment required. More recently, prices of £60/odt have been offered in 10 year contracts to supply feedstock for co-firing at the Drax power station.

At prices of £50/odt, Miscanthus can produce similar net margins to arable cropping. In comparison with an arable rotation of wheat (at £136/t), oilseed rape (at £333/t) and beans (at £165/t), Miscanthus can return a net margin of £330/ha compared to the arable rotation margin of £302/ha. By comparison, SRC would yield a net margin of £189/ha. Long term contracts could be attractive to growers, offering both guaranteed profits and stability compared to very volatile arable crop returns, together with a reduction of pressure on labour. Against this should be considered the high establishment costs and limited income in the 3-5 year establishment phase.

In recent years, set-aside has resulted in some restructuring with farms being equipped to efficiently farm 95% of the total arable area. It is possible therefore that the remaining 5% could be dedicated to energy cropping. Given the higher profitability of Miscanthus compared to SRC, it is likely that the majority would be planted with miscanthus, which would result in 1.84 million odt per year of biomass resource.

1.3 Combinable crops

The three main arable crops of wheat, barley and oilseed rape represent nearly 80% of the cropped area of 4.3 million ha, producing 21.7 million tonnes of grain per annum. Straw residues represent 49% of total above ground biomass of wheat and barley and 70% of oilseed rape. Total UK straw production is therefore estimated at 23.1 million tonnes per annum. Allowing for stubble and efficiency of baling only 60% can be recovered which is calculated to be 13.9 million odt. It is estimated that some 5.8 million odt is used for livestock feed and bedding, leaving a current biomass resource of 8.1 million odt, much of which is currently incorporated back into the soil. The majority of this will be available in the East Midlands and East Anglia. Whilst this resource is considered to be available a number of barriers would need to be addressed for it to be utilised.

Straw incorporation is seen as a useful means of sequestering carbon and thus mitigating Greenhouse Gas (GHG) emissions. However, straw incorporation is inefficient at sequestering carbon and is estimated to fix only 733kg CO_2/ha/yr into soil organic matter. In comparison baled wheat straw from 1ha would replace 2.4 t of coal, saving over 5,000kg CO_2.

The logistics and labour implications for straw collection would be significant, requiring between 3,000 and 6,300 staff over a typical 30 day harvest period, assuming that the scale of the exercise would facilitate an efficient operation. This is a significant task which the existing workforce (which the Defra June Census of 2007 reported 182,000 full-, part-time and casual staff and 344,000 farmers, directors, etc. involved in agriculture) would be unable to deliver.

Straw is also a valuable source of nutrients which have become increasingly expensive when purchased and applied in inorganic form. The current nutrient value of wheat straw is calculated at £16/t, barley at £21/t and oilseed rape at £23.39/t. Given a cost of £15/t for baling and carting, it is estimated that a price of at least £55.50/odt (£48 fresh weight) would be required to bring the majority of the currently incorporated straw to the market.

1.4 Underutilised arable land

Set-aside has been a feature of UK agriculture since the early 1990s. Over the period 2007-08, 480,000ha were set-aside plus 175,000ha of bare fallow or voluntary set-aside. Of this only 90,000ha were used for non-food crops, mostly oilseed rape. In 2008 the set-aside level was set at 0% and the wheat area increased by 13%. However, 296,000ha remained uncropped as bare fallow.

As a result of the increased cereal area in 2008 an additional 1.19 million odt of straw biomass was produced. If that same area were to be cropped in a rotation of wheat and oilseed rape this would increase to a biomass resource of 1.21 million odt.

The uncropped bare fallow area of 2008 could be brought back into production, probably as Miscanthus to produce a future biomass resource of 3.55 million odt. However, it is worth noting this could have happened at any time before set-aside was reduced to 0% and at a time when cereal prices were lower; it is likely that this failure of the biomass market to develop was due to low prices and grower confidence.

1.5 Grassland

Grassland is the single largest land use category at 12.7 million ha comprising 1.2 million ha short-term, 5.9 million ha long-term and 5.6 million ha rough grazing (including 1.2 million ha of common land). UK annual grass production is estimated at an average of 34.3 million odt, much of which is currently grazed.

The area of temporary grass has reduced from 1.8 million ha to 1.2 million ha in recent years mainly due to declining reseeding rates and the re-classification of grass over 5 years to permanent. By virtue of its' suitability for frequent reseeding, it is possible that the entire temporary grassland area, together with up to 600,000 ha of permanent grassland could be suited to production of either SRC or Miscanthus. If areas of temporary grassland were to be either redundant or unprofitable, opportunities might exist for energy cropping. A simple analysis of supply and demand for livestock products indicates that none of the existing grassland resource is currently classed as surplus to requirements. However, profitability of livestock enterprises is low and even relatively low biomass prices could make conversion of grassland to biomass production attractive. However, given that livestock production continues to give low and even negative net margins, factors other than economic, would appear to influence land use.

A review of beef and sheep numbers by Defra indicated a reduction of beef numbers by 12.8% over the period 1992 to 2007 and a reduction in sheep numbers of 23.8% over the same period. Grassland areas remained relatively constant over the same period indicating an exstensification of stocking rates. If stocking rates on temporary grassland were to return to those of the 1990s this would release a total of 133,380ha, which, if cropped 50% Miscanthus and 50% SRC would produce a future annual biomass resource of 1.4 million odt with potentially little impact on current food production but requiring increased intensity of management of the remaining grassland.

Similar trends with regard to stocking rates have been experienced on both long-term grassland and rough grazing. Assuming the same reductions in numbers and an intensification of stocking rates, areas of 586,000 ha long-term grassland and 1.24 million ha rough grazing could be released for energy cropping. Given that most of the land released would not be suited to cultivation, it is likely that it would be returned to woodland as much of it was prior to clearance for agriculture. If planted to broadleaf trees a biomass resource of 2.54 million odt could be obtained from this area of 1.8 million ha. If conifer woodland comprising Douglas Fir, Larch and other conifer were planted the annual biomass resource would rise to 3.31 million odt. If a more intensive high yielding Short Rotation Forestry (SRF) were to be planted it might be possible to achieve annual biomass yield of 7.52 million odt. This would be concentrated in upland areas of Wales, North Western Scotland and England.

Such large scale changes to 20% of the rough grazing area and 10% of permanent pasture would require careful consideration, together with effects of intensification of remaining areas. This might be balanced by increased biodiversity in well-managed new woodland.

1.6 Forestry production

Total UK woodland area is 2.75 million ha, comprising 1.57 million ha conifer and 1.17 million ha broadleaf. Yields from woodland are normally calculated in terms of useable timber rather than biomass yield but 5 year average UK woodland production for the period 2002-06 is calculated at 4.43 million odt, comprising 4.15 million odt softwood and 273,000 odt hardwood, of which only 4% was used in heat or power generation.

If all existing forest areas were to be managed to maximise production and material not suited to existing markets was recovered, it calculated that 1.9 million odt from coniferous forest and 2.9 million odt from broadleaf forest could be harvested to produce an annual biomass resource of 4.2 million odt. There could be significant impacts on site sustainability and physical and economic constraints on recovering this resource.

1.7 Non-agricultural/forestry land

The UK has 3.5 million ha which is used for urban, recreational and transport purposes. Within this area is a considerable biomass resource much of it in "soft" landscaping on the margins of the transport networks, public amenity spaces and industrial/corporate situations. Much of this is currently managed by cutting and leaving *in situ*. The total transport network is estimated to amount to some 180,000 ha. Assuming an annual biomass yield of 3odt/ha this equates to an annual biomass resource of 0.54 million odt. Subject to improved management such as revised cutting regimes and higher biomass planting to increase yield potential to 5 odt/ha this could be increased to a future biomass resource of 0.9 million odt.

This is a significant and valuable biomass resource, not least because the cost of management and harvesting is already covered, leaving only additional marginal costs of transport and logistics to be found. The scope and diversity of this resource is yet to be fully quantified but if it is assumed that 10% of the non-agricultural, non-forestry land, in addition to the transport network, an area of 350,000 ha could be exploited. Assuming annual biomass yields of 5odt/ha this would represent an additional biomass resource of 1.75M odt/yr.

1.8 Total UK biomass resource

Current UK annual biomass resource is defined as extant biomass resource which could become available without entailing land use change and is calculated to be 14.7 million odt. This comprises 8.1 million odt straw, 4.2 million odt forestry, 0.09 million odt SRC and Miscanthus, 0.54 million odt from the transport network and 1.75 million odt from urban green areas.

A similar quantity of 15.7 million odt could be produced in the future with relatively little impact on existing markets but which would require a change in land use. This comprises 1.2 million odt from previously set-aside land brought into production in 2008, 3.6 million odt from Miscanthus on currently fallow land, 1.8 million odt from Miscanthus on 5% of current (2002-07) arable land, 1.6 million odt of SRC and Miscanthus on temporary grassland and 7.5 million odt from SRF on long-term grassland and rough grazing.

Table A. Current* and Potential annually available UK biomass resource from agriculture and forestry

Cropping source	**Currently produced biomass**	**Potential future biomass production**
	Oven dry tonnes (million)	**Oven dry tonnes (million)**
Wheat straw	4.2[1]	-
Barley straw	1.6[2]	-
Oilseed rape straw	2.3[3]	-
Straw from set-aside brought into cropping 2008	-	1.2
Miscanthus on 2008 set-aside area	-	3.6
Miscanthus (currently 5036ha)	0.06	-
Miscanthus on 5% arable land	-	1.8
Temp grassland - misc/SRC	-	1.6
Rough grazing - SRF	-	7.5
SRC (currently c3000ha)	0.03	-
Transport network	0.54	-
Urban green space	1.75	-
Conifer woodland	1.9[4]	-
Broadleaf woodland	2.3[5]	-
Total	**14.7**	**15.7**

1.9 Biomass production areas

The locations of the main production areas for each biomass resource are shown in the table below. The current resource comprises mainly, straw in the

[1] Based on Harvest Index (HI) in HGCA Winter Wheat Growth Guide and assuming 60% straw material actually collected and baled and 50% utilised for livestock feed and bedding.
[2] Based on Harvest Index (HI) in HGCA Winter Barley Growth Guide and assuming 60% straw material actually collected and baled and 50% utilised for livestock feed and bedding.
[3] Based on Harvest Index (HI) from J.Spink and P Berry (2005) Yield of UK Oilseed Rape: Physiological and Technological Constraints, and Expectations of progress to 2010." Yields of Farmed Species (2005) ISBN 1-904761-32-2 also assuming 60% straw material can be realistically collected.
[4&5] By improved utilisation of existing forestry resource.

South, South East, East and Midlands; broad leaf forestry in the South, South East and South West and conifer production in Northern England, Wales and Scotland. In the future, potential production of Miscanthus on arable land would be concentrated in the Midlands and East England. Miscanthus on temporary grassland areas would be mainly in the South West and West Midlands and SRC evenly distributed through the Central and East Midlands, East of England, Northern England and Wales. SRF would be concentrated on the higher ground in Wales, Scotland and parts of Northern England.

Table B. Summary of potential key production areas for each biomass source.(odt)

Biomass resource	South	South East	South West	West Midlands	Eastern Counties	East Midlands	North	Wales	Scotland
Cereal and oilseed rape straw	1.5M	1.5M	300k	600k	1.2M	1.2M	600k		300k
Broadleaved woodland	650k	650k	650k	100k		100k		100k	
Coniferous woodland							600k	600k	600k
Miscanthus[1]	300k		300k	600k	900k	900k	300k		
Miscanthus[2]			300k	300k	600k	600k			
SRC[3]					50k	50k	50k	50k	
Miscanthus[4]			650k	600k					
SRF[5]							1.3M	3M	3M

Current biomass resource shown in black. Potential future resource shown in blue.

[1] 2008 Set-aside area [2] 5% Arable land

[3/4] 133 kha grassland [5] 1.8M ha rough grazing

1.10 Conclusions and recommendations

- There is a significant quantity of biomass currently produced, the majority of which is unutilised which is estimated at 14.7 million odt. However this should not be considered a low value waste and will not be made available to the renewable energy industry without a price being offered which covers its inherent value, the cost of collection and a margin for the producer.

- The utilisation of biomass co-products for energy production offers significantly greater green house gas savings than its incorporation or return to the land which is an inefficient method of carbon sequestration.

- There are significant logistical issues and management changes needed to make available and for the collection of currently available biomass, not least the availability of suitably qualified staff. It is likely that this will most efficiently be achieved from the end user end or via supply groups rather than from individual producers.

- There appears to be significant biomass (c. 2.3 million odt) potentially available from non agricultural or forestry land such as transport infrastructure and urban green spaces. However, information on the form, distribution and ownership of this biomass is not as readily available as for agricultural land and a more detailed study of this resource is required to quantify more accurately the volumes and develop strategies for its collection and utilisation.

- At current biomass values the returns are sufficient to compete favourably with some current land uses particularly lower return livestock systems, but also arable cropping if input costs continue at their high level and the world prices do not increase. The returns from arable cropping are highly variable due to fluctuations in the world price – the wheat price having varied by almost £100 per tonne in the 2008 cropping season. Whilst biomass does not currently compete at higher grain prices long term contracts and stability of return may be an attractive option to some producers.

- There is significant scope to increase future biomass production with potentially an additional 15.7 million odt. It is predicted this could be produced from Miscanthus grown on currently fallow land and arable land for which the infrastructure might not exist for efficient arable production. And Miscanthus or SRC on temporary grassland and SRF on permanent pasture and rough grazing which could be made available by tightening stocking densities.

- There are a number of barriers to this expansion including the significant up-front costs of establishment and lag period until significant returns are realised. This could be overcome by support for the cost of establishment for the producer which is repaid once biomass sales start or a share farming approach where the farmer owns the land but the end user or fuel supply company owns the crop.

- There needs to be a significant expansion in the production of planting material and infrastructure to establish the crops, we estimate that it would take 10 years to bring Miscanthus and SRC into full production and 20 years to bring SRF into full production even with rapid expansion of the industry, this will not happen without long term political and end user commitment providing the confidence to invest.

- If burnt to produce electricity at 30% conversion efficiency, current biomass could provide 5.3% of our energy requirements and potential future biomass of 5.6% so that in 20 years biomass as a whole could supply more than 10% assuming no change in overall energy consumption.

- In order to maximise the efficiency and greenhouse gas savings from the biomass industry the biomass sources need to be targeted at the most suitable areas of the country and the utilisation facilities similarly located. Although advanced biomass processing techniques and densification technologies are likely to ease these restrictions somewhat.

2. Introduction

One of the roles of the NNFCC is to develop markets for UK renewable feedstocks. The development of renewable fuel and energy markets is an important part of this strategy. Biomass has the potential to supply energy for heating, electricity production and as liquid transport fuel. Concerns over the detrimental environmental effects of fossil fuels, security of supply and cost make this an area of considerable importance and potential value for Greenhouse Gas (GHG) reduction.

Energy markets are large and the potential demand for biomass is consequently large; the issue of land use will therefore become increasingly important with the need to satisfy both food, and energy markets. The increasing global and national populations and the demand to replace fossil fuels with biofuels make it vital that land resources are used as efficiently as possible to maximise production. As land is a limited resource, particularly in the UK, increasing biomass yield, using more efficient conversion technologies and greater integration of the supply chain infrastructure through multiple use of one feedstock will influence the potential scale of the UK bioenergy sector.

As with all industries transport logistics must be optimised. Bio-based activities are no different in this respect; in fact due to the low density or high moisture content of many of the potential biomass sources this is a more acute problem. This aspect is often underestimated as it affects every stage from the field to the final retail outlet. The distributed nature of land based rather than factory based production reinforce the importance of transport issues.

Whilst the UK can undoubtedly produce some of its bioenergy requirements, two major questions remain which will influence how this demand can be met these are; where can the biomass be produced (and on what scale) and the form that the biomass might take. The answers to these questions will influence the structure of the bioenergy industry and the conversion systems used. To answer these questions, the NNFCC have commissioned this report to inform future decisions on the potential viability of large scale utilisation of biomass in the UK.

This report will establish the current scale and location of biomass production in the UK and will assess the potential for increasing biomass production in the future. This report was commissioned by the National Non-Food Crops Centre (NNFCC) on behalf of the Department for Environment, Food and Rural Affairs (Defra).

The key issues and drivers for future land use are outlined below; however, as most of the land in the UK is in private hands, it is how these drivers alter the economics of various land use options that will ultimately influence land use and biomass production.

2.1 Renewable Transport Fuels

In 2003 indicative targets for the reduction of carbon emission in EU member states were laid down in the European Commissions Biofuels Directive (EU 2003). The Directive promoted the use of biofuels and other renewable fuels for transport as a means of reducing carbon emissions. In the UK, targets from the Directive were incorporated into the Renewable Transport Fuels Obligation (RTFO) which became effective on 15 April 2008. The RTFO is expected to deliver net savings of around 1 million metric tonnes of carbon dioxide annually by 2010. As an added incentive to biofuel production, a tax rebate of 20p/litre has been granted (currently guaranteed to run until 2009/10) to make biofuels more competitive with petroleum based products.

The RTFO requires that 2.5% of petrol and diesel used in the UK is produced from biofuels in 2008/9, in 2009/10 this rises to 3.75% before rising again in 2010/11 to 5% (by volume). In recent months, the UK Government has recognised that questions have been asked about the indirect effects of biofuels on food supplies and prices, on deforestation and on their overall impact on greenhouse gas emissions. The recently published Gallagher report[1] proposed that in the UK the rate of increase in the RTFO should be slowed to 0.5% per annum so that the RTFO reaches 5% in 2013/14 rather than 2010/11 as currently planned. Consequently the UK Government has announced its' intention to consult formally on slowing down the rate of increase in the RTFO, taking the level to 5% by 2013/14.

At present the main domestic crop feedstocks for biofuel production are oilseed rape (OSR) for biodiesel and wheat and sugar beet for bioethanol. Although very small areas of land are involved in biofuel production (considerably less than 1% of global arable area), this has resulted in fears of competition between the food and fuel markets and has been claimed to have exacerbated recent world-wide increases in agricultural prices. The Gallagher report expressed concern that there is a risk that the uncontrolled expansion and use of biofuels could lead to unsustainable changes in land use - such as the destruction of rainforest to make way for the production of crops. The introduction of sustainable production criteria and assurance standards are a significant step in addressing some of these concerns.

The NFU have estimated that 1.35 billion litres of biodiesel and 1.2 billion litres of bioethanol will be required to meet the 5% biofuel target in the UK[2]. The biodiesel target would require 2.7 million tonnes of oilseed rape. This equates to 840,000 ha of oilseed rape (OSR) at current yield levels purely for biodiesel production, to put this into perspective the largest area ever grown in the UK was 682,000 ha in 2007 of which about 80,000 ha was grown on set-aside for non-food use. To achieve an additional 1.2 billion litres of bioethanol using current fermentation based conversion technologies would require 3 million tonnes of wheat[1]. This would require about 375,000ha of wheat, compared to a total area of just over 1.8M ha p.a. over the last 3 years. Whilst a proportion of this could come from current production, the average

[1] Review of the indirect effects of biofuels. Renewable Fuels Agency, July 2008
[2] NFU Online – Oct 2006

UK wheat production over harvests 2005-07 was 15M t and consumption was 13.5M t (USDA stats), it should be bourn in mind that this would impact on overseas markets, representing 1.4% of wheat traded on the world market.

2.2 Renewable Power

In contrast to the demands of the RTFO the Renewables Obligation requires licensed electricity suppliers to source a specific and annually increasing percentage of the electricity they supply from renewable sources; rising from 7.9% in 2007/08, to 9.1% in 2008/09 and ultimately to 15.4% by 2015/16. Although wind and landfill biogas have been quite widely developed, progress to date on sole biomass combustion has been slow and currently installed capacity, including wastes such as poultry litter amounts to 221.3 MWe. Renewables co-firing adds a further 310.2 MWe[1]. Total UK power generation is 392,979 GWh.

Miscanthus and short rotation coppice (SRC) are being developed as dedicated biomass crops on the basis of their high yield potential but planting is fairly limited. The majority of biomass currently being utilised is in the form of biomass co-products such as sawmill waste, forestry residue, straw as well as imported products in preference, as these resources are available at advantageous prices. Much of the established miscanthus and SRC, originally planted for use in smaller biomass plants is now being co-fired at large fossil-fuel burning power stations.

2.3 Renewable Heat

To date, biomass for heat has not been promoted by Government in the same way as other renewable energy end uses. In 2005 the Biomass Taskforce observed that biomass for heat represented the most efficient utilisation of biomass, particularly as it comprises over one third of primary energy consumption. It should be noted that the government is aware and is looking to address this which may result in increased demand for biomass for heat.

2.4 Addressing the land use issue

On a global scale, population is rising by approximately 120 mouths a minute, driving the demand for food. In addition, rising affluence particularly in Eastern Asia is driving an increased demand for meat, milk and fuels. The grain mountains or surpluses of the past are likely to remain consigned to history, as world stocks come under long term pressure, although there will be seasonal fluctuation in the supply and demand balance due to season effect on production. Against this backdrop of increased demand for food and fuels we are faced with the reality of finite land resources, and the need for increased productivity in an increasingly unpredictable climate and volatile markets.

The question of satisfying both the food and fuel market with agricultural crops is complex and a clear way forward has not yet been identified. One potential option is to increase the amount of land available to agricultural cropping.

[1] DBERR Digest of UK energy statistics 2007. http://stats.berr.gov.uk/energystats/dukes07_c7.pdf

However, not all land is suitable for the production of agricultural crops. In addition, conversion of long-term and permanent grassland or forest and woodland to annual cropping can result in the release of large amounts of carbon into the atmosphere due to repeated cultivation as well as the loss of carbon sinks. Moreover, there is increasing pressure to ensure that biodiversity isn't unduly adversely affected where a change of land use takes place.

Instead of increasing the area of land used for the production of agricultural crops it could be argued that increasing productivity of existing agricultural land by maximising crop yield per unit area is a more sustainable solution. High productivity per unit area will minimise the area of grassland and forest lost to agriculture, keep food affordable and allow a mix of crops for both food and for energy production. Considering the growing world population it could be argued that extensive, low yielding agricultural systems are unsustainable and possibly even unethical. However, the dependence of intensive agricultural systems on inorganic fertilisers already releases significant quantities of greenhouse gases and without technical innovation further intensification of agricultural systems could exacerbate this. Increased biomass productivity for food and fuel will therefore need to be achieved through new technology, improved agronomy, advances in plant breeding and increased utilisation of new crop species such as high yielding perennial non-food crops.

It is unlikely that domestically produced agricultural crops will meet all of the 5% replacement of transport fuel demanded by the RTFO, and impossible that all of our renewable energy demands (electricity, transport fuels and in the future possibly heat) can be met from biomass. To put the scale of our energy requirements into perspective relative to potential biomass production; in the UK we use approximately 50M t of coal per year to produce 33% of our electricity, a further 37% of our electricity is produced from gas; to completely replace the gas and electricity with biomass would need about 220M t of biomass per year, the total UK land area is 24.25M ha, we would therefore need to produce over 9 t/ha of biomass for every hectare in the UK (including roads, towns and cities!) to supply 70% of our electricity requirement alone.

The contribution of biomass can, however, be maximised and the carbon savings achieved can be maximised by matching the conversion technology used and the location of the processing plants, to the mix of agricultural and forestry products available in different parts of the country. Densification technologies might be adopted in order to minimise the impact of processing plants. The adoption of more advanced conversion technologies such as biomass to liquid which allow a wider range of biomass sources to contribute to any given end use could play a significant role in matching potential supply to demand. A range of conversion technologies is described in Appendix I. A series of mass flow diagrams showing various conversion systems are shown in Appendices III-XII. A case study to examine the development of a 200,000 tonne Biomass to Liquid plant can be found in Appendix II.

It is clear therefore that there is large demand for biomass to provide electrical and motive power and potentially heat. It is also clear that in the future as technology develops that the form in which the biomass is required for any one of these markets will be less restrictive than given current technology. The aim of this report is therefore to quantify the potential production of biomass in its various forms and where in the country it is most likely to be produced.

3. Historic changes in land use, crop production and drivers for change

3.1 Total agricultural land use

An analysis of the potential for biomass production must consider the likelihood of land use change. A useful first step in this process is to consider historic land use changes and the political and market drivers that have precipitated these changes. There follows therefore a brief summary of historic land use in the UK.

The total land area of the UK is 24.25M ha of which some 17.4M ha is farmed (crops and grass), 0.5M ha on agricultural holdings is not cropped e.g. tracks, buildings etc the remainder is made up of roughly 3.5M ha of urban land waterways etc and 2.8M ha of forest. Non agricultural land use has been increasing. Therefore the potential to increase the farmed area is severely limited.

3.1.1 Land use for cropping

Since the mid-1980's the total arable land in the UK has declined by over 1M ha (Figure 1). There are 2 prime explanations for this:

- Total farmed area has declined from 19M ha in 1987 to 18.4 in 2004, largely due to an increase in forest area. Figures for 2007 show this to be down to 17.25M ha but this is likely to be due to a change in the way the statistics are collated rather than a further real decline.
- There has been a significant decline in temporary grass land (grass less than 5 years old), from 1.8M ha to 1.2M ha. This loss has been partly due to the replacement of temporary grass with forage maize (included in 'other crops' Figure 1), and grass not being reseeded and being classed as permanent pasture (grass over 5 years old) and therefore not classed as 'arable' land.

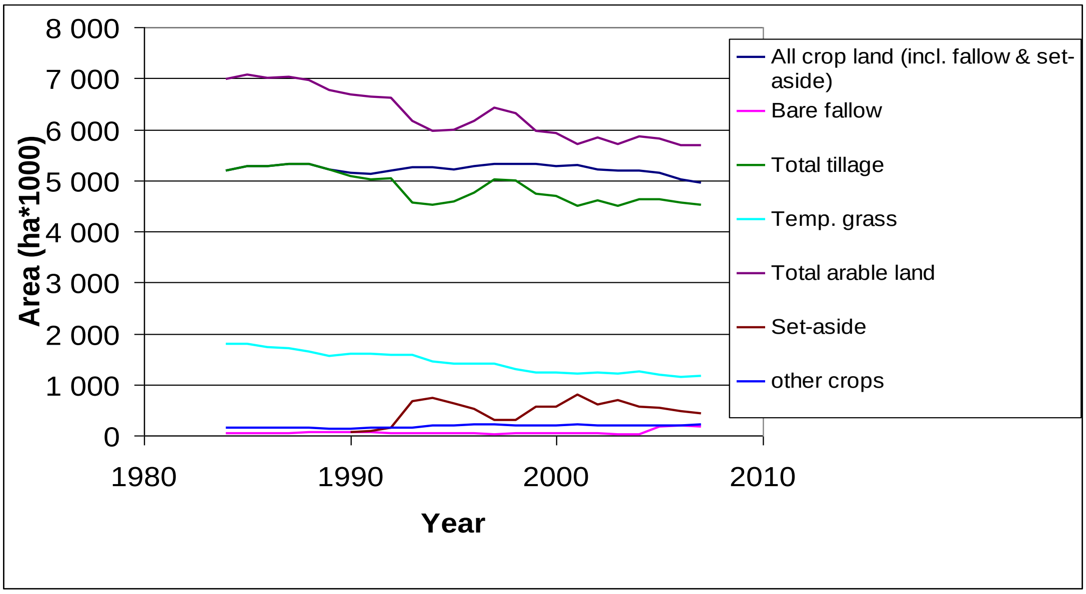


Figure 1. UK land use (ha) 1984-2007 (Source: Defra June Census data)

3.1.2 Land Use - Cereals

Changing land use and production of commodity crops in the UK is nothing new. Figure 2 shows the areas of the major cereal crops since the late 19th Century. The cereal crop area has always been changing in response to market conditions. There were 3M ha in the 1890's, which rose briefly during the First World War to 3.4M ha and fell to an all time low of 2M ha in the depression of the 1930's. The area peaked again during the Second World War at 3.4M ha and stimulated by price support policies rose to an all time high of 4M ha in the mid-1980s. Since then, due to cost/price squeezes the area has fallen to 3M ha in the early 21st Century but is now beginning to increase again due to improved commodity prices. Therefore, it is clear that farmers have the propensity to respond to market stimuli and to plant a particular species at the expense of other crops. It must be recognised however that switching from one annual species to another is more easily accommodated within a farming business, than switching from an annual to a perennial crop.

Market conditions and technology will determine which crops are grown and the balance between annual and perennial crops. This is ably demonstrated by the changes in the areas of the cereal species. Oats were the major cereal crop until the middle of the 20th century when the area went into rapid decline as the internal combustion engine replaced the horse as the source of motive power, the age of renewable transport fuels ended and was replaced by liquid fossil fuels! Oats were replaced by barley as the main crop until the 1980's.

In the 1970's a number of factors including; the development of the Chorleywood baking process (which allowed UK wheat to be included in bread grists at higher proportions), the advent of semi-dwarf wheat and increased yield potential compared to barley, resulted in the wheat area increasing at the expense of barley.

Wheat has remained the dominant cereal crop for over 20 years, with an area of about 2M ha p.a. whilst the area of barley has continued to decline due to low prices making its production uneconomic in many circumstances.

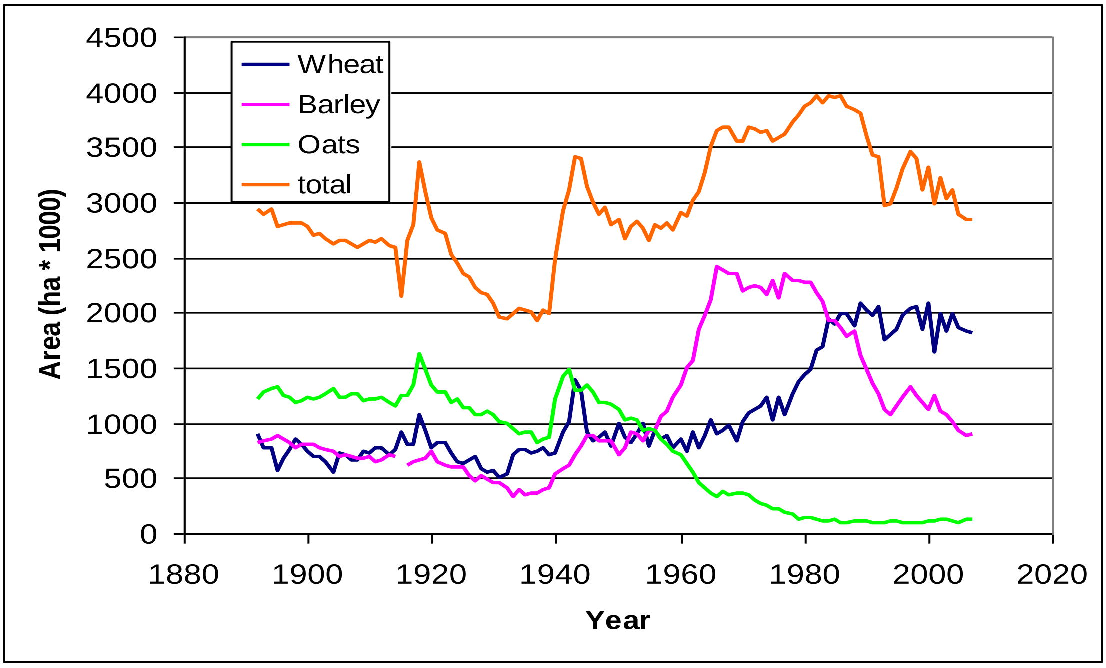


Figure 2. UK Cereal areas (ha) (Source: HGCA and Defra June census 1892-2007).

3.1.3 Land Use - Oilseed rape

Oilseed rape grown for oil is a relatively new crop to the UK; in 1970 there were less than 4,000 ha grown. The crop started to be grown more intensively in the mid 1970's and by 1980 there were 91,594 ha. Since the introduction of set-aside in the early 1990's, oilseed rape has been allowed to be grown for non-food uses on set-aside land, to meet the growing demand for rapeseed oil for biodiesel and other industrial raw stocks. The area has continued to increase. Figure 3 shows that it increased from less than 300,000 ha in 1983 to the maximum area in 2007 of 682,000 ha, of which 80,000 ha was grown for non-food use on set-aside land and a further 240,000ha for industrial use on non set-aside land. This increased production is mainly competing with other break crops such as pulses for land.

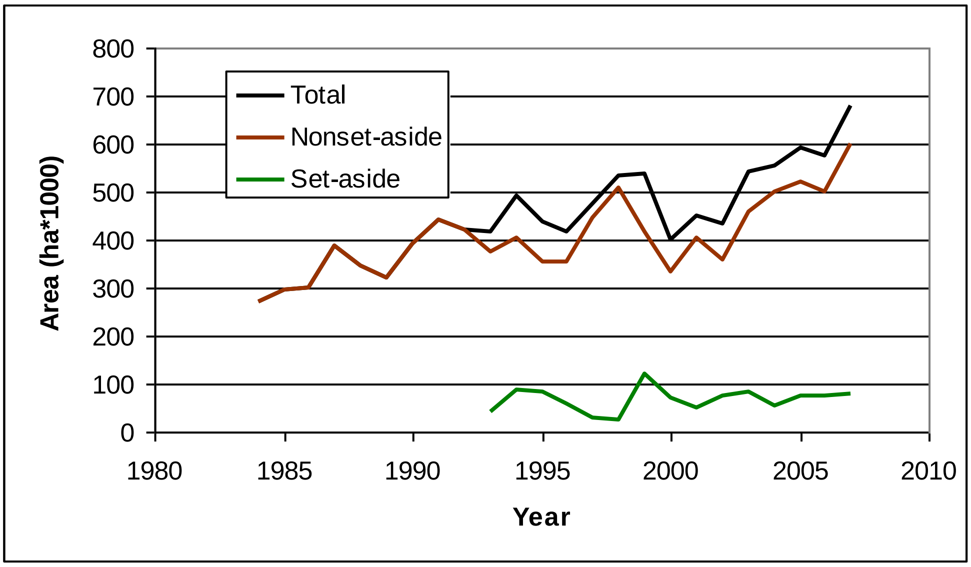


Figure 3. UK Oilseed rape area (ha), 1984-2007 (Source: Defra June Census data)

This analysis shows that land use will change in response to market conditions and political priorities. It is worth noting that these historic changes have taken place in an industry made up of a large number of individual farming businesses with much higher numbers of individuals involved in agriculture than at present. Arguably therefore with fewer people involved and fewer, larger farming businesses involved in change the impacts could be greater as well as occurring faster. The subject of the remainder of the report is to identify the likely changes in land use for the production of biomass or biomass availability as a by-product of existing land uses (such as food production) as influenced by the current drivers for change outlined earlier in the introduction.

4. Current crop production and land-use patterns in the UK and the potential for change.

As a result of the changes outlined previously in the UK we currently have 77% of the total land area classed as agricultural, some 17.4 million hectares of which 37% (6.1 million ha) is considered suitable for cropping, with 4.3 million ha of the cropping area dedicated to arable and horticultural crops[1] (Table 1).

Table 1. UK Land use (Thousand hectares).

	June 2005	June 2006	June 2007
Total area on agricultural holdings	**17 284**	**17 491**	**17 363**
Total cropable area	**6 347**	**6 159**	**6 131**
Total crops	**4 455**	**4 359**	**4 350**
Cereal crops	2 919	2 861	2 871
Other arable crops	1 366	1 332	1 310
Horticultural crops	170	166	169
Other croppable land	**1 892**	**1 800**	**1 781**
Bare fallow / land withdrawn from production	164	197	165
Set-aside	535	466	440
Temporary grass (sown in the last 5 years)	1 193	1 137	1 176
Total permanent grassland	**10 065**	**10 458**	**10 278**
Grass over 5 years old	5 711	5 967	5 965
Sole right rough grazing	4 354	4 491	4 313
Other land on agricultural holdings	**872**	**874**	**954**
Woodland	583	606	663
All other land	289	268	291

4.1 Arable Land

The majority of the cropped land is under arable cropping with horticultural crops accounting for only 170,000 ha out of a total cropped area of 4.3M ha. The horticultural area is generally characterised by high value, high input cropping; due to this and the relatively small area this analysis will be restricted to the arable cropping area.

Cereals account for nearly 70% of the total cropped area and wheat is the single largest crop accounting for over 60% of the cereal area. Oilseed rape is by far the broadest acre non-cereal crop accounting for 602,000ha in 2007 (the largest UK area on record) just under 15% of the cropped area, there was however, a further 80,000 ha of industrial oilseed rape grown on set-aside giving a total area of 682,000ha. No other single non-cereal crop exceeded 150,000 ha, although potatoes, sugar beet and maize all exceeded 100,000 ha, and pulses (peas and beans combined) just exceeded 150,000 ha. See Table 2 for more detail.

[1] Agriculture in the UK 2007 Defra Statistics. http://statistics.defra.gov.uk/esg/publications/auk/2007/default.asp

Table 2. UK Arable crop areas (non set-aside land only). (Thousand hectares).

		June 2005	June 2006	June 2007
Total arable crops		**4 285.0**	**4 192.7**	**4 180.9**
Cereals		**2 919.2**	**2 860.8**	**2 870.6**
Wheat		1 867.2	1 833.0	1 815.9
Barley		937.7	881.4	897.9
Of which:	Winter	384.2	387.6	382.9
	Spring	553.4	493.8	515.0
Oats		90.4	121.5	129.4
Rye, mixed corn and triticale		23.9	25.0	27.4
Oilseed crops		**564.1**	**532.2**	**612.6**
Oilseed rape (winter and spring)		518.8	499.6	601.6
Linseed (a)		45.2	32.6	11.0
Potatoes		**137.0**	**140.2**	**140.2**
Other (non horticultural) crops		**664.8**	**659.5**	**557.6**
Sugar beet (not for stock feeding) (b)		148.3	130.1	125.0
Field beans and peas for harvesting dry (c)		238.8	231.1	161.0
Maize (fodder and grain maize)		130.9	137.3	146.3
Other crops for stock feeding		69.4	66.1	72.9
All other crops (inc flax, hops and miscanthus (d)		77.3	94.9	52.4

Notes:
(a) Linseed figures for Wales not included. This is recorded under All other crops category.
(b) England only.
(c) Great Britain only.
(d) Includes linseed figures for Wales.

4.1.2 Energy crop production

The current area under energy crops, planted under the Energy Crops Scheme is considerably dwarfed by the total area of cereals, and is currently so small that it does not figure in Defra's national statistics. Data in Table 3 obtained from Natural England shows the area currently under energy crop agreements up to and including 2007 planting. These show a total of 5,036ha of Miscanthus and 1,476 ha of SRC and represent **biomass yields of 64,000 and 13,284 odt/yr** respectively. These data show the areas of crops under live agreements and therefore of five years or less, and therefore need to be treated with some caution. For example they indicate that there are no live agreements in the North East, however, other data indicate that crops were planted in the North East prior to 2003 (outside of the current 5 year live agreements).These crops will have been planted over 5 years ago and if still existing will already be producing full harvestable yields. For this purpose we have assumed an area of 1,500ha SRC planted in early 2000s in association with the ARBRE project to represent a **biomass resource of 13,000 odt/yr.**

Table 3. Hectares currently under energy crop agreements for each region*.

Region	Miscanthus area (total ha)	SRC area (total ha)
North East	302	1 500[1]
North West	67	153
Yorkshire and Humberside	1 317	309
East Midlands	1 172	752
West Midlands	758	18
South West	891	21
Eastern England	263	0
South East	266	223
Total	**5 036**	**1 476**

*areas are under live agreement for a period of 5 years, crops outside this five year agreement are not recorded in the above table.
[1] SRC planted for ARBRE project; not included in Total

4.1.2.1 Potential for change

Current areas of production have developed in response to market pull, for example potential supply to power stations such as Drax in Yorkshire, which is the reason for the largest planted areas being situated in the Yorkshire, Humber and East Midlands region. This has been driven by the requirement for funding under the energy crops scheme which requires details of final crop destination in order to secure funding. However, Drax and production in the surrounding area, demonstrate the need for the correct package to be put together to encourage primary producers to switch land use particularly to a long term perennial crop such as Miscanthus or SRC.

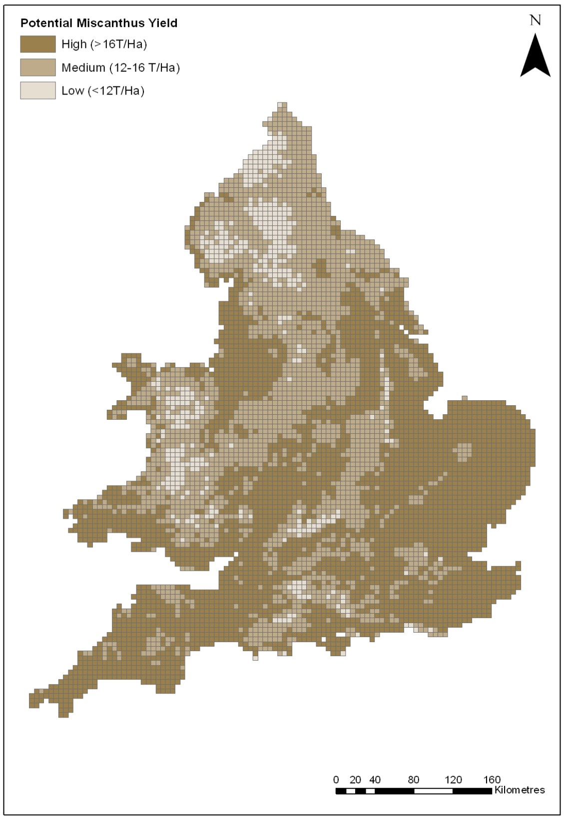
In April 2007 it was reported[1] that Bical had substantially increased its Miscanthus supply contract with Drax, with a demand for a further 14,000 ha of the crop within a 50 mile radius of the plant from spring 2008. In August 2008 Bical announced that 10 year contracts of £60/odt would be available for miscanthus growers to provide feedstocks for an extended facility at Drax. Data from Natural England indicate that only a further 3,242 ha of Miscanthus and 264 of SRC were approved for planting in 2008 in the area covering the East Midlands and Yorkshire and Humber area, with the final area planted likely to fall short of this. Given that these crops also take at least 3 years to reach maximum harvestable yields, this gives an indication of the lead in period needed to meet future predicted requirements.

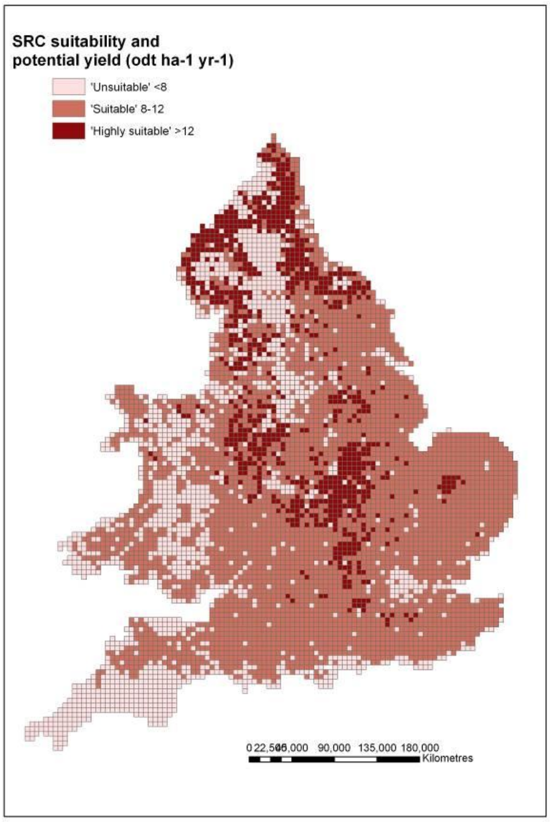
The following sections will show that given the right price for biomass it can compete with arable crops and some of the livestock enterprises currently utilising temporary grass and permanent grass suitable for cultivation. The yield potential of biomass crops varies according to soil type and climate and clearly they are most economically produced where yield potential is highest. The following maps (Figures 4 and 5) therefore highlight land suitability in terms of yield potential per unit area (t/ha) for Miscanthus and SRC respectively.

[1] Farmers Guardian April 6th 2007 “Yorkshire Farmers will benefit from Green Power”.

Comparison of the maps indicates that Miscanthus tends to be better suited to the warmer more southerly regions as would be expected from a C4 plant from Asian origins. In contrast Short Rotation Willow Coppice (SRC) is better suited for growing in the North of England and down through the central/east Midlands as indicated in the potential yield maps for England and Wales.

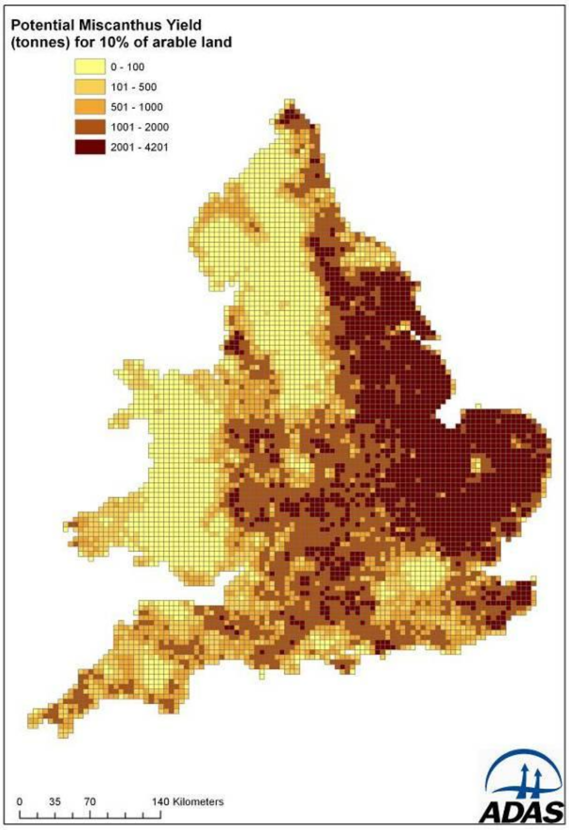
It is worth noting that the ‘highly suitable’ category for SRC is defined as >12 odt/ha comparable to the medium suitability category for Miscanthus at 12-16 odt/ha and significantly behind the high yield potential areas at >16 odt/ha. It is also worth noting that generally speaking the yield potential of wheat and OSR crops increases from southern England into southern Scotland. This is because the duration of grain or pod filling is under thermal control and the cooler conditions in the north lead to longer yield forming periods which are coincident with slightly longer days and therefore faster rates of yield formation. This is demonstrated by consistently higher oilseed rape yields in Scotland than England and the record UK wheat crop being grown in southern Scotland. The competitive ability of dedicated biomass crops with arable crops will therefore decline in Northern England and Scotland compared to southern counties.

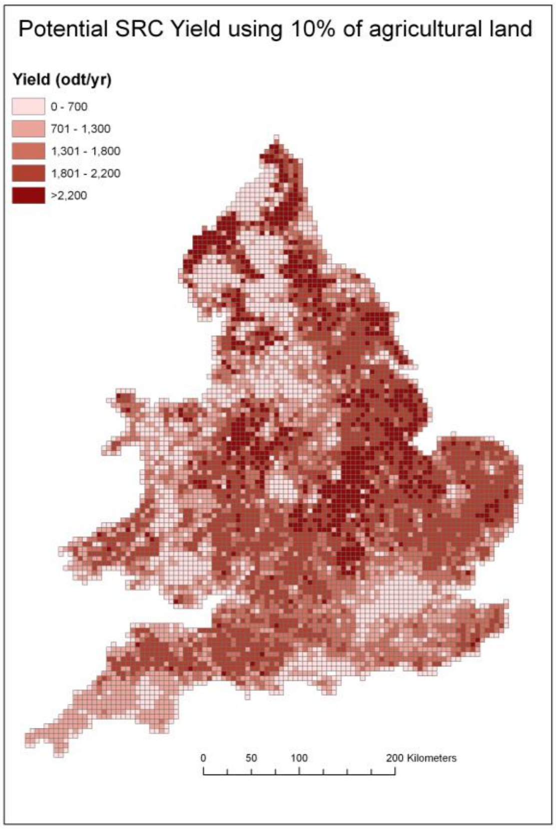




Figures 4 and 5. Maps showing potential Miscanthus and SRC yield ha $^{-1}$ yr $^{-1}$

In terms of location of any biomass utilisation facility however it is not just the efficiency of production per unit area that is important but the total productivity within a defined radius of a plant, in order to keep the environmental and financial costs of transport to a minimum. The potential productivity per 10km^2 area is given in figures 6 and 7. These use the potential yield per unit area and take the potential productive area within each grid square to be 10% of the total arable area. Figures 6 and 7 indicate areas that based purely on the yield potential might seem suitable, but given a lack of readily cultivatable land would have a relatively low density of production. These areas include; the south west due to a low density of arable land and in the Liverpool and Manchester areas due to a high density of housing and limited agricultural land.





Figures 6 and 7. Potential Miscanthus and Short Rotation Willow Coppice (SRC) productivity per $10km^2$ grid.

A recent review by Turley and Liddle[1] indicated that Miscanthus and SRC could only compete with arable crops when the wheat price was relatively low (£72/t), wheat yields moderate to low and energy crop yields above average. That review however compared energy crops with wheat, which is usually grown as part of a rotation and when compared to other combinable crops is usually the most profitable point in the rotation. In order to make a fair comparison energy crops should be compared to the average margin across a standard arable rotation. It is also worth noting that the costs of production of arable crops particularly fertiliser inputs have increased dramatically since that review was completed, and prices being offered for biomass significantly increased.

In order to assess the competitiveness of dedicated energy crops and the likelihood of currently uncropped land being brought back into energy

[1] David Turley and Nicholas Liddle (2008). Analysis of the economic competitiveness of perennial energy crops on arable farms.

cropping rather than arable cropping, a comparison has been made between a wheat, OSR, wheat, beans rotation at current production costs and Miscanthus and SRC. This is shown in table 4 below.

Table 4. Arable crop enterprise comparison (£/ha)

	Wheat	OSR	Beans	Rotation	Miscanthus	SRC
Yield (t/ha)	8.25	3.2	4		12	9
Price	136	333	165		50	50
Output	**1122**	**1066**	**660**	**992**	**600**	**450**
Seed	45	45	55		60[2]	51[3]
Fertiliser	360	340	110			
Sprays	140	120	100			
Variable costs	**545**	**505**	**265**	**465**	**10**	**20**
Gross margin	**577**	**561**	**395**	**527**		
Operations	225[1]	225	225	225	200[4]	190[5]
Net margin	**352**	**336**	**170**	**302**	**330**	**189**

[1] stubble to stubble contract charge
[2] Establishment cost of £2000/ha less 40% grant over 20 years including costs of all cultivations and weed control in the establishment phase
[3] Establishment cost of £1700/ha less 40% grant over 20 years including costs of all cultivations and weed control in the establishment phase
[4] annual harvesting and baling charge
[5] £570 harvesting charge every 3 years

This analysis shows that even using the lower forward prices currently available for the 2009 harvest and significantly higher costs of production of arable crops due to fuel, spray and fertiliser prices, neither Miscanthus nor SRC can compete with a first wheat crop in terms of profitability, even at biomass prices of £50/odt. However, Miscanthus is very close in terms of net margin to Oilseed rape, and exceeds the margin of a 4 year rotation including 2 wheat crops, an oilseed rape and bean crop. It should be noted that the above analysis only represents one possible scenario, and the relatively small difference between the rotation and Miscanthus could increase or decrease dramatically given different yields or relatively small prices changes compared to the variations seen in the past year. In addition the arable rotation assumes no margin for the sale of straw for biomass, assuming fertiliser replacement costs as in table 5, baling costs of £15/t and biomass value of £42.50/t at 85% dm (equivalent to £50/odt), this would add £42.64/ha/yr to the wheat margin and £18.90/ha/yr to the OSR margin assuming straw yields of 4 and 4.6 t/ha @85% dm respectively. This would add £26.05/ha/yr to the rotational gross margin, eroding any differential to the Miscanthus margin.
One of the biggest issues currently facing arable farmers is the volatility of input and crop prices, taking the 2008 cropping season as an example the feed wheat price has varied from a high of over £180/t in February to a low of £110/t at harvest and oilseed rape from over £370 in February to less than £280/t at harvest. The volatility in input prices has generally been an upward trend with the cost of fertiliser increasing by about 150% over the cropping

season. Taking wheat and OSR prices as the lowest during the cropping year reduces the rotational net margin to £153 this represents a return below the rentable value of the land and compared with standard arable fixed costs of £610/ha, the rotational gross margin of £378 represents a loss making situation. Taking the highest prices seen during the season increases the net margin to £514, but a relatively small profit over standard fixed costs of only £128.50/ha.

Given that long term contracts in excess of 10 years at £60/odt for biomass are being offered, which for Miscanthus could offer net margins of £450/ha and for SRC of £279/ha both of which are significantly above the rentable value of the land it would not be surprising if arable farmers considered putting a proportion of the land into biomass cropping. This approach would offer guaranteed profits and therefore stability which is not currently available with arable cropping. It would also represent a much lower labour input enterprise (nil if harvesting is contracted out), which may be an attractive option if it allows the remainder of the farm business to be restructured. It could also free up labour to meet some of the additional labour required for straw harvesting to increase the margin of the remaining arable land. However, the significant upfront costs of establishment of biomass crops should not be ignored, nor should the lack of any significant income for the first 3-5 years after establishment, representing a significant capital investment and impact on cashflow.

Given the above analysis it is economically reasonable to assume that some arable land may be put into dedicated energy cropping, and that this could be precipitated by end users offering sufficiently long buy back contracts of £60/odt or more. It might be helpful, therefore, to consider the likely impact of varying proportions of arable land being dedicated to biomass production.

One percent of cropped area equates to 42,200ha, which if growing Miscanthus at an average yield of 12 odt/ha would produce 506,400 odt or if growing SRC at an average yield of 9 odt would produce 379,800 odt. However, if it is assumed that for every 1% of cropped area lost, 1% of cereals (28,840ha) and 1% of oilseed rape (5,400ha) land is lost, then there is a loss of straw production of 115,343t and 22,680t assuming straw yields of 4 and 4.2 t/ha for cereals and oilseed rape respectively. This gives a net biomass gain for 1% of arable land dedicated to Miscanthus of 368,377odt and for SRC of 241,777 odt.

If it is assumed that the arable farming industry is equipped in terms of staff and machinery to be able to actively farm 95% of the total arable area due to restructuring during the set-aside years, then it is possible that 5% of the arable area could be put into dedicated energy cropping. Given the apparent higher profitability of Miscanthus it seems reasonable to assume that the vast majority of the area would go into Miscanthus production, this would result in a **net biomass production of 1.84M odt per year**.

4.1.3 Combinable crops

The three main broad acre crops wheat, barley and oilseed rape, which together account for nearly 80% of the cropped area, are grown primarily for their grain for the food market, although an increasing proportion of oilseed rape seed is being used for industrial and biodiesel markets. Together these crops produce on average 21.7M t/annum of grain. Straw residues from these key agricultural crops therefore represent a significant potential biomass resource. Generally grain represents 51% of the total above ground biomass of wheat and barley, and about 30% of the total above ground biomass of oilseed rape. Total UK straw production for the three crops (average over 2003-2007 harvests) is therefore estimated at 23.1M t/annum. Due to the height above ground at which the straw is cut and the efficiency of recovery of straw balers generally only about 60% of the straw can be recovered, harvestable yield is therefore estimated in Table 5 below.

Table 5. Total UK cereal and oilseed rape production (average last 5 years).

Crop	**Grain/seed yield (M tonnes)**	**Straw Yield (M tonnes)**	**Harvestable straw Yield (M tonnes)**
Wheat	14.5	13.9	8.4[1]
Barley	5.6	5.4	3.2[2]
Oilseed rape	1.6	3.8	2.3[3]
Total	**21.7**	**23.1**	**13.9**

There are no formal records of the amount of straw baled, however industry experts estimate that currently, approximately half of the cereal straw produced is used for livestock feed and bedding (5.8M t/annum), the remainder, mostly being incorporated into the soil, represents a **biomass resource of 8.1M odt/ annum**.

4.1.3.1 Potential barriers to utilisation

Whilst the straw biomass resource described above is considered available, to the extent that it arises from existing crop production and land use, a number of direct and indirect effects of its' utilisation would need to be addressed in order to render it available for utilisation.

It might be considered that the removal of straw for burning would have an adverse effect on green house gas emissions compared to incorporation. Straw incorporation is, however, an inefficient method of sequestering carbon Bhogal *et al* estimated that 30-70kgC/ha/yr/tonne of straw is incorporated into soil organic carbon, if an average figure of 50kgC/ha/yr/t is assumed this represents only 12.5% of the 400 kgC contained in a tonne of straw, with the remainder released to the atmosphere. This represents only 200 kgC/ha/yr or

[1] Based on Harvest Index (HI) in HGCA Winter Wheat Growth Guide and assuming 60% straw material actually collected and baled.

[2] Based on Harvest Index (HI) in HGCA Winter Barley Growth Guide and assuming 60% straw material actually collected and baled.

[3] Based on Harvest Index (HI) from J.Spink and P Berry (2005) Yield of UK Oilseed Rape: Physiological and Technological Constraints, and Expectations of progress to 2010." Yields of Farmed Species (2005) ISBN 1-904761-32-2 also assuming 60% straw material can be realistically collected.

733kgCO_2/ha/yr for a 4 t/ha straw crop. In comparison baled wheat straw with a yield of 4 tonne/ha could be used to replace 2.4 tonnes coal in energy production saving approximately 5,468 kg CO_2 emissions (sequestration by proxy). It is also worth noting that the sequestration of carbon from straw into the soil either by direct incorporation or as a component of manure once it has been fed or used for bedding is a practice that is already carried out and thus cannot be counted as *additional* carbon storage in mitigation or carbon trading schemes.

It appears therefore that in terms of straw utilisation the greatest CO_2 savings result from its use as a fuel, thus increasing potential for the development of markets in the fuel sectors including combustion or the generation of liquid fuels through processes such as BTL. This is further aided by the fact that utilising biomass materials increases productivity/unit area for cereal crops as more of the crop is fully utilised. In addition supplying straw from arable crops reduces the need to bring additional land into production and doesn't compete with existing grain production, rather it inherently compliments it. These considerations of land use are important as arguably the greatest mitigation of climate change is through more efficient use of land already in cultivation and therefore avoidance of disturbing currently uncultivated land which can act as an effective long term carbon store.

Whilst there is significant potential biomass availability from straw the logistics and labour requirements for its collection should not be underestimated. The actual availability will be dependant on seasonal factors such as poor weather conditions during harvest as experienced in the (2008) harvest, which will severely limit availability. The impact of such seasonal variability will depend on how close to capacity the industry is operating to harvest straw. If it is assumed that a modern efficient baling operation using Hesston bales can bale 15t/hr and operate for 10 hours per day during harvest, one person can bale 150t of straw per day. To bale the estimated 8.1M t of straw not currently harvested would therefore require 54,000 staff days, There would be additional time required to cart bales to the edge of field or roadside for collection, if done with a loader it is assumed that 15ha per day (60t) could be cleared but if using a bale trailer this could be increased to 50ha (200t) requiring 135,000 or 40,500 staff days respectively. Assuming in an average year there are 30 suitable baling and carting days during the harvest period would require 6,300 staff if carting using standard on farm loaders or 3,150 staff if using dedicated bale trailers more often used by contractors. The vast majority of this staffing would be in addition to that currently available on-farm as the work would occur during the annual peak workload for an arable farm. Additional time would be required for the loading of lorries for transport, however, it is assumed that the majority of this could supplied be from the existing workforce in non-peak times. For comparison the Defra June census in 2007 showed a total agricultural work force of 182,000 full-time, part-time and casual paid staff, and a further 344,000 farmers, directors, partners and spouses involved in agriculture either part or full time. In a poor year (such as the current 2008 harvest) significantly greater numbers would be needed as the number of available days for straw baling would be lower. It should be noted that this is a conservative estimate of the additional staff requirement which assumes a very efficient baling operation, Nix estimates that baling takes 0.8 hours per ha plus and additional 2.6 hours per ha to cart the bales, this would equate to an additional 688,483 staff days or 22,949 staff.

Given the large volume of straw material the location of processing facilities close to areas of production is key to efficiency. The pattern of UK cereal production has resulted due to a combination of factors, which support intensive production of the land. The topography and fertility of the land having a marked effect on the areas which are suitable for cereal and oilseed crop production as do factors such as transport links, accessibility for heavy machinery and favourable weather. Other factors come into play too, such as market pull. For example, areas of high barley productivity are associated with the malting industry and pockets of lighter land, preferred by the crop. Historically the area under cereal production have spread westwards in line with improvements in fungicides and breeding for disease resistance which has meant that the limitations on production imposed by disease pressures in the wetter west were significantly reduced from the late 1970's onwards.

These factors have resulted in the crop distributions shown in the figures below which give total crop yield (grain production (t)/10km^2 grid square) for the key UK crops, wheat, barley and oilseed rape. The yield is a combination of yield per unit area (tonnes/ha) and the proportion of land dedicated to cropping within the grid square, and so gives an estimate of total productivity.

Total harvestable straw availability for wheat or barley will equate to 58% of the grain yield and for oilseed rape 144% of the grain yield given in the maps. As stated above roughly half of the total harvestable cereal straw is currently used for animal feed and bedding, the majority of this will be taken from the cereal crops closest to the areas of animal production in the west and also the north of the country, the majority of the available 5.8M tonnes of cereal straw is therefore located in east Anglia and the east midlands. Very little oilseed rape straw is currently harvested the majority being chopped and returned to the land; the distribution of its availability is therefore very close to the distribution of seed production.

UK crop production areas are shown in Figure 8 below.

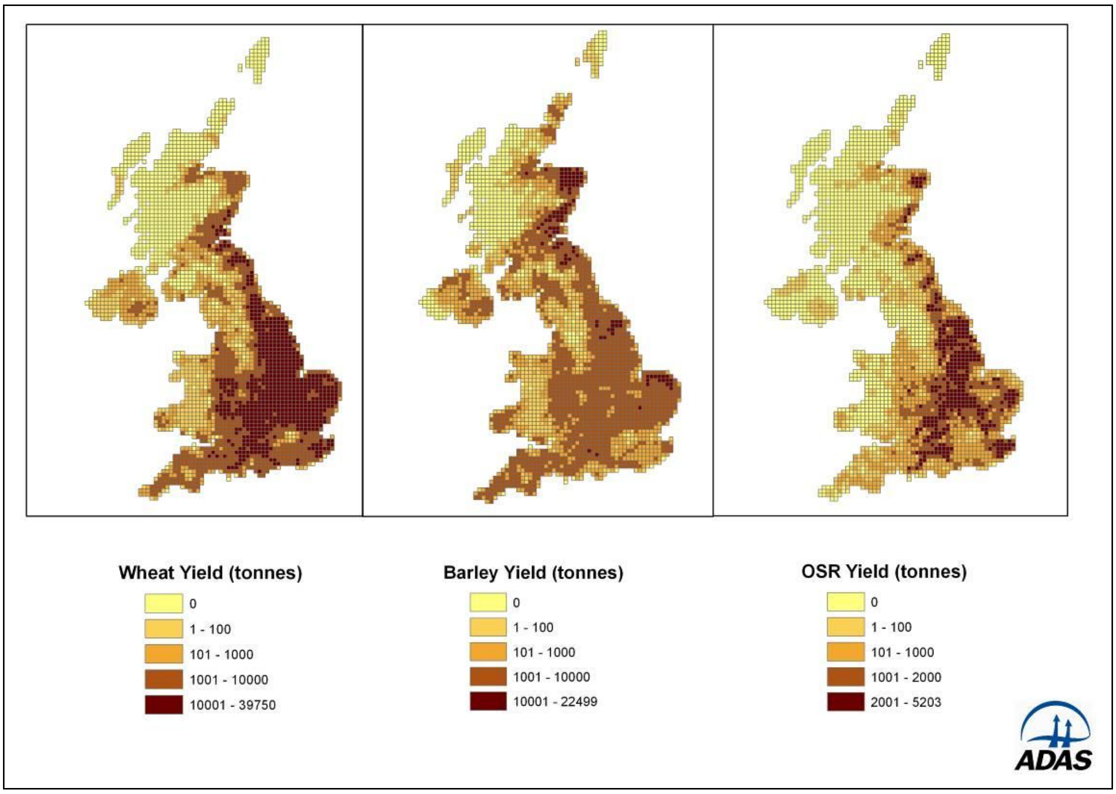


Figure 8. Cereal and oilseed production areas in the UK based on $10km^2$ grid. (Yield is expressed as total for the grid square).

With current UK annual availability of about 8 million odt of unutilised straw, it could make a significant contribution to the UK biomass resource as well as reducing GHG emissions. It should not however be considered as a waste or free resource. Fertiliser prices have increased dramatically in recent years: Ammonium nitrate (34.5% N) is quoted as £390/t for December delivery or £1130 per tonne of nitrogen. Triple superphosphate (TSP) (47% P_2O_5) is quoted at £675/t or £1436/t P_2O_5. Muriate of potash (MOP) (60% K_2O) is quoted at £600/t or £1000/t K_2O. Hence the fertiliser replacement value of straw is now quite significant at £16.84 /t of wheat straw, £21.56/t of barley straw and £23.39/t for OSR straw (see Table 6 below).

In order to encourage any of this potentially available straw biomass into the biomass supply chain the price for baled straw would need to cover the fertiliser replacement value plus the baling and handling cost of £15/t plus an additional margin of say 50% to cover value of other nutrients, soil structural benefits and a profit margin to cover the time and effort involved.

Table 6. Nutrient values of straw.

Nutrient value /t		£/kg*	Value £/t
Wheat			
N - 5.0 kg		1.13	5.65
P_2O_5 - 1.3 kg		1.45	1.89
K_2O - 9.3 kg		1.00	9.30
	Total		**16.84**
Barley			
N - 6.0 kg		1.13	6.78
P_2O_5 - 1.5 kg		1.45	2.18
K_2O – 12.6 kg		1.00	12.60
	Total		**21.56**
Oilseed rape			
N - 7.7 kg		1.13	8.70
P_2O_5 - 2.2 kg		1.45	3.19
K_2O – 11.5 kg		1.00	11.50
	Total		**23.39**

* Source Farm Brief 14 August 2008

The above analysis indicates that a price of £47.76/t fwt (86% dm) or £55.50/odt would be required to encourage currently incorporated wheat straw into the market. Comparable figures for barley and oilseed rape straw are £54.84/t fwt (£47/odt) and £57.59/t fwt (£49.52/odt) respectively. Current prices with straw in the swath selling for £100 or more per ha (c. 4t, which has to be baled and removed by the buyer) or between £33 and £40/t baled seem to confirm that these estimates are reasonable.

Clearly the availability of straw is going to be price related, taking wheat as an example, a straw price:supply curve can be calculated (Figure 9) in the absence of any available data the following assumptions have been made:

- No straw will be sold at a price that does not cover its nutrient value and baling and removal costs.
- An average price of £35/t will bring half the straw to market (current situation); i.e. around 4 million tonnes
- The price calculated above (a 50% mark up on value and costs) would encourage 90% of cereals growers to bale and remove their straw.
- Even at £60/t there would be some growers (2%) who would not bale and remove straw because of the beneficial effect its incorporation has on soil quality.

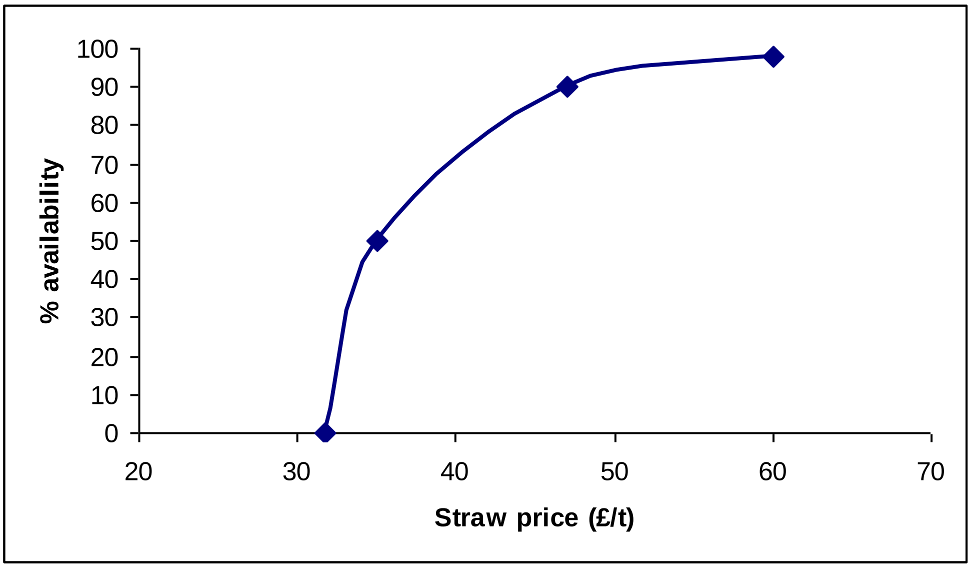


Figure 9. Example wheat straw price: supply curve.

It is worth noting that the fertiliser prices used above are predicted to rise, the market can't give estimates longer than 3 months due to uncertainty over raw material and fuel prices. The best industry estimates are however that ammonium nitrate will increase to £430/t, TSP to £700/t and MOP to £650; this would increase the fertiliser replacement value of wheat straw to £18.27, an increase of 8.5%. Clearly the inherent value of straw is going to be closely linked to fertiliser prices and the cost of fuel for baling and transport, and likely changes in these should be factored in when considering the likely future price of straw, current trends would indicate however that for the foreseeable future the prices calculated above are likely to increase.

4.1.4 Root crops

4.1.4.1 Current production

The two main root crops produced in the UK in any quantity are potatoes and sugar beet. Requiring good quality, workable soils, potato and sugar beet production is mainly concentrated in the East and West Midlands with smaller areas in the South and West, particularly where the climate favours early production of potatoes.

The variable costs of production for root crops are high, as are the fixed costs of production for farms producing cereals and root crops due to high machinery demand. Table 7 below shows the average costs of production and breakeven prices for potatoes and sugar beet.

Given that both potatoes and sugar beet are only about 15-25% and 25% dry matter respectively these equate to breakeven prices of about £360 and £96/odt respectively. Given the high cost of such raw materials, only excess production, waste streams or by-products of root crop production should be considered as possible sources of biomass.

Table 7. Average costs of production and breakeven prices for potatoes and sugar beet.

	Potatoes	Sugar beet
Fixed costs (£/ha)	750	750
Variable costs (£/ha)	2500	690
Yield (t/ha)	45	60
Breakeven (£/t)	£72	£24

4.1.4.2 Potential for change

Currently there is little by-product production from sugar beet production as excess beet production is being diverted into bio-ethanol production, although tops could be utilised in an AD plant. About 5-10% of ware potato production consists of out grades, misshapen tubers, or damaged tubers which are diverted into stockfeed at an average price of £10/t or £50/odt. Assuming an average UK total production of 6M t and an availability of 7.5% this equates to a potential biomass resource of only 450,000t fresh or 90,000 odt.

Figure 10 below, highlights the main root crop growing areas of the UK, due to the high moisture content of the material produced any facility such as an AD plant to utilise by-products would clearly want to be located as closely as possible to the centres of production.

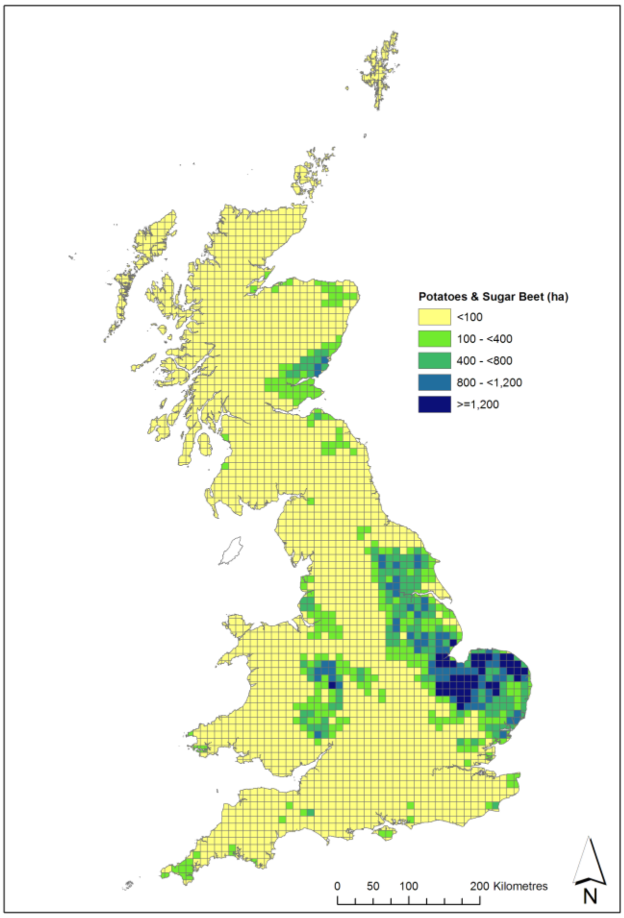


Figure 10. Potato and Sugar Beet production areas in the UK.

4.1.5 Underutilised agricultural land

Since the early 1990's there has been 'set-aside' land which had been removed from food production as part of the Common Agricultural Policy to reduce oversupply of food crops. This land has been available for the production of 'non-food' crops including biomass for energy production. From the Table 1 it can be seen that over the 2005-7 period in the UK there was an average of 480,000 ha of set-aside with a further 175,000 ha of bare-fallow or voluntary set aside. However taking 2007 as an example of the 480,000 ha, 97,000 ha were used for the production on non-food crops, of which 80,000 ha was oilseed rape.

For the 2008 season the set-aside rate was set at 0% to help stabilise food prices and production levels. In response to this and higher commodity prices cropped areas increased; compared to the 2007 the wheat area increased by 13%, barley by 10% but there was a reduction in the oilseed rape area by 10% due to relatively weak oilseed prices and high cereal prices at planting.

Despite this increased arable crop area in 2008, a significant area of uncropped land classified as bare fallow and (voluntary) set-aside remained, the latest estimate being 296,000 ha. As good quality arable land this could be readily returned to production, either as arable crops or dedicated energy crops to produce additional biomass resource.

4.1.5.1 Potential for change

A significant amount of straw was produced as a result of the increased area of cereals grown in 2008. Additionally it is worth noting that 2007 was the highest oilseed rape area ever recorded[1]. It is calculated that this additional cereal production will result in a net increase in available biomass straw of 8.6% or **1.19 million odt future biomass resource**.

Alternatively, if the same area were to be brought back into production in a simple rotation of wheat and oilseed rape, with recoverable straw yields of 4 and 4.2 t/ha respectively, this could result in an additional **future biomass resource of 1.21 million odt** comprising 592,000 t of wheat straw and 621,600t OSR straw.

The 296,000 ha of bare fallow in 2008 could of course be brought back into production for any use, including biomass production. As good quality arable land, a change of use to energy cropping would probably largely be comprised of miscanthus rather than lower yielding SRC, in which case an average yield of 12 odt/ha would produce an additional **future biomass resource of 3.55 million odt.** It must be bourn in mind however that this land could have been brought back into biomass production at any time prior to the set-aside rate being set to 0%. Given that this did not occur when cereal prices were low consideration must be given to the reasoning and this should be addressed.

[1] ADAS data prepared for Defra

4.1.6 Grassland

Grassland is the single largest land use in the UK representing about two-thirds of total agricultural land. Grassland is categorised into; short-term (temporary) grass - under 5 years (1.2 million ha), permanent grass - over 5 years (5.9 million ha) and rough grazing (5.6 million ha, including 1.2 million ha of common land). The productivity of the various categories differs significantly with typical yields of 8-10, 4-6 and 1-3 odt/ha for short-term, permanent and rough grazing respectively, which relates to the quality of the land and the intensity of the management. Total UK annual production is estimated at 34.3 million odt. If biomass facilities, particularly AD, were to exist in the locality grass would be a suitable feedstock. However, grass is difficult to store so there would be some logistical challenges when compared to other biomass. The fibrous nature of grass also leads to higher retention times during the AD process.

Whilst it is feasible to produce grass for AD, the potential is mainly limited to those areas already at the more intensive levels of production which are hence the most profitable and least likely to be considered for other uses. The sites would have to be capable of being mown which precludes most, but not all, rough grazing. Furthermore grass requires high levels of nitrogen fertiliser to reach optimum yields, MAFF Reference book RB209 recommends between 300 and 420 kg N/ha/yr for silage grass, current usage is however lower than this; the British survey of fertiliser practice shows the average N rate on silage grass to be 130kg/ha/yr, even with this lower use of N the production of silage grass for biomass production would have a high green house gas cost.

4.1.6.1 Current production – temporary grassland

Figure 11 shows UK temporary grassland production and this demonstrates that the availability of grassland is primarily to the west of the UK. The utilisation of biomass from this area would therefore spatially compliment that available as a by-product of arable crop production in the east. However, as outlined above the use of grass as an intensively produced biomass resource potentially has a high GHG cost. Consideration needs to be given of the opportunity to produce dedicated biomass crops from the grassland area as a potentially lower green house gas cost alternative. The potential production of biomass from grassland will be affected by the suitability of the land for cultivation and machinery use and the agro-climatic conditions and their suitability for biomass crop production. The likely biomass production will then be influenced by the economic considerations of land use change as well as the social considerations.

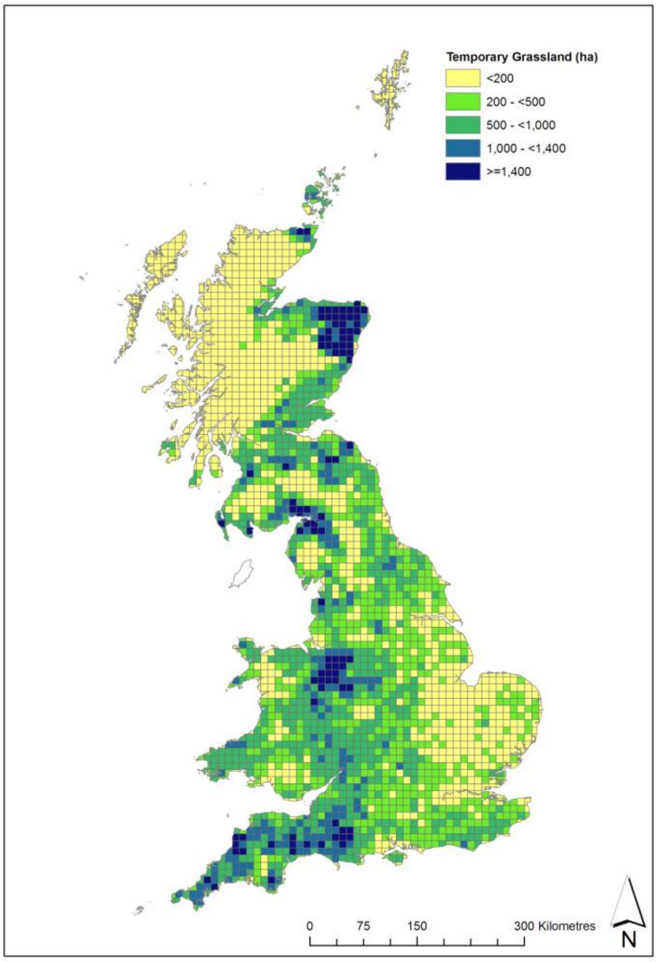


Figure 11. Distribution of temporary grassland in the UK.

4.1.6.1.1Temporary grass – potential for change

The UK currently has 1.2M ha of temporary grass which by its very nature is suitable for cultivation and machinery use as it is regularly reseeded and most of it harvested for silage or hay. This area is down from 1.8M ha in the mid-1980's, which is largely due to grassland being re-categorised as permanent (over 5 years old) due to declining reseeding rates as the profitability of livestock production has declined or conversion to the production of forage maize. In terms of predicting the area potentially available for the production of dedicated biomass crops it would seem sensible to assume that all of the temporary grassland could be used plus a further 600,000 ha of permanent grassland. The vast majority of this land is located in areas deemed as suitable or highly suitable for the production of SRC or Miscanthus.

Consideration must now be given to the current enterprises utilising this grassland and the likelihood of a change in land use. Figures are not available that can be used to tie specific livestock enterprises to specific grassland categories due in part to the integrated nature of most livestock enterprises. However based on livestock numbers and stocking densities on livestock units it is possible to estimate the usage of the grassland resource by enterprise:

Table 8. Estimate of % usage and area of temporary grassland and cultivatable permanent grassland resource by enterprise.

Enterprise	%age of area	Area (ha)
Dairy	54	972,000
Beef	30	540,000
Sheep	15	270,000
Other (outdoor pigs, chickens, goats etc)	1	18,000
Total	**100**	**1,800,000**

Firstly it is worth considering 'redundancy' within this extant land use i.e. are there enterprises producing an output significantly in excess of domestic requirement or without a market. Defra market stats for 2006 and 2007 show that for mutton and lamb the UK imported 139,300 and 137,000 t of dressed carcase weight for the 2 years, which were off-set by exports of 95,000 and 76,400 t respectively, the UK is therefore producing in the order of 52,000 t less lamb and mutton than is demanded by consumption. Comparable figures for beef and veal indicate that over the 2 years imports outstripped exports by 208,850 t/annum. It is only in the dairy sector where production of raw milk exceeds demand, wholesale deliveries to dairies outside of the UK amounted to 542 million litres in 2007 compared to imports of 49 million litres, it should also be noted that this is a relatively small apparent oversupply of 4.3% compared to the 12,725 million litres utilised by UK dairies. It is also worth noting that the UK is not self sufficient in dairy products and whilst raw milk is exported to non-UK dairies a significantly greater equivalent amount of processed dairy products are re-imported. Based purely on this simple analysis of supply and demand within the UK, none of the existing grassland resource could be considered to be surplus to requirements for food production.

Despite the fact that the meat products produced from grassland are required by the market, the enterprises are not necessarily the most profitable use of the land. The farm management pocketbook[1] gives gross margins of £66/ha, £178/ha and £343/ha for low, average and high performance lowland spring lambing enterprises. For lowland suckler enterprises the figures are £117/ha and £216/ha for average and high performance. For dairy units using average stocking rates of 2 cows per forage ha the figures are £1398/ha, £1918/ha and £2172/ha of low, medium and high milk yield per cow respectively. Direct comparison of these figures with returns for energy crops is fraught with difficulty due to the very significant direct costs of the enterprises. Nix 2007 gives enterprise fixed costs of £1025/ha for mainly dairying farms of over 125ha and £590 for mainly sheep/cattle (lowland). It is worth noting that for all levels of performance of sheep and beef enterprises these give negative net margins, and for dairy enterprises net margins of between £373 and £1147/ha. The CSL Report[2] for the NNFCC used enterprise margins to

[1] John Nix Pocketbook 38th edition (2008)

[2] David Turley and Nicholas Liddle (2008). Analysis of the economic competitiveness of perennial energy crops on arable farms

compare energy crop and wheat profitability – this approach essentially includes all costs as contractor charges, and is a reasonable approach for cropping enterprises but not applicable to livestock enterprises due to the daily nature of the work.

Given the higher proportion of total costs included in the enterprise margins than the gross margin calculations in Nix, any comparison of the two will favour the livestock enterprises, however such a comparison can be used to investigate the likely shift in land use as the value of biomass changes, the methodology and outcome of such a comparison is given below.

The low, average and high gross margin data given by Nix have been assumed to represent the 5th, 50th and 95th percentile of the total area dedicated to each enterprise in the table above. Linear fits of the cumulative area achieving up to a given gross margin were then plotted. These gave the following equations, where the area of any given enterprise which would, on purely economic basis, be replaced by biomass production for any given biomass gross margin (GM):

Sheep Area = 0.8667GM - 34.58 (R^2 = 0.9879)
Beef Area = 1.5283GM + 91.189 (R^2 = 1)
Dairy Area = 1.0874GM - 1503.3 (R^2 = 0.9621)

These equations were then populated with margin data given in Turley and Liddle[1] (2008) for biomass prices of between £30 and £55/ odt (the highest price given), for Miscanthus and SRC at yield levels of 12 odt/ha/yr and 9 odt/ha/yr (taken as a mean of the figures for 8 and 10 odt) respectively. The outputs of the analysis were delimited to exclude negative land conversion values and to the maximum grass area assumed to be committed to each enterprise. The outputs are given in figures 12 and 13 below.

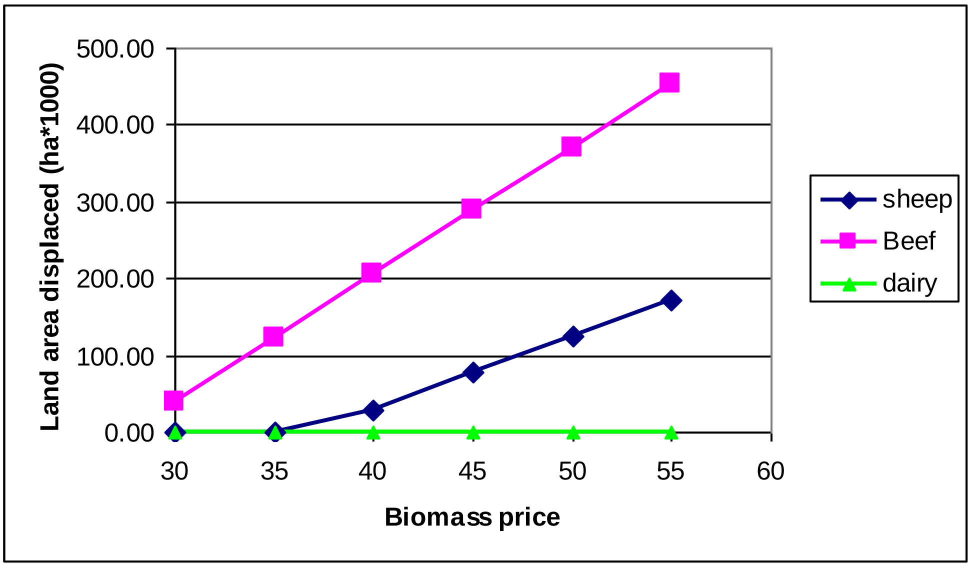


Figure 12. Predicted conversion of grassland to Miscanthus production assuming a yield of 12 odt/ha/yr as affected by the price of biomass.

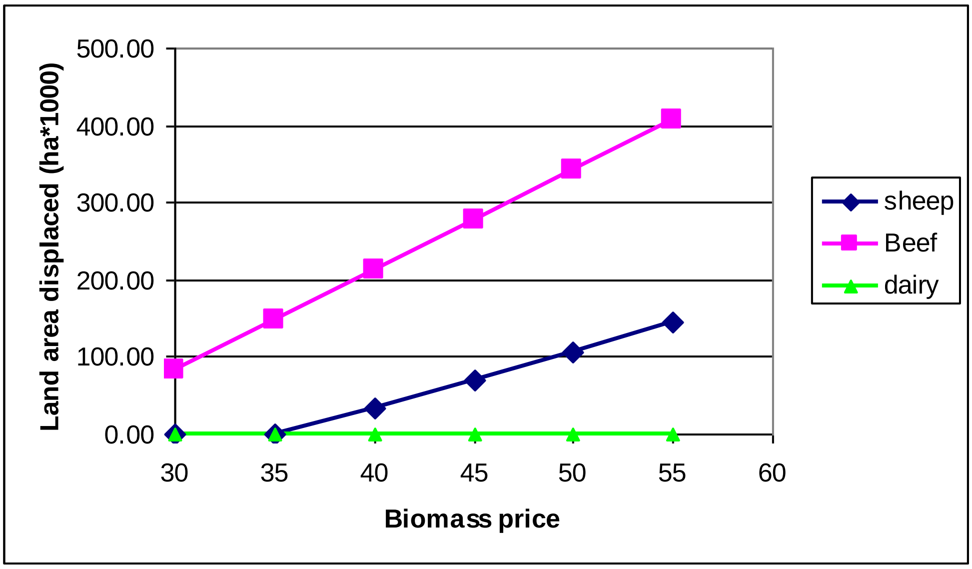


Figure 13. Predicted conversion of grassland to SRC production assuming a yield of 9 odt/ha/yr as affected by the price of biomass.

Clearly on a purely economic analysis even relatively low biomass prices would make the conversion of grassland to biomass production attractive. This is particularly emphasised for beef and sheep enterprises where even the highest gross margins are predicted to be insufficient to cover standard fixed costs. Conversion of these units to biomass production would significantly reduce fixed costs particularly if the operations were contracted out.

That the production of meat on better quality grassland continues given negative net margins indicates that changing land use of this land is a significantly more complex issue than can be dealt with from a purely economic analysis.

A review of beef and sheep numbers from Defra June census data shows that their numbers peaked in 1998 at 1,947,400 (beef breeding herd) and 1992 at 44,539,900 (total sheep and lamb numbers) respectively. By 2007 these numbers had declined to 1,698,000 and 33,946,000, reductions of 12.8% and 23.8% for beef and sheep respectively, the reduction being greater in sheep due to the effects of the foot and mouth epidemic in 2001 being greater in areas of high sheep population. Over this period there has been no significant reduction in grass area indicating an extensification of stocking rates. Similar reductions in the grass area utilised by each enterprise could therefore reasonably be envisaged with intensification of the stocking rate on the remaining area to those achieved during the 1990's without affecting current food supplies, it should be noted however that the long term trend for reduced fertiliser inputs to grass would be needed to maintain stock numbers. This would release 69,120ha and 64,260ha of grass for alternative uses from beef and sheep production respectively. Using the economic analysis above this would require a biomass price of only about £30/odt to release the beef land but closer to £45/odt to release sufficient sheep land. Whilst there have been similar declines in the dairy herd, this has been characterised by the loss of whole enterprises and as the herds have been lost the land has been diverted into alternative uses. The remaining dairy units are still stocking their land at high densities and so there is not the scope for releasing land as there is within the beef and sheep industries.

UK livestock production is reliant on a highly complex, integrated and stratified system of grassland production which has resulted in the various areas of short-term, long-term and rough grazing. The act of reducing the area of temporary and permanent grassland, if offset by increased intensification on the remaining area, would not necessarily impact on the utilisation of permanent pasture unsuitable for cultivation or on rough grazing.

If it is assumed that a total of 133,380 ha of grassland could be released (through the re-intensification of beef and sheep enterprises combined) for biomass production and utilised 50% for SRC and 50% for Miscanthus and assuming average yields of 9 odt/ha and 12 odt/ha respectively this would produce a total **future biomass resource of just over 1.4M odt/annum**, without impacting on current food production. This production would be likely to be concentrated in the areas currently with the highest proportions of temporary grass as shown in figure 11 above, i.e. the northern marches and south west of England.

Whilst there may be concerns about loss of biodiversity from re-intensification of grazing it should be noted that this is not generally an issue with intensively managed temporary grassland.

As outlined above changing land use is not driven solely by economic concerns, one of the issues that mitigates against the uptake of perennial biomass crops is the long term nature of the commitment and significant up-front investment required. It is therefore likely that a proportion of this land if released from livestock production would be utilised for the production of annual crops such as maize or cereals, which could feed into the biomass market to fuel; AD plants, 1st generation biofuels or biomass (straw) markets. It should be noted however that the energy and GHG costs of supplying these markets from annual crops will generally be significantly higher than from perennial crops.

4.1.6.2. Permanent grass and rough grazing – current production

As well as the extensification of grazing on temporary grass there has been a similar reduction in stocking rates on permanent grass and rough grazing. A return to previous levels of intensity of stocking on rough grazing (5.6M ha) and the remaining 5.3M ha of permanent pasture not included in the above analysis could release significant areas for alternative uses.

As the intensity of grassland management is reduced so the proportions utilised by dairy and beef production decline and the proportion used for sheep production increases. As with temporary grassland absolute data on the proportions committed to specific enterprises is not available, the proportions shown in Table 9 have therefore been based on livestock numbers, livestock units and stocking densities.

Table 9. Permanent grassland and rough grazing utilisation by enterprise.

	Grass >5 years old		Rough grazing	
	%age allocation	**Area (ha*1000)**	**%age allocation**	**Area (ha*1000)**
Dairy	35	1 855	0	0
Beef	40	2 120	15	840
Sheep	25	1 325	85	4 760
Total		**5 300***		**5 600**

* excludes 600,000ha included as suitable for cultivation under temporary grass.

4.1.6.2.1 Permanent Grassland and Rough Grazing – potential for change

Using the same reductions in livestock numbers as in the previous section i.e., 12.8% and 23.8% for beef and sheep respectively, and assuming grazing intensity could return to those used in the 1990's then (as with temporary grass land fertiliser inputs would need to increase on permanent grassland to achieve this) land released for alternative uses is shown in Table 10.

Table 10. Permanent grassland and rough grazing land potentially released for alternative uses due to re-intensification of livestock production

	Grass >5 years old		Rough grazing	
	Area released (ha*1000)	**SRF Biomass production (t/yr *1000)**	**Area released (ha*1000)**	**SRF Biomass production (t/yr *1000**
Beef	271	1 115	108	444
Sheep	315	1 296	1 133	4 663
Total	**586**	**2 411**	**1 241**	**5 107**

Historically this land was woodland (prior to clearance for agriculture in the 17th and 18th Centuries) and as stated previously the vast majority is not suitable for cultivation, indeed to repeatedly cultivate such land would release significant quantities of GHG emissions from the breakdown of soil carbon stores. If a proportion was to be released from livestock production it would therefore be most likely to be returned to woodland.

Theoretically, and assuming a use for higher value forest products harvested from new plantings could be found, around 2.54 million odt yr^{-1} of wood fuel could be produced if 1.8M ha of the rough pasture in the UK was planted with broadleaved woodland (growing at yield class 4). If conifer woodland was established instead, this figure would rise to 3.31 million odt yr^{-1} (assuming a mix of yield class 14 Douglas Fir, yield class 8 Larch and yield class 10 'Other Conifer' was planted). If a more intensive Short Rotation Forestry (average yield 4.18 odt/ha/yr) approach was adopted then it may be possible to produce **a future biomass resource of 7.52 million odt yr^{-1}**.

The location of this new biomass resource would be likely to be distributed similarly to the current distribution of permanent grassland and rough grazing as shown in figures 14 and 15 below i.e. the upland areas of Wales, north western Scotland and the upland areas of north, west and south west of England .

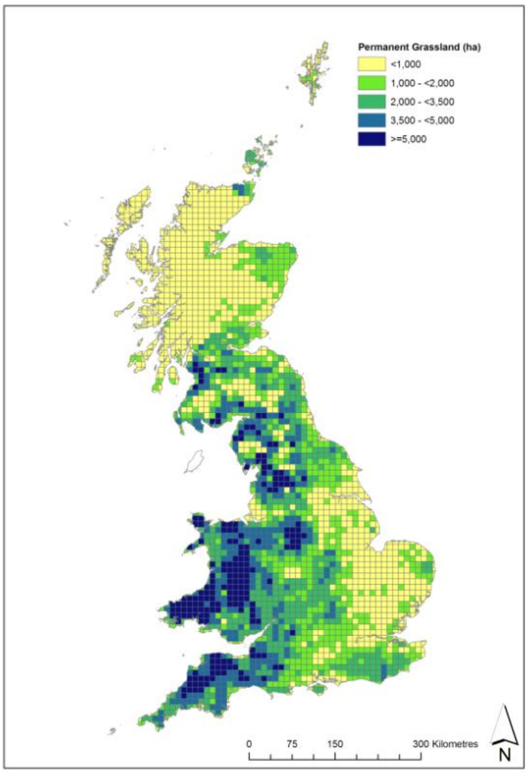


Figure 14. Distribution of permanent grassland (ha).

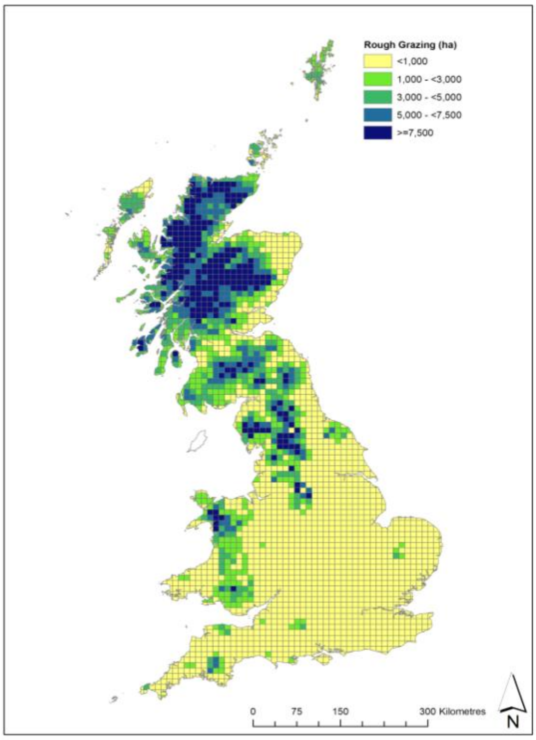


Figure 15. Distribution of rough grazing (ha).

The implications of such large scale land use change would also need to be given careful consideration. There would be significant landscape impacts of converting back to woodland over 20% of the rough grazing area and 10% of permanent pasture, as well as potentially significantly impacting on the amenity value of such land without careful planning. Releasing this quantity of land whilst maintaining existing livestock numbers may lead to concerns about deterioration of the quality of the remaining land due to over grazing however, as long as the stocking densities proposed here were evenly distributed over the available land, and the enterprises well managed this should not lead to overgrazing damage. There are also likely to be beneficial effects in terms of increased biodiversity of the converted land assuming the new woodland was well planned and managed.

4.2 Forestry Production

The total area of woodland in England, Wales and Scotland is 2.75 million ha comprising 1.57M ha of conifer and 1.17M ha of broadleaf woodland. Conifer is the dominant species at 57%. The Forestry Commission is responsible for managing 28% of the UK woodland. Scotland has the majority of woodland at 49%, England 41% and Wales 10%. This is detailed in Table11.

Table 11. Area of forestry in England, Wales, and Scotland (thousands of ha).

	Broadleaf	**Conifer**	**Total**
Forestry Commission			
England	53	149	202
Scotland	27	430	457
Wales	13	93	106
Sub-Total	*93*	*672*	*765*
Non FC			
England	704	218	922
Scotland	266	618	884
Wales	114	65	179
Sub-Total	*1084*	*901*	*1985*
Total	**1177**	**1573**	**2750**

Yields from forestry are expressed in terms of usable timber and total biological yield is not generally calculated or defined. In order to quantify potential for biomass production it is helpful to note that slow growing broadleaf species such as oak is capable of annual wood yields of 4-8 m^3 which equates to 2-4 odt and fast growing conifer species such as sitka is capable of up to 18 m^3 or 9 odt.

The 5 year average UK total woodland production for the period 2002-06 was 4.43 million odt comprising 4.15M odt softwood and 273k odt hardwood.

Table 12 shows the amount of softwood and hardwood harvested from the existing forest resource in the UK during the period 1997 – 2006. The majority of this material went to non-fuel markets such as fibre board production and construction. Only approximately 4% of this material was used in heat or power generating projects.

Table 12. Softwood and hardwood harvested from UK woodlands.

	Thousands of oven dry tonnes harvested from existing UK woodlands[1]	
Year	**Softwood**	**Hardwood**
1997	3397.5	409
1998	3413.0	358.5
1999	3640.0	338
2000	3715.0	327.5
2001	3752.0	320.5
2002	3824.0	310.5
2003	4167.0	281.5
2004	4263.0	257
2005	4245.5	297
2006	4250.5	219.5

4.2.1 Utilisation of existing forestry resources

The highest potential yields are generally situated well away from areas of cereal production and hence complement rather than compete with existing cropping, offering instead a new potential fuel source utilising an existing resource. The utilisation of woodland materials in this way can help bring neglected woodlands back under active management practices.

Production from commercial forestry systems is usually more complex than for annual or perennial energy crops or for short rotation forestry in that production takes place as a series of episodes over the life cycle of a forest stand (i.e. thinnings and fellings) and a mix of biomass components is obtained (i.e. sawlogs, roundwood, branches and conceivably roots and stumps), To complicate matters further, it is unlikely that sawlogs would be accessible for utilisation as woodfuel due to their high value as a source of structural material. This also applies to some extent to roundwood production, particularly from coniferous forests. There will, however, be an opportunity to supply woodfuel from secondary production arising from sawmills notably in the form of wood chunks and sawdust.

In order to estimate the potential amount of available biomass for a range of common tree species by yield class, a representative range of conifer and broadleaf species were derived from the Forestry Commission yield models[2] and processed through the BSORT biomass model[3] to produce estimates of potential biomass, in oven dry tonnes, over full rotations of the selected forest stands. Outputs were broken down into relevant tree components, specifically:

[1]Data taken from Forestry Statistics 2007, http://www.forestry.gov.uk/website/forstats2007.nsf/LUContents/88BDD8FEA0D881448025734E004F27BB and assumes that fresh felled, green timber has a moisture content of 50%

[2] Edwards, P.N. and Christie, J.M. (1981) *Yield models for forest management*. Forestry Commission Booklet 48. Forestry Commission: Edinburgh.

[3] Matthews, R. W. and Duckworth, R. R. (2005) BSORT: a Model of Tree and Stand Biomass Development and Production in Great Britain. In: Imbabi, M.S. and Mitchell, C.P. (eds.) Proceedings of World Renewable Energy Congress (WREC 2005), 22-27 May 2005, Aberdeen, UK. Elsevier: Oxford, 404-409.

- Roots
- Stumps
- Sawlogs
- Roundwood
- Stem tips
- Branches
- Foliage.

An example of the output for a thinned stand of yield class 8 Scots pine is shown in Table 13. The total production of each component over a rotation was annualised assuming a two year fallow period, as illustrated in the table. The fraction of total biomass production available as wood fuel was estimated by applying the generalised biomass flow chart to the results for total biomass. These calculations are illustrated in Figure 16, based on the results from Table 13.

Table 13. Example output from BSORT model for Scots pine, yield class 8. Biomasses are given at each thinning age and for the final felling in odt ha^{-1}

Age	Roots	Stump	Sawlog	Roundwood	Stem Tips	Branches	Foliage	Total
31	6.3852	0.5154	0.0000	9.1282	3.6049	4.7694	2.1983	26.60
36	5.5088	0.4355	0.0054	10.0862	2.1452	3.8596	1.7730	23.81
41	4.3187	0.3262	1.0310	9.79.5	1.0806	2.9167	1.3328	11.00
46	3.7945	0.2828	2.5961	8.2181	0.9293	2.5327	1.1491	19.50
51	3.5199	0.2575	4.3343	6.5380	0.7891	2.3620	1.0621	18.86
56	3.3441	0.2394	6.1860	4.9315	0.5159	2.2799	1.0141	18.51
61	35.8851	2.4970	83.1315	26.3761	3.2240	25.9701	11.1475	188.23
Total	62.7563	4.5538	97.2843	75.0686	12.2890	44.6904	19.6769	316.32
[1]**Annualised**	0.9961	0.0723	1.5442	1.1916	0.1951	0.7094	0.3123	5.02

[1] Calculated from total biomass by dividing by 63 years (61 year rotation plus 2 fallow years).

The estimated wood fuel production for different species, yield classes and management regimes was then plotted against yield class to investigate whether a simple relationship could be established. Three characteristic equations describing the relationship between potential biomass production and yield class were derived for the major species groups of:

- Broadleaf stands
- Larches and Douglas fir stands
- Other conifer stands

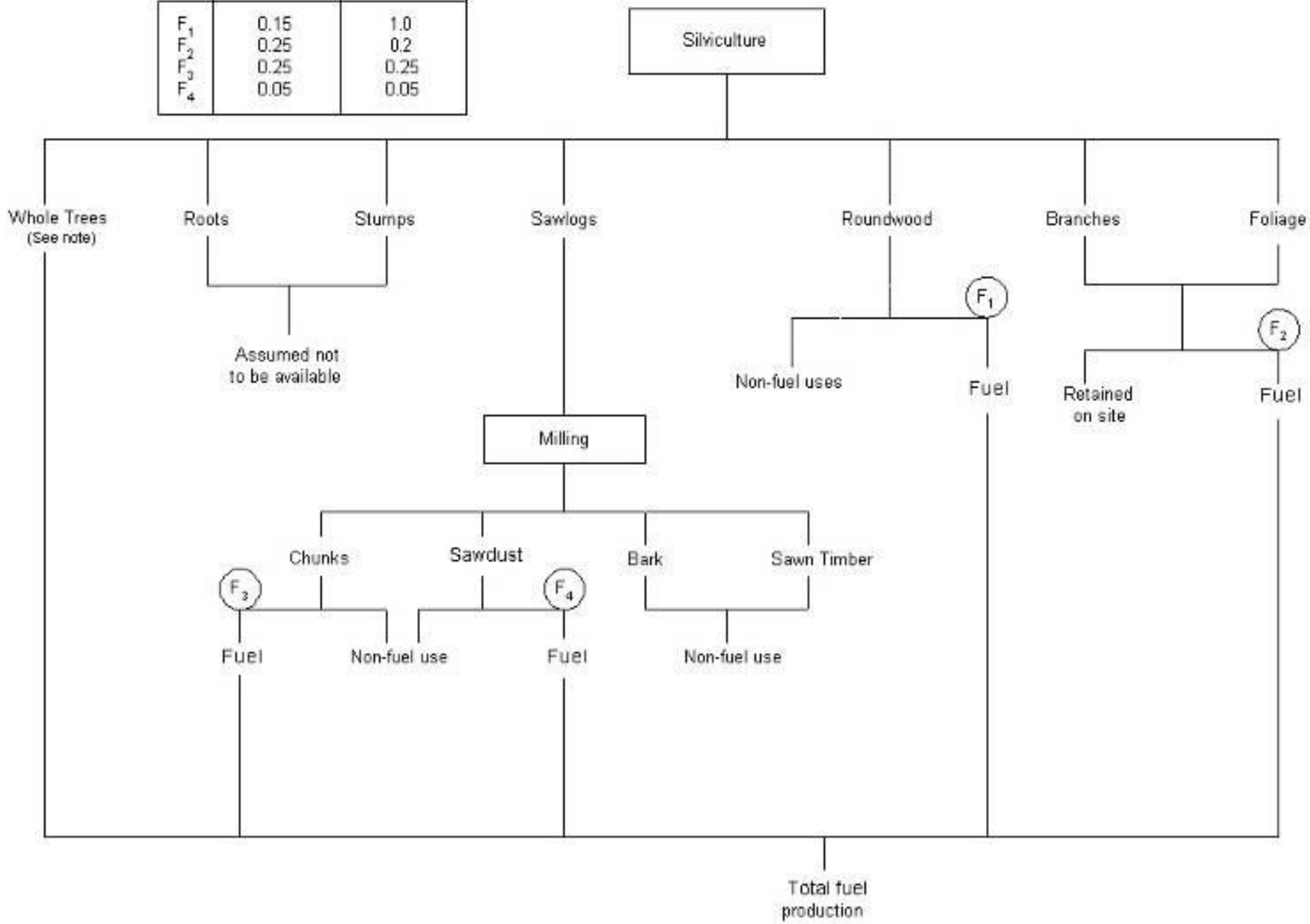
In order to map the yield potential of existing forests, predictions of forest biomass potentially available for different regions of Britain were made using a combination of forest inventory data, expert system yield class estimates and associated biomass equations.

Figure 16. Generalised biomass flow chart for conventional forestry systems.

Values assumed for partition coefficients F_1-F_4

	Conifer	Broadleaf
F_1	0.15	1.0
F_2	0.25	0.2
F_3	0.25	0.25
F_4	0.05	0.05

Note: For thinned conifer stands, production from the first two thinnings was assumed to consist of removal of whole trees for use as fuel (not including stumps and roots). A similar assumption was made for broadleaf stands but involving the first three thinnings, with the exception of beech and oak (first five thinnings).



The National Inventory of Woodland Tree survey (NIWT)[1], was carried out between 1994 and 2000. The estimates of woodland cover provided by the NIWT survey were grouped into 5 categories with similar productive potentials:

- Pines and Larches
- Spruces, Douglas Fir and other conifers
- Mixed conifer woodland
- Broadleaves
- Mixed broadleaf woodland

4.2.2 Expert system yield class estimates

The Ecological Site Classification (ESC) is a software-based decision support tool, developed as expert system[2]). The ESC software was used to obtain yield class potentials that were aggregated up to achieve a resolution of 20 km x 20 km and aligned to the Ordnance survey grid.

ESC predictions of yield class potential were generated for species groups compatible with those used for analysis of the NIWT data. These estimates were interpreted using local knowledge and previous spatial analyses of yield class (Matthews *et al*., 1996; Matthews and Methley, 1996; Tyler *et al*., 1996; Waring, 2000) to derive robust predictions of yield class for existing forest areas.

4.2.3 Combining inventory, yield class and biomass estimates

The groupings of species for estimation of yield class and for estimation of biomass potential were slightly different. In order to integrate the two sets of predictions, NIWT area data was distinguished using a consistent species classification of:

- Pines
- Larches
- Douglas Fir
- Spruces & other conifers
- Mixed Conifers
- Broadleaves
- Mixed Broadleaves

The potential biomass production from existing forests in each 20 km grid square was estimated by:

- Estimating the yield class for each species group identified above based on the adjusted ESC predictions.

[1] Smith, S. and Gilbert, J. (2003) *Forestry Commission: National Inventory of Woodland and Trees. Country report for Great Britain*. Forestry Commission: Edinburgh.

[2] Pyatt, D. G. and Ray, D. *et al.* (2001) *An Ecological Site Classification for Forestry in Great Britain*. Forestry Commission Bulletin 124, Forestry Commission: Edinburgh.

- Deriving an estimate of potential biomass production for each species group in odt ha^{-1} yr^{-1} using the equations to convert yield class to biomass production.
- Multiplying the estimate of potential biomass production for each species group by the area for the species in the 20 km square, obtained from NIWT.
- Summing the biomass estimates for each species group to obtain the total biomass potential in the 20 km square.

The final estimates of potential production from existing forest areas are shown as maps in Figures 17 and 18, for broadleaf and conifer forests. It should be emphasised that these results assume that all woodlands in Britain are available for bringing into full sustainable yield production. If all existing forests were actively managed for timber production and material not suited for use by existing markets (e.g. construction and board manufacturers) was recovered, 1.9 million odt of wood from coniferous forest and 2.3 million odt of wood from broadleaved forest could be harvested for use as fuel each year (Table 13) a total **current forestry biomass resource of 4.2M odt.** This figure ignores environmental constraints such as long term site sustainability and physical and economic constraints such as cost of harvesting and extracting this material from the forest. UK timber prices and costs of extraction are discussed at 4.2.4 below.

Potential fuel produced from existing woodland can be estimated by referring to:

- Data on forest area by species from the Forestry Commission National Inventory of Woodlands and Trees[1]
- Assumptions about productivity of tree species growing in UK conditions used in the Ecological Site Classification system[2,3]
- Predictions made by forestry yield models[4]
- Application of models to convert yield predictions to biomass estimates[5]

4.2.4 UK Timber prices

Most of the timber used in the UK is imported which makes UK timber producers price takers i.e. dock-side prices dictate what UK growers and merchants can charge for their products. There is a vibrant market for round timber in most parts of the UK, serving the needs of a modern round timber processing industry for conifers. Prices for UK timber vary according to

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[1] Smith, S. and Gilbert, J. (2003) *Forestry Commission: National Inventory of Woodland and Trees. Country report for Great Britain*. Forestry Commission: Edinburgh.

[2] Pyatt, D. G. and Ray, D. *et al.* (2001) *An Ecological Site Classification for Forestry in Great Britain*. Forestry Commission Bulletin 124, Forestry Commission: Edinburgh

[3] Ray, D. (2001) *Ecological Site Classification: A PC-based Decision support system for British Forests V1.7 User Guide*. Forestry Commission: Edinburgh.

[4] Edwards,P.N. and Christie, J.M. (1981) Yield Models for Forest Management. Forestry Commission booklet 48. Forestry Commission, Edinburgh.

[5] Matthews, R. W. and Duckworth, R. R. (2005) BSORT: a Model of Tree and Stand Biomass Development and Production in Great Britain. In: Imbabi, M.S. and Mitchell, C.P. (eds.) Proceedings of World Renewable Energy Congress (WREC 2005), 22-27 May 2005, Aberdeen, UK. Elsevier: Oxford, 404-409.

circumstances which are briefly outlined below. However, indicative data on average prices is held on the Forestry Commission's website[1].

A number of factors affect price:

- Timber products are sold in numerous ways – 'standing' or 'roadside', by volume (cubic metres or m^3) or weight, by green tonne or oven dry tonne as well as a number of more minor methods. They may also be sold by negotiation, tender, auction or on a long term arrangement. Roadside sale is where timber is cut into individual specifications and sold separately at roadside to a number of customers. In standing sales, areas of trees are sold to one customer to cut to his own requirements.

- Trees yield more than one product. First thinnings tend to offer a more limited range of products than older (larger) trees. Larger timber is mainly used for sawlogs. Price depends on quality. For conifer timber, 'green' logs are best (used for construction and sawn fencing) and 'red' logs are of lower quality (used for pallets and packaging). The GB average price for 'Green logs' in Spring 2008 was £37.77/m^3 and for 'Red logs' £27.90/m^3 (1m^3 is approximately equal to 0.5 odt) actual prices can vary considerably by region. Further up the tree is material which, due to size, can be used for lower grade sawn material similar to red logs. At the top of the tree is small roundwood which is used for pulp, panelboard such as chipboard or MDF, shavings or woodfuel. Indicative prices for small roundwood are between £15 and £25 per tonne at roadside. Branchwood, tops and dead wood is seldom currently used although interest is increasing. Hardwood timber prices are even more dependent on quality. For example, in 2007 'hard wood poles' attracted an auction price of £184.33/m^3 in England. Shorter 'hard wood logs' attracted a price of £95.78/m^3. The UK hardwood market is not currently as well developed as the conifer market.

- Size and species of tree also have a bearing on price. The sawmilling industry has developed a degree of specialisation for what is most common locally. Unusual species tend to attract a lower price.

- Costs vary with terrain, tree size and species, labour availability and distance from both forest to processor and processor to market i.e. haulage. The cost of felling and extracting timber will also depend on the nature of the forest and the equipment available to the contractor carrying out the operations. As a rough guide the price for felling and extracting timber to roadside will be up to £20-25 per cubic metre for small-scale operations in hardwoods, but could be as low as £8-10 per cubic metre in large-scale, mechanised conifer clearfells. Haulage costs will be dependent on journey times and lengths and load capacity but are likely to be in the region of £8.5–16 per cubic meter. Producing woodchips from extracted timber will cost around £10 per cubic meter. Storing and drying timber prior to chipping is estimated to cost around £10 per cubic meter.

[1] Forestry Commission http://www.forestry.gov.uk/forestry/infd-7ayh6n

However, this assumes there are no management constraints to storage at roadside.

All of the information above refers to operations within the existing, conventionally-managed forest estate. More intensive systems of management could be established, e.g. Short Rotation Forestry, which may lead to the costs associated with production being reduced.

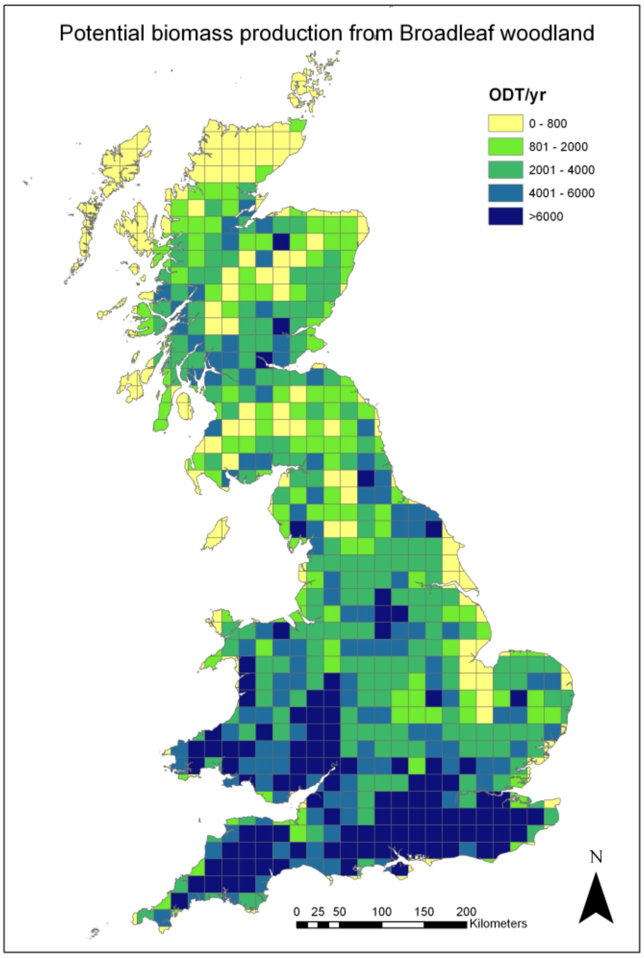

Figure 17. Potential additional production from extant broadleaf woodland in England, Scotland and Wales.

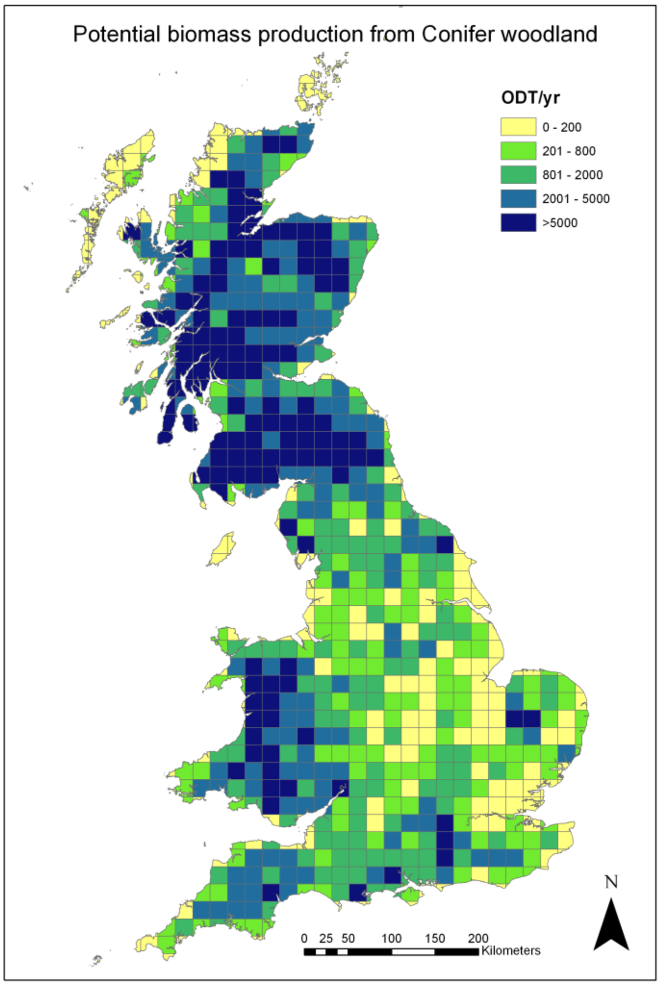

Figure 18. Potential additional production from extant coniferous woodland in England, Scotland and Wales.

4.3 Non-agricultural/forestry land

The UK has a total land area of 24,251,000 ha, of which 73.92% is in agricultural use and 11.65% in forest and woodland, this leaves 14.43% or just under 3.5M ha of land which is used for urban, transport and recreational uses.

The potential to utilise currently underutilised biomass resource or increase biomass production from agriculture and forestry is dealt with elsewhere in this report. However there is clearly a significant additional land area from which there is currently little or no biomass utilisation.

The vegetation growing on the 'soft' landscaping of this 3.5M ha (e.g. the margins of transport routes, together with municipal, corporate, industrial and educational open spaces) is actively managed for a variety of reasons. These include landscape value, access, safety, visibility and specific examples such as minimising leaf-fall onto railway lines and removing overhanging branches from power lines. In the majority of cases, the harvested material, including significant quantities of chipped wood, is cut down and left *in situ* to decompose, releasing the majority of the GHGs trapped during the growth of the biomass back to the atmosphere.

The total road, rail and canal network in the UK amounts to some 433,900 km; if it is assumed that the average margin on the network amounts to 4m (2m either side) then this equates to a potentially cropable area of 180,000 ha. Assuming an annual biomass yield of 3 odt/ha (equivalent to that of rough grazing grassland) this equates to an additional **biomass resource of 0.54 million odt**, which is of the same order which might be obtained by substituting 1.75% of the UK arable area with dedicated energy crops of miscanthus and SRC. It is predicted that with improved management aimed at maximising biomass production, such as revised cutting regimes and the establishment of higher biomass planting in appropriate areas the average yield potential could be increased to 5t/ha (equivalent of permanent pasture or SRF) increasing the total **future biomass resource to 0.9M odt**. Available data for this land class in terms of current usage and management is much more limited. More detailed data does exist, however it is in much more diverse data sources than for agricultural or forestry land, for example ADAS holds survey data for railway embankments to predict leaf fall. A more detailed study is required to provide a more accurate calculation of the biomass resource which could be obtained from non-agricultural land.

There are also significant areas of amenity land and grounds, such as public parks, golf courses, industrial estates, airfields, schools, college and university campuses which are also currently managed. This is a potentially valuable source of biomass which could be readily utilised, if the facilities are established sufficiently close to the source of biomass and their feedstock requirements planned to match the biomass available.

This is a potentially significant and valuable source of biomass especially as the cost of management and harvesting/cutting is already being incurred, leaving only the additional costs of transport/logistics to be accounted for. It is also produced conveniently close to existing transport infrastructure and a significant proportion of it close to potential users of electrical and heat energy. The impact of optimising biomass production from this resource would be very low with little change required to current land use and landscape value and no competition for resources for food production.

Because of the scale and diversity of this land resource its exact quantification is beyond the scope of this project, and should be the subject of a more detailed study to identify the scale, location and types of biomass available or potentially available as affected by the alternative requirements for the management of the land.

However if it is assumed that 10% of the total non-agricultural non-forestry land is in soft landscaping in addition to that allowed for transport verges this would equate to 350,000 ha. Assuming biomass production rates equivalent to permanent grassland (5 odt/ha/yr) this equates to a **biomass resource of 1.75M odt/yr**.

5. Discussion

5.1 Total UK biomass resource

It is clear that there is currently significant potential demand for biomass for the production of road transport fuels and electricity production and in the future it is likely that there will be greater demand for biomass for heat.

Our analysis shows that there is already a significant biomass resource in the form of by-products from food or forestry production which is being produced but is not utilised for energy production. Clearly in terms of increasing biomass supply this represents the easiest source for any rapid expansion of supply, as no change in land use is required. The first question to be asked therefore is how can this resource be drawn into the market? It seems clear from our analysis that this is firstly an economic question and as the price of biomass increases so the amount available on the market will increase. We estimate that there is potentially **14.59M odt** of biomass (made up of 4.2M odt from forestry, 8.1M odt of wheat, barley and oilseed rape straw, 0.54M odt from road and line side verges and 1.75M odt from urban green areas, Table 14) currently produced and largely unutilised. This is in addition to production from extant dedicated Miscanthus and SRC biomass crops which we estimate to be an additional **0.09M odt**. The majority of this biomass will be available in relatively dry form with the exception of the 2.29M odt from transport verges and urban areas which would be a mix of ligno-cellulosic biomass and green material.

In addition to biomass already produced but not used for energy production there is a similar quantity of biomass production (**15.7M odt**) which could be made available with relatively little impact on production for existing markets but would require a change in land use. Of this potential additional biomass resource there is a relatively small quantity of 1.2m odt from straw production in arable crops on previously set-aside land brought back into production for the 2008 harvest. The remainder 14.5M odt is made up of 3.6M odt from Miscanthus established on currently fallow land, 1.8M odt from Miscanthus on 5% of current arable land, 1.6M odt from Miscanthus and SRC on temporary grassland and 7.5M odt from SRF on permanent pasture and rough grazing (Table 14).

Table 14: Current* and Potential annually available UK biomass resource from agriculture and forestry

Cropping source	**Currently produced biomass**	**Potential future biomass production**
	Oven dry tonnes (million)	**Oven dry tonnes (million)**
Wheat straw	4.2[1]	-
Barley straw	1.6[2]	-
Oilseed rape straw	2.3[3]	-
Straw from set-aside brought into cropping 2008	-	1.2
Miscanthus on 2008 set-aside area	-	3.6
Miscanthus (currently 5036ha)	0.06	-
Miscanthus on 5% arable land	-	1.8
Temp grassland - misc/SRC	-	1.6
Rough grazing - SRF	-	7.5
SRC (currently c3000ha)	0.03	-
Transport network	0.54	-
Urban green space	1.75	-
Conifer woodland	1.9[4]	-
Broadleaf woodland	2.3[5]	-
Total	14.7	15.7

*Current biomass is defined as extant biomass resource which could become available without entailing land use change.

Guideline figures for the volumes of currently available biomass from different sources are given by region in Table 15. Straw production for biomass would be mostly concentrated in the South, South East, East and Midlands. Broad leaf forestry is concentrated in the South, South East and South West and conifer production in Northern England, Wales and Scotland. In the future, potential production of Miscanthus on arable land would be concentrated in the Midlands and East England. Miscanthus on temporary grassland areas would be mainly in the South West and West Midlands and SRC evenly distributed through the Central and East Midland, East of England, Northern England and Wales. SRF would be concentrated on the higher ground in Wales, Scotland and parts of Northern England.

As well as the not inconsiderable issues discussed above in relation to biomass establishment and supply, the utilisation of the biomass and the location of facilities needs to be considered. Figure 19 shows the location of currently available biomass indicating that large scale utilisation facilities would in terms of logistics and transport be best placed down the eastern side of the country, across the midlands and down to the south coast. The

[1] Based on Harvest Index (HI) in HGCA Winter Wheat Growth Guide and assuming 60% straw material actually collected and baled and 50% utilised for livestock feed and bedding.
[2] Based on Harvest Index (HI) in HGCA Winter Barley Growth Guide and assuming 60% straw material actually collected and baled and 50% utilised for livestock feed and bedding.
[3] Based on Harvest Index (HI) from J.Spink and P Berry (2005) Yield of UK Oilseed Rape: Physiological and Technological Constraints, and Expectations of progress to 2010." Yields of Farmed Species (2005) ISBN 1-904761-32-2 also assuming 60% straw material can be realistically collected.
[4&5] By improved utilisation of existing forestry resource.

location of potentially available biomass i.e. that requiring planting is shown in Figure 20, this shows that utilisation facilities would be best placed in the north and west of the country, Wales and Scotland. Again potential availability is summarised in Table 15.

Table 15: Summary of potential key production areas for each biomass source.(odt)

Biomass resource	South	South East	South West	West Midlands	Eastern Counties	East Midlands	North	Wales	Scotland
Cereal and oilseed rape straw	1.5M	1.5M	300k	600k	1.2M	1.2M	600k		300k
Broadleaved woodland	650k	650k	650k	100k		100k		100k	
Coniferous woodland							600k	600k	600k
Miscanthus[1]	300k		300k	600k	900k	900k	300k		
Miscanthus[2]			300k	300k	600k	600k			
SRC[3]					50k	50k	50k	50k	
Miscanthus[4]			650k	600k					
SRF[5]							1.3M	3M	3M

Current biomass resource shown in black. Potential future resource shown in blue.

[1] 2008 Set-aside area

[2] 5% Arable land

[3/4] 133 kha grassland

[5] 1.8M ha rough grazing

The areas identified above have been selected for highest potential yield as avoidance of possible inter-competition between the resources. It is clear that energy crop production doesn't need to be in direct landscape conflict with key cereal production areas, instead it enables a pattern of production to develop that fully utilises available land potential across the UK. No crop offers a "one stop" answer to the problem of overcoming fuel and food supply concerns, rather the utilisation of a range of biomass resources managed to achieve the highest productivity per hectare is clearly the way forward. Development of individual processing facilities could skew demand in particular locations.

The total current biomass resource together with transport network and principal conurbations is shown below in Figure 19. The concentration of **potential future biomass resource** on temporary, permanent and rough grazing is shown in Figure 20. Miscanthus production on 5% of arable land is shown in Figure 21.

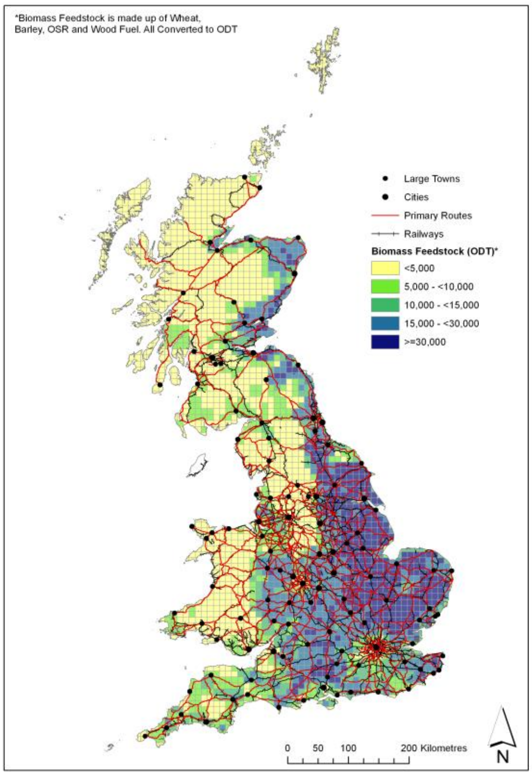

Figure 19. UK current biomass availability, transport network and principal conurbations

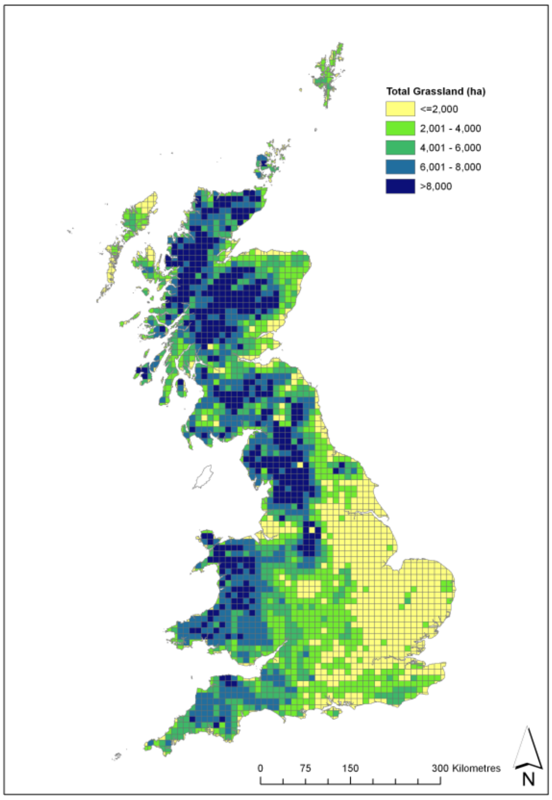

Fig 20. UK Grassland production areas showing likely concentration of future energy crop planting

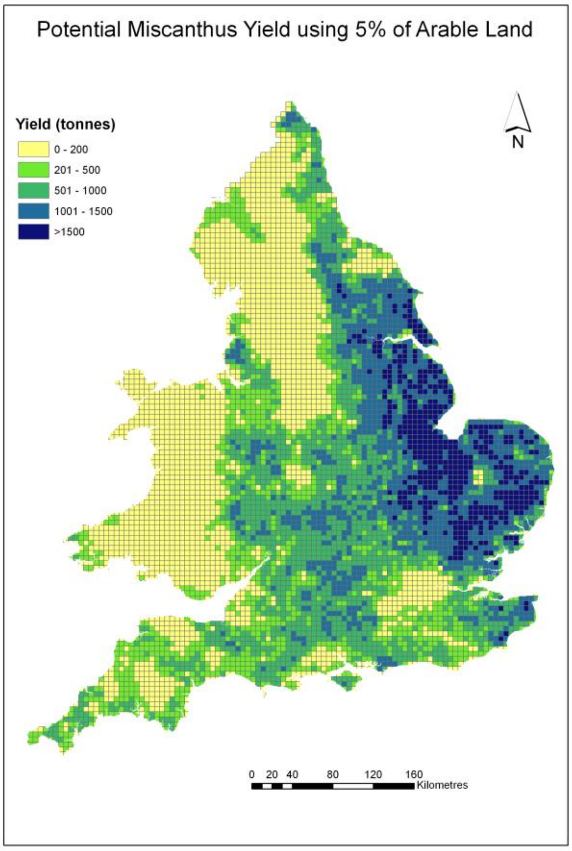

Figure 21. Potential Miscanthus yield on 5% of Arable land

5.2 Current and potential UK biomass resource – contribution to UK power

The **currently available biomass resource** which could be produced and captured from extant areas of wheat, barley, OSR, miscanthus, SRC, under utilised woodland and non-agricultural land is **14.7 million odt** which represents a total energy yield of 250 Petajoules or 69,444 GWh of power. The individual components of current and potential UK biomass resource are shown in Table 15 above.

A biomass resource of 69,444 GWh could be utilised in a number of ways, for example:

- if burnt to produce electricity at a modest conversion efficiency of 30% it could provide 5.3% of current UK electricity generation,
- rising to 10.6% (generated electricity equivalent) if converted for CHP (60% efficiency)
- and 14.1% generated electricity equivalent if converted to heat alone (80% efficiency).

This demonstrates considerable potential to increase the exploitation of the existing biomass resource beyond currently installed renewables capacity without the need for significant change to UK land use patterns. Clearly this is due to the 8.1 million odt volume of straw which could be utilised. Table 16 below shows a range of scenarios for utilisation of the existing biomass resource and contribution to renewable power generation.

Table 16. UK power production from existing biomass resource by varying conversion technologies.

Utilisation	Electricity[1] GWh	CHP[2] GWh	Heat[3] GWh	Total GWh	% UK total
100% electricity	20,833	-	-	20,833	5.3
100% CHP	-	41,666	-	41,666	10.6
100% heat	-	-	55,555	55,555	14.1
Equal ratio	6,937	13,887	18,516	39,340	10.0
2:4:4	4,177	16,666	22,222	43,065	11.0
4:2:4	8,333	8,333	22,222	38,888	9.9
4:4:2	8,333	16,666	11,111	36,110	9.2

1. 30% conversion efficiency
2. 60% conversion efficiency
3. 80% conversion efficiency

The **potential additional biomass resource** produced and captured from land use changes described above is estimated at **15.7 million odt** which represents a total energy yield of 267 Petajoules or 74,139 GWh of power. Table 17 below shows a range of scenarios for utilisation of that additional theoretical biomass resource and contribution to renewable power generation.

The individual components of current and potential UK biomass resource are shown in Table 15 above.

A biomass resource of 74,139 GWh could be utilised in a number of ways, for example:

- if burnt to produce electricity at a modest conversion efficiency of 30% it could provide 5.6% of current UK electricity generation,
- rising to 11.2% (generated electricity equivalent) if converted for CHP (60% efficiency)
- and 15.1% generated electricity equivalent if converted to heat alone (80% efficiency).

Table 17. UK power production from existing biomass resource by varying conversion technologies.

Utilisation	Electricity[1] GWh	CHP[2] GWh	Heat[3] GWh	Total GWh	% UK total
100% electricity	22,242	-	-	22,242	5.6
100% CHP	-	44,483	-	44,483	11.2
100% heat	-	-	59,311	59,311	15.1
Equal ratio	7,413	14,826	19,768	42,007	10.7
2:4:4	4,418	17,793	23,724	45,965	11.6
4:2:4	8,897	8,897	23,724	41,518	10.6
4:4:2	8,897	17,793	11,862	38,552	9.8

4. 30% conversion efficiency
5. 60% conversion efficiency
6. 80% conversion efficiency

5.3 Logistics

It is important to note that this biomass should not be considered as ‘waste’, and the price offered needs to take into consideration the cost of recovery of the biomass to the road side, inherent (e.g. fertiliser) value and a mark up to make its supply worthwhile to the grower. In terms of forestry residues harvesting costs are estimated at between £20-25/t for small scale broadleaved forestry, it is likely that the cost of recovering the potential biomass fraction will be this or slightly more. In the case of straw the cost of baling and getting to the roadside is about £15/t but as shown earlier straw has an inherent fertiliser value which the grower needs to buy in fertiliser to replace which together mean a price of £41-49.50/odt would need to be paid depending on the straw type. It is difficult to estimate the cost of recovery of biomass from transport verges and urban green areas, as little is known about the form and distribution of the material, the cost would probably be offset to some extent by the fact that there is already a cost of management of such areas.

As well as the large influence of price on biomass availability the second significant issue with the recovery of available biomass is one of logistics. We have calculated that in order to harvest all of the currently unharvested straw from wheat, barley and oilseed rape would require in the order of an additional 6,300 staff if using common on farm equipment or 3,150 if using an efficient contracting operation with the most up-to-date dedicated equipment. The baling could be done with approximately 2000 additional balers if fully utilised this is unlikely on individual units, the cost of equipment and labour would therefore be disproportionately high for all but the largest arable farms. It should also be noted that the staff needed are skilled labourers trained in the use of the equipment, it is likely, therefore, that end users would be able to more economically carry out the baling and handling operations either directly or through a sub-contracting arrangement with a co-operative or similar, and buy the straw as a standing crop. If the cost of baling and transport were borne by the end user a 50% mark up on the fertiliser value of wheat straw would bring the price to £21.47/odt. Any such operation would however have to ensure that the grower was not hindered from establishing following crops due to late removal of straw which would be a significant disincentive to the grower.

5.3.1 Densification

A potential method of accessing biomass growing in areas some distance away from a biofuels plant could be to establish one or more processing hubs close to the rail or motorway network or a port. Local or regional hubs could take primary products from forestry or agriculture and process or condition the material ready for conversion at a centralised plant. This could ease pressure on land close to the plant whilst providing additional income streams to growers well away from the site of end use. Conditioning could include the use of pyrolysis to produce a slurry of condensate and char. This process retains around 90% of the calorific value[1] of the biomass and significantly improves the energy density of the feedstock. Once transported to the centralised conversion plant the slurry can be converted to synthetic diesel via gasification and FT synthesis. The processes that could be undertaken at these hubs are shown in mass flow diagrams in appendices III-XII. Local processing facilities are already in use in supply chains producing woodchip for heat and power generation. Material can come from forestry, SRC and arboricultural arisings. It could be possible to extend this to include straw and miscanthus. Combining existing drying, chipping and milling operations with semi mobile pelletising plant[2] or pyrolysis equipment could increase the markets available to the biomass processors and provide more flexibility to the location of the biofuel conversion plant.

Based on the details obtained from the mapping exercise and considering the UK's road and rail infrastructure, a pyrolysis oil hub situated within the Bristol, Reading, Gloucester triangle would be well sited to receive energy crop and woodland biomass from Wales along the M4, material from the Southwest and Southern England and well as the West Midlands via the M5. In addition, the proximity to the Bristol Channel and South Coast of England offer potential shipping opportunities. Rail transport may also be an option, though travelling from the Southwest to the Northeast by rail, is not the most straight forward route and may have implications on the economics. An additional pyrolysis oil hub sited on the East around the Nottingham area would be able to take in biomass, predominantly cereal and rape straws from the East Midlands and Eastern regions as well as forestry and energy crop materials from the East Midlands area. A hub sited here would be able to take advantage of the M1 motorway and the fast rail service that runs down the east of the country. It is important to note at this point that the need for intermediary hubs will largely be determined by the logistics and economics, as well as need for these intermediaries based on the resource that is available local to the BTL plant. The scale of a central plant will also affect the economics and need for

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[1] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[2] Biojoule are developing a containerised wood pelleting plant with a capacity to produce 10,000 tonnes of pellets per year http://www.biojoule.co.uk/

densification hubs. An example scenario for a BtL plant on Teeside is presented in Appendix I.

5.3.2 Timescale

Whilst there is therefore significant potential to increase biomass production it should be bourn in mind that there would be a significant time delay between planting and the biomass becoming available. Whilst some harvestable yield can be taken from year two onward miscanthus does not reach full productivity until between the third and fifth year after establishment, depending on the initial planting density, higher densities shortening the time to full productivity but also significantly increasing establishment costs. In contrast the first harvest in SRC does not occur until the fourth year after establishment. By far the biggest single source of new biomass would arise from the reversion of permanent pasture and rough grazing; we have assumed that this would be managed as SRF which would not commonly have its first yield until 15 years after establishment.

The timescale to reaching mature yield and also the costs of establishment could be reduced by the production of crops established from seed. This is possible with both Reed canary Grass and Switchgrass. Very limited research has been done but European field trials have reported yields of 8-12 odt/ha for Reed Canary Grass[1] and up to 18 odt/ha for Switchgrass in NW Europe[2]. Whilst yields are observed to increase year-on-year, those in the years immediately following establishment tend to be higher than seen at the same stage in Miscanthus.

The scale of the operation to establish the quantity of biomass described above should not be underestimated. There are two large obstacles to overcome: first the availability of planting material and second the labour force and machinery required to plant the crops. If it is assumed the SRF is planted over a 15 year period so that the first plantings are coming to harvest as the last are established, it would require roughly 120,000ha to be established each year, this is equivalent to planting up an area equivalent to the Kielder forest (the largest man made forest in Europe each year) each year. Figure 22 shows the potential timing of new biomass availability. It assumes that there would be a 5 year lag period before significant SRF planting could occur to allow for production of planting material and development of infrastructure, and that the total area would be planted up over the following 15 years by which time the first plantings would be harvested. It is assumed that a maximum of 30,000ha of Miscanthus could be planted per year for the first three years by which time new rhizome multiplication would come on stream, to give a peak planting of 150,000 ha per year by year seven. Miscanthus yield has been assumed to start in year two at 3t/ha increasing linearly to 12 t/ha by year five. For SRC it has been assumed that the 67,000ha could be planted over a six year period and that harvesting would start in year four.

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[1] Energy Crop Species in Europe. Luger, BLT Wieselburg, Austria http://www.blt.bmlf.gv.at/vero/artikel/artik013/Energy_crop_species+.pdf

[2] Wolter Elbersen, Rob Bakker, Wageningen UR, Agrotechnology & Food Innovations bv, the Netherlands. Revised: 01/10/2003 http://www.switchgrass.nl/summary.htm

This analysis shows that starting today it would take 10 years to bring SRC and Miscanthus fully on stream and producing about 8M odt/year and 20 years until SRF could come on stream to give the total potential production.

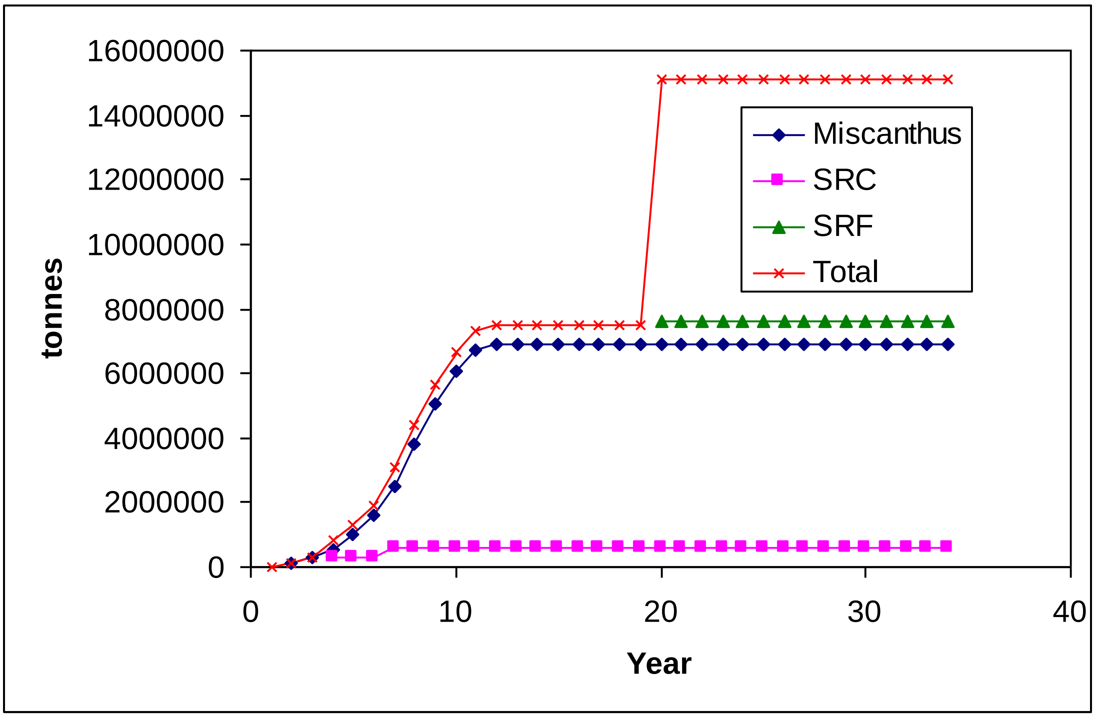

Figure 22. Timescale for future biomass availability

If it is assumed that for SRF an individual can plant 0.5 ha per day and that there is an 80 day planting period per year then 3,000 staff would be required for a 4 month period overwinter each year for 15 years.

The planting rates for SRC and Miscanthus are much higher than for SRF due to mechanisation and the areas to be planted each year assumed to be considerably smaller in the early years, as this work is carried out at a relatively slack time in terms of arable farm work it is assumed that this could be resourced from within the current agricultural workforce.

5.1.4 Other biomass resource

There are other potential sources of biomass which could be made available as a by-product of existing cropping, such as outgrade potatoes. However, the quantity that could be made available is relatively insignificant, for example 90,000 odt of potatoes, on a national scale. They may however be locally important for example by locating an AD plant close to large potato processing operations, which incorporate them as part of a mixed feedstock. It is worth noting however that some of the existing markets, even though the price is relatively low e.g. £10/t fwt for stock feed potatoes, is relatively high compared to their calorific value.

6. Conclusions and recommendations

- There is a significant quantity of biomass currently produced, the majority of which is unutilised which is estimated at 14.7M odt. However this should not be considered a low value waste and will not be made available to the renewable energy industry without a price being offered which covers its inherent value, the cost of collection and a margin for the producer.

- The utilisation of biomass co-products for energy production offers significantly greater green house gas savings than its incorporation or return to the land which is an inefficient method of carbon sequestration.

- There are significant logistical issues and management changes needed to make available and for the collection of currently available biomass, not least the availability of suitably qualified staff. It is most likely that this will most efficiently be achieved either from the end user end or via supply groups rather than from individual producers.

- There appears to be significant biomass (c. 2.3M odt) potentially available from non agricultural or forestry land such as transport infrastructure and urban green spaces. However, information on the form, distribution and ownership of this biomass is not as readily available as for agricultural land and a more detailed study of this resource is required to quantify more accurately the volumes and develop strategies for its collection and utilisation.

- At current biomass values the returns are sufficient to compete favourably with some current land uses particularly lower return livestock systems, but also including arable cropping if input costs continue at their high level and the world prices do not increase. The returns from arable cropping are highly variable due to fluctuations in the world price – the wheat price having varied by almost £100 per tonne in the 2008 cropping season. Whilst biomass does not currently compete at higher grain prices long term contracts and stability of return may be an attractive option to some producers.

- There is significant scope to increase future biomass production with potentially an additional 15.7M odt. It is predicted this could be produced from Miscanthus grown on currently fallow land and arable land for which the infrastructure might not exist for efficient arable production. And Miscanthus or SRC on temporary grassland and SRF on permanent pasture and rough grazing which could be made available by tightening stocking densities.

- There are a number of barriers to this expansion include the significant up-front costs of establishment and lag period until significant returns are realised. This could be overcome by support for the cost of establishment for the producer which is repaid once biomass sales start or a share farming approach where the farmer owns the land but the end user or fuel supply company owns the crop.

- There needs to be a significant expansion in the production of planting material and infrastructure to establish the crops, we estimate that it would take 10 years to bring Miscanthus and SRC into full production and 20 years to bring SRF into full production even with rapid expansion of the industry, this will not happen without long term political and end user commitment providing the confidence to invest.

- If burnt to produce electricity at 30% conversion efficiency, current biomass could provide 5.3% of our energy requirements and potential future biomass of 5.6% so that in 20 years biomass as a whole could supply more than 10% assuming no change in overall energy consumption.

- In order to maximise the efficiency and greenhouse gas savings from the biomass industry the biomass sources need to be targeted at the most suitable areas of the country and the utilisation facilities similarly located. Although advanced biomass processing techniques and densification technologies are likely to ease these restrictions somewhat.

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Appendix I: Case Study to examine provision of feedstock for a 200,000 tonne BTL facility on Teesside

The NNFCC report International Biofuels Strategy Project (April 2008) suggested that it “may be advantageous to locate a BTL facility near to an existing cracker such as that located at Wilton, Teeside.” Assuming a 200,000 tonne BTL situated in Teesside the following maps have been produced that consider the supply radius that would be required to:

- Provide 1.3 million tonnes of biomass local to a BTL plant situated in Teesside (figure 8a).
- Provide 1.3 million tonnes of biomass to a BTL plant situated in Teesside supplemented by two pyrolysis hubs (figure 8b).
- Provide 1.3 million tonnes of biomass to a BTL plant situated in Teesside supplemented by 3 pyrolysis hubs (figure 8c).

The data used to generate the maps has been based on existing biomass resource streams of cereal and oilseed straws and broadleaf and coniferous woodland biomass potential. It excludes energy crops, as the current available cropping is relatively small.

In Scenario 1 a radius of 128km (80 miles) is required around the BTL plant to supply sufficient biomass (crop straws and woodland origin). This is based on an assumption that 35% of the straw from cereals and oilseeds would be available to the plant together with surplus forestry in the respective areas. Whilst energy crops are not included in the scenario, it is thought that the energy crops could be utilised to increase the amount of available resource in the region and be used to reduce the overall size of the supply radius.

In scenario 2 (figure 8b) the BTL is supplemented by two pyrolysis hubs, one near Nottingham and one in the South West. The assumption is that 50% of biomass will be supplied by the hubs (with a 20/30 split between the two). When these assumptions are used the radius around the BTL plant becomes 80km (50 miles), the radius around the Nottingham hub becomes 46km (29 miles), and the radius around the third site in the SW. Again the same assumptions of biomass availability exist as in scenario 1. Whilst the hubs could potentially pull in biomass from relatively small areas, the actual final radii around the hubs and the plant would be determined more by the logistic and economic climate as well as the fuel quality requirements of the BTL plant. What the maps do show is that sufficient biomass is available and that pyrolysis hubs offer potential for utilisation of biomass over a wider range, enabling utilisation of different biomass types. They also show that there is room to expand the pyrolysis hubs further whilst reducing the requirement around the BTL plant. In addition the hubs are situated to take advantage of future opportunities in energy crops and may act as a catalyst in these areas for future plantings of Miscanthus and SRC. Again this will be driven by the balance between economics and the fuel quality demands of the BTL plant itself.

Scenario 3 (figure 8c) takes things one step further with the addition of a further hub situated in the east of England, which would predominantly take cereal and oilseed straw. This scenario is depicted as a 40:30:15:15 split and radii of 69km (43 miles), 46 km (29 miles), 30 km (19 miles) and 26 km (16 miles) develop as a result. There is potential for the hubs to collect materials from a wider area. For example the one in the SW is sited to take advantages of road links to Wales and the South where there is significant forestry resource and similarly to the North of Teesside in the North and Scotland (Fig 8d).

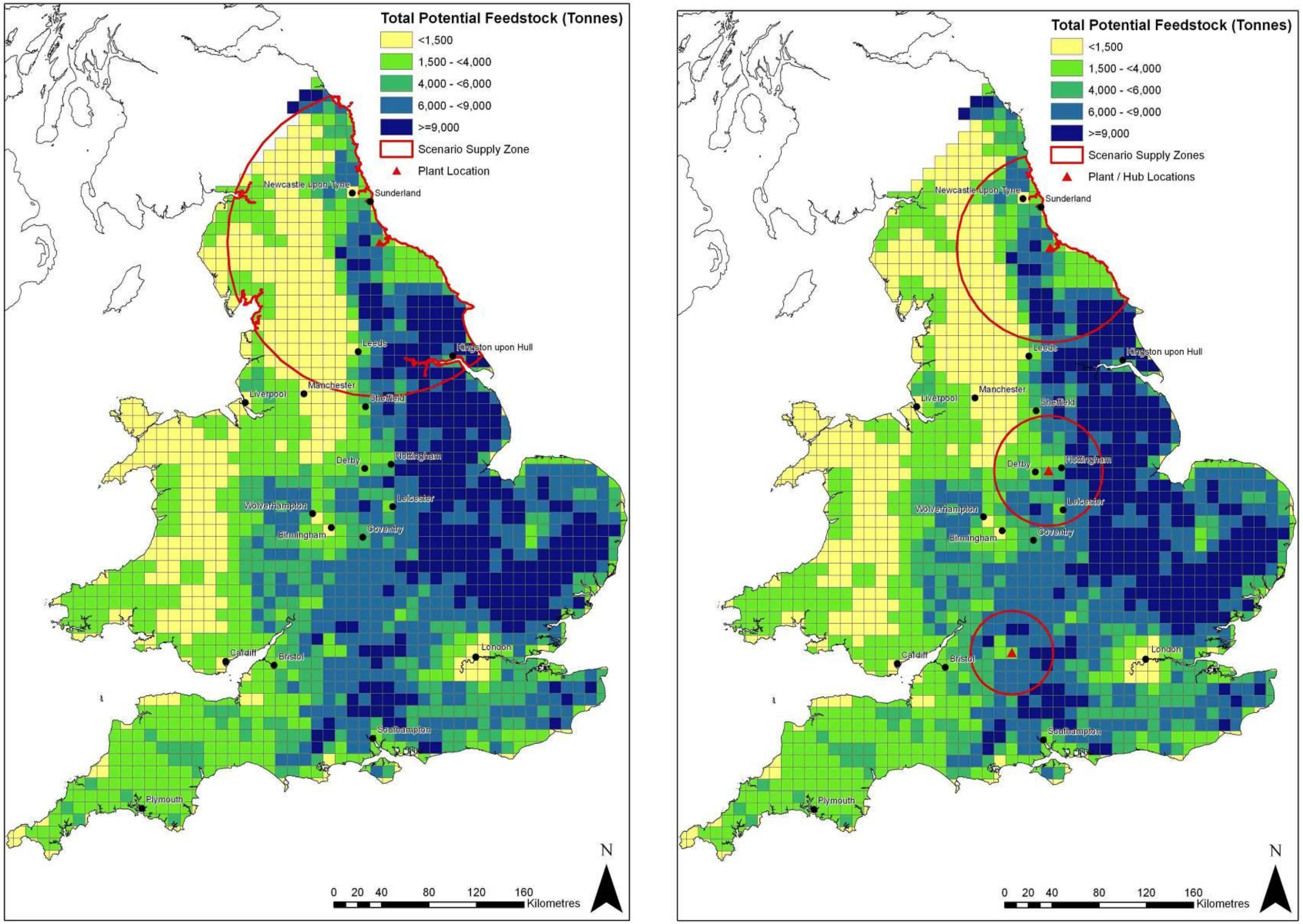
Table 1. Conversion technology, supplychain and associated land requirement required to produce 200,000 tonnes of liquid fuel per year.

Conversion technology	**Supplychain**	**Biomass to fuel conversion ratio, by mass, from field to fuel[1]**	**Annual biomass requirement (oven dry tonnes)**	**assumed yield, odtha-1yr-1**	**Annual harvested area (ha)**	**'Operational' land area requirement (ha) for sustainable production**	**radius of refinery catchment assuming 10% of land is used to produce feedstock (km)**
Transesterification	Winter oil seed rape seed	4.2:1	840,000	5.50	152,727	458,182	121
Fermentation	Sugarbeet	3.5:1	700,000	16.00	43,750	131,250	65
Fermentation	Winter wheat grain	4.3:1	860,000	10.80	79,630	238,889	87
Hydrolysis/ fermentation	Forestry (broadleaf)	5:1	1,000,000	2.78	6,918	359,712	107
Pyrolysis at hub/ FT synthesis	Forestry (broadleaf)	6.2:1	1,240,000	2.78	8,578	446,043	119
Gasification/ FT synthesis	Forestry (broadleaf)	5:1	1,260,000	2.78	8,716	453,237	120
Torrefaction at hub/ FT synthesis	Forestry (broadleaf)	7.1:1	1,420,000	2.78	9,823	510,791	128
Hydrolysis/ fermentation	Forestry (coniferous)	5:1	1,000,000	1.39	13,835	719,424	151
Pyrolysis at hub/ FT synthesis	Forestry (coniferous)	6.3:1	1,260,000	1.39	17,432	906,475	170
Gasification/ FT synthesis	Forestry (coniferous)	5:1	1,000,000	1.39	13,835	719,424	151
Torrefaction at hub/ FT synthesis	Forestry (coniferous)	7.3:1	1,460,000	1.39	20,199	1,050,360	183
Hydrolysis/ fermentation	Short rotation coppice	5.3:1	1,060,000	7.30	48,402	159,242	71
Pyrolysis at hub/ FT synthesis	Short rotation coppice	6.6:1	1,320,000	7.30	60,274	198,301	79
Gasification/ FT synthesis	Short rotation coppice	5.3:1	1,060,000	7.30	48,402	159,242	71
Conversion	**Supplychain**	**Biomass to fuel**	**Tonnes of**	**assumed**	**Annual**	**'Operational' land**	**radius of refinery**

[1] Details of mass flows and assumptions used are show in appendices 1-10

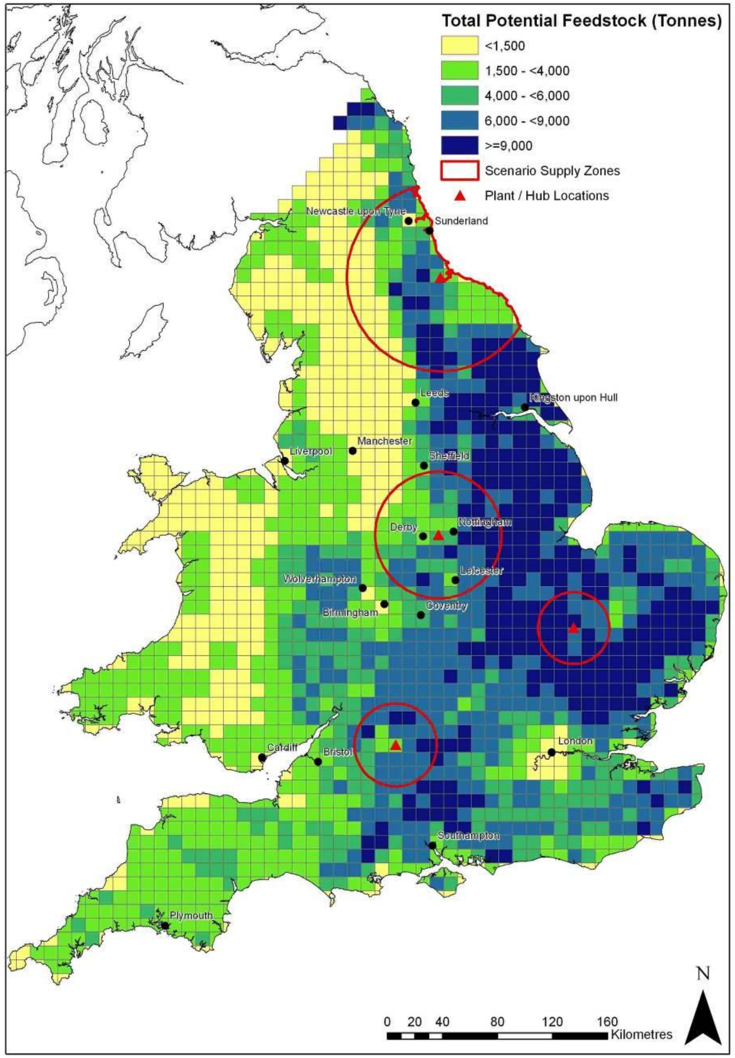
technology		conversion ratio, by mass, from field to fuel[1]	biomass required annually	yield, odtha-1yr-1	harvested area (ha)	area requirement (ha) for sustainable production	catchment assuming 10% of land is used to produce feedstock (km)
Torrefaction at hub/ FT synthesis	Short rotation coppice	7.6:1	1,520,000	7.30	69,406	228,347	85
Hydrolysis/ fermentation	SRF (whole tree)	5.3:1	1,060,000	5.30	13,333	226,667	85
Pyrolysis at hub/ FT synthesis	SRF (whole tree)	6.6:1	1,320,000	5.30	16,604	282,264	95
Gasification/ FT synthesis	SRF (whole tree)	5.3:1	1,060,000	5.30	13,333	226,667	85
Torrefaction at hub/ FT synthesis	SRF (whole tree)	7.6:1	1,520,000	5.30	19,119	325,031	102
Hydrolysis/ fermentation	SRF (small round wood)	5:1	1,000,000	3.05	21,858	371,585	109
Pyrolysis at hub/ FT synthesis	SRF (small round wood)	6.2:1	1,260,000	3.05	27,541	468,197	122
Gasification/ FT synthesis	SRF (small round wood)	5:1	1,000,000	3.05	21,858	371,585	109
Torrefaction at hub/ FT synthesis	SRF (small round wood)	7.1:1	1,420,000	3.05	31,038	527,650	130
Hydrolysis/ fermentation	Miscanthus	3.3:1	660,000	12.00	55,000	55,000	42
Pyrolysis at hub/ FT synthesis	Miscanthus	7.3:1	1,460,000	12.00	121,667	121,667	62
Gasification/ FT synthesis	Miscanthus		1,000,000	12.00	83,333	83,333	52
Hydrolysis/ fermentation	Winter wheat straw	3.3:1	660,000	3.40	194,118	582,353	136
Pyrolysis at hub/ FT synthesis	Winter wheat straw	7.2:1	1,440,000	3.40	423,529	1,270,588	201
Gasification/ FT synthesis	Winter wheat straw		1,000,000	3.40	294,118	882,353	168

[1] Details of mass flows and assumptions used are show in Appendices II – XI



Figure

Figures 1a, 1b Maps indicating available biomass resource and radius around BTL plant, assuming in Scenario 1 a single 200,000 tonne BTL plant, operating with out pyrolysis hubs and (1b). Scenario 2 radius around BTL plant with supplementary supply from 2 pyrolysis hubs



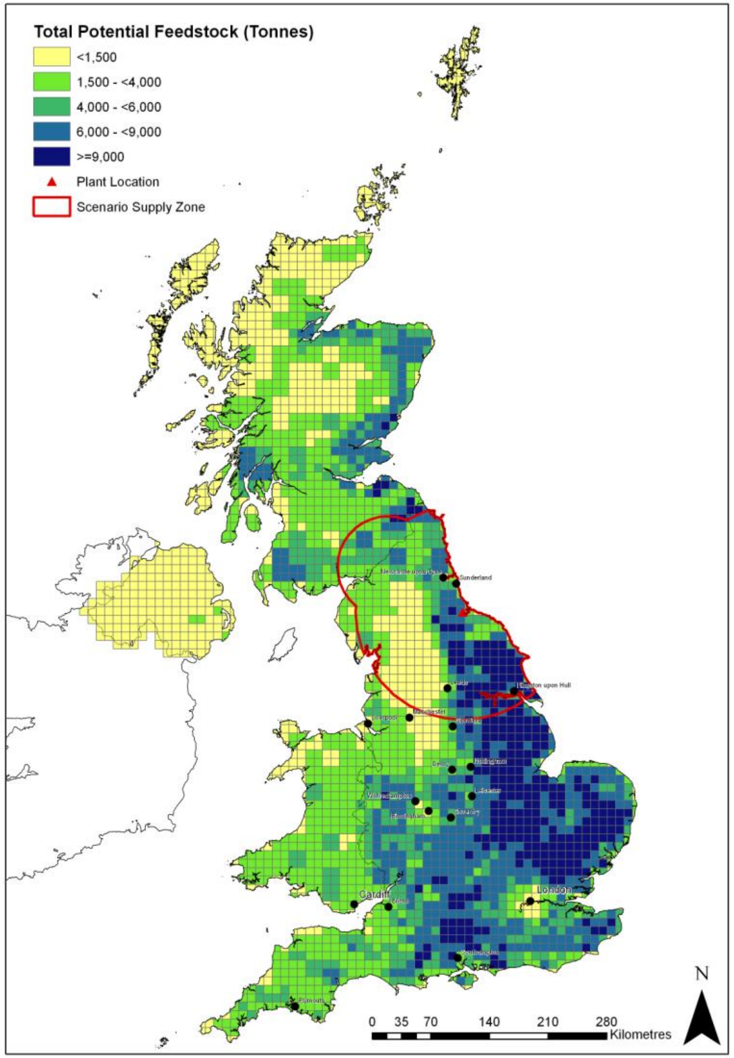
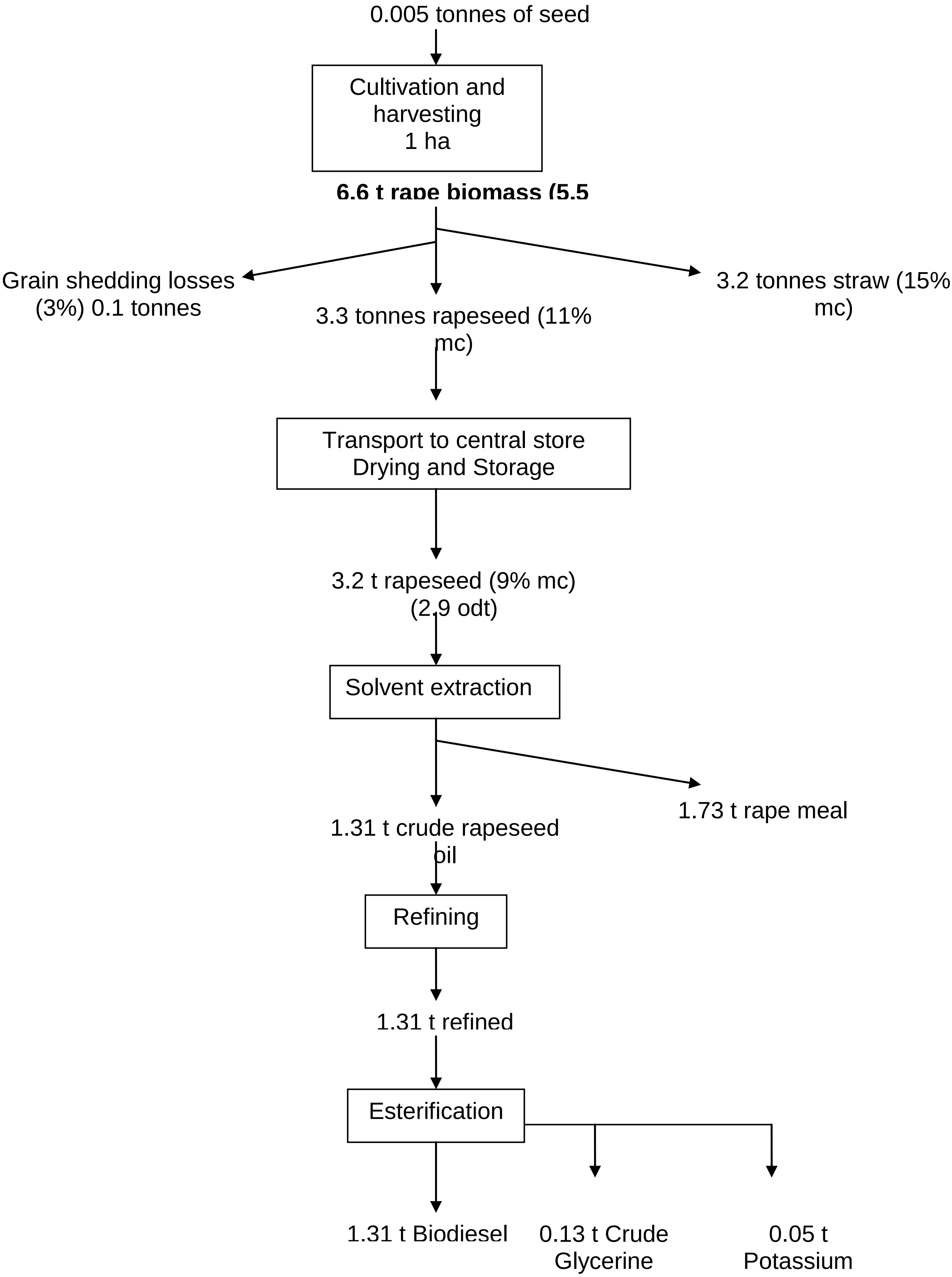


Figure 1c: Scenario 3 based on BTL plant plus 3 pyrolysis hubs. Figure 1d: variation on Scenario 1 to include Scottish forestry.

Logistics and economics will come into play as to how far it is viable to transport crops. For examples some of the biomass sources will be cheaper than others and this will impact on their economic transport distance. In addition the economics of pyrolysis hubs will determine whether a number of larger hubs is better, or whether multiple hubs on a very local scale are more appropriate. The hubs identified in the maps above are examples only and are based on considering biomass resource as a whole. Hub location will be determined by the source fuel, for example if utilising forestry resource only hubs would perhaps be located in Wales on the English/Scottish border and in the South of England, depending upon the size of the BTL plant and the total biomass requirement.

Appendix II-XI: Mass flow diagrams for biomass utilisation.

Appendix II: Winter oil seed rape for the production of biodiesel – mass flow and assumptions used



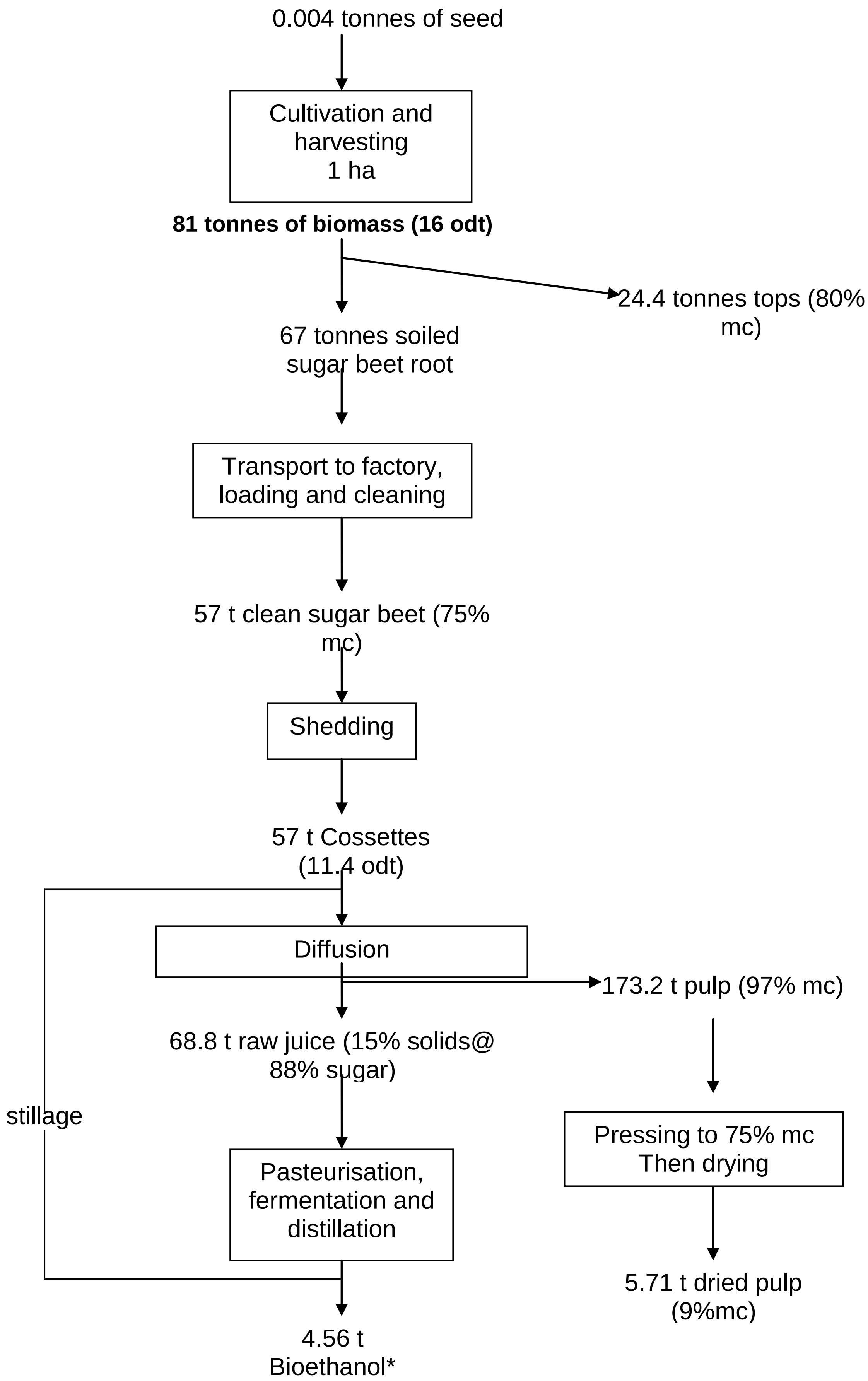
Winter oil seed rape to biodiesel

- Flow chart is based on mass flow charts produced by Elsayed et al (2003)[1]
- Ratios for conversion of oilseed to biodiesel based on the HGCA greenhouse gas calculator[2].
- Yield of oilseed rape 3.2 t/ha (9%mc).
- Yield of crude rapeseed oil t/t oilseed = 0.41, rape meal t/t dried rapeseed = 0.54.
- Yield of biodiesel t/t rapeseed oil = 1, glycerine = 0.1 and potassium 0.04 t/t of rapeseed oil.

[1] Elsayed M.A, Matthews R., Mortimer N.D, (2003) Carbon and Energy Balances for a range of Biofuel Options. Department of Trade and Industry (DTI) report B/B6/00784. http://www.berr.gov.uk/files/file14925.pdf

[2] HGCA Greenhouse gas calculator for OSR to Biodiesel. http://www.hgca.com/document.aspx?fn=load&media_id=3534&publicationId=2135

Appendix III: Sugarbeet for the production of ethanol - mass flow and assumptions used



*When glucose is fermented to produce ethanol it should be noted that CO2 is also released in the process. However, this is equivalent to that taken up by the crop when it is growing and hence values are not included here. Small discrepancies in dry matter may occur in the simplified charts as a result.

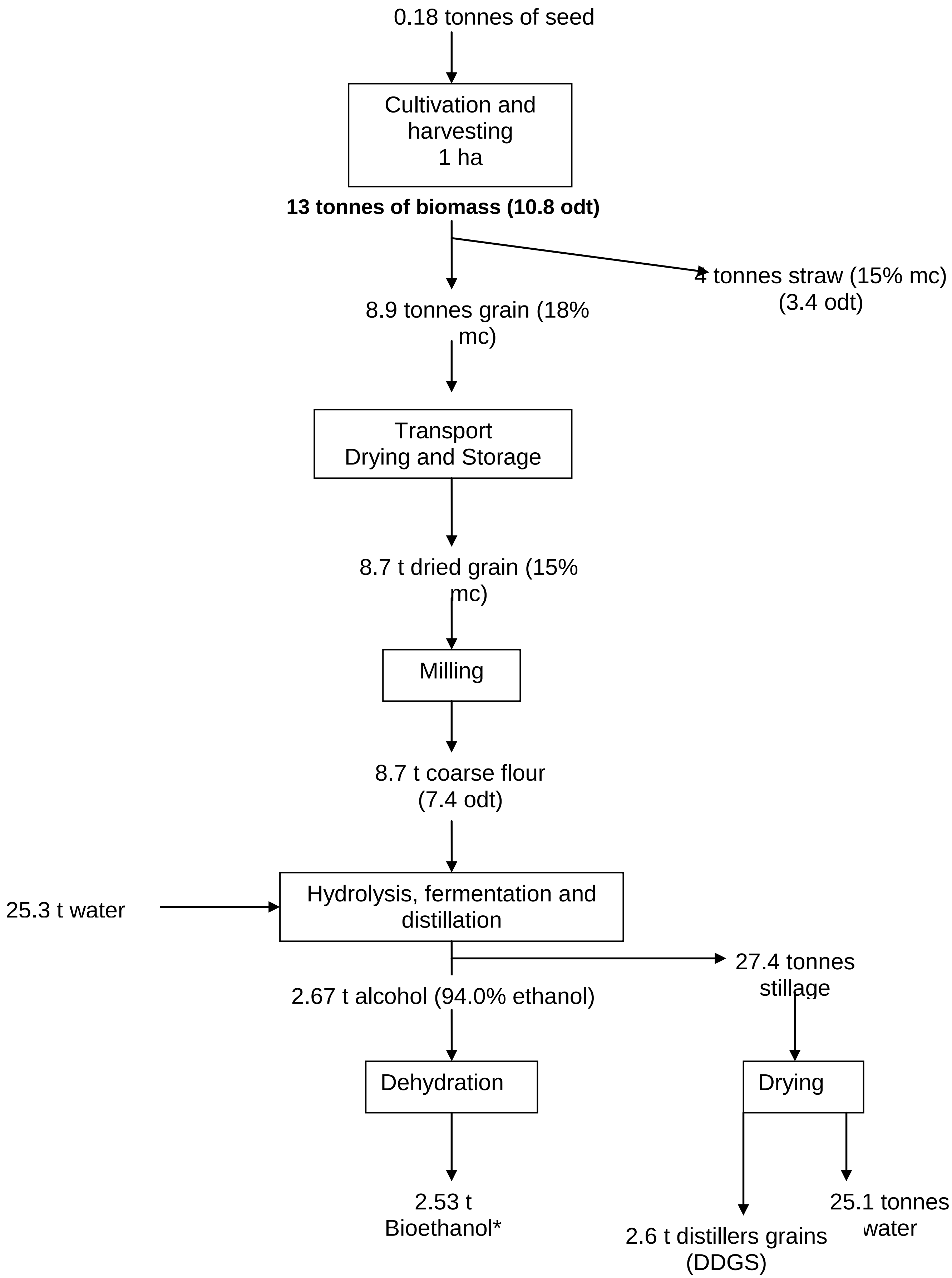
Sugarbeet to Bioethanol

- Flow chart is based on mass flow charts produced by Elsayed et al (2003)[1].
- Fresh weight cleaned yield of 57 tonnes/ha(75%mc).
- Alcohol and pulp yields based on report by E4Tech[2].
- Release of CO_2 by the fermentation of sugars is a related to that taken in by the plant during photosynthesis and hence not included.
- 1271 litres of bioethanol in 1 metric tonne.

[1] Elsayed M.A, Matthews R., Mortimer N.D, (2003) Carbon and Energy Balances for a range of Biofuel Options. Department of Trade and Industry (DTI) report B/B6/00784. http://www.berr.gov.uk/files/file14925.pdf

[2] E4Tech (2007). A Review of the UK Innovation System for Low Carbon Road Transport Technologies. A report for the Department of Transport. http://www.dft.gov.uk/pgr/scienceresearch/technology/lctis/e4techlcpdf.

Appendix IV: Winter wheat grain for the production of ethanol - mass flow and assumptions used



*When glucose is fermented to produce ethanol it should be noted that CO2 is also released in the process. However, this is equivalent to the taken up by the crop when it is growing and hence values are not included here. Small discrepancies in dry matter may occur in the simplified charts as a result.

Winter wheat grain to Bioethanol

- Flow chart is based on mass flow charts produced by Elsayed et al (2003)[1]
- Yields of crop and end products based on report by Smith T.C et al (2004)[2].
- Yield 8.7 tonnes/ha (15%mc).
- Alcohol yield/tonne dried straw (0%mc) 341.8 kg.
- Brewers grain yield/ tonne dried straw (0%mc) 350kg.
- Release of CO_2 by the fermentation of sugars is a related to that taken in by the plant during photosynthesis and hence not included.
- Water requirements of the process based on Punter G et al (2004)[3].
- 10 tonnes water for 1 tonne of bioethanol.
- 1271 litres of bioethanol in 1 metric tonne.

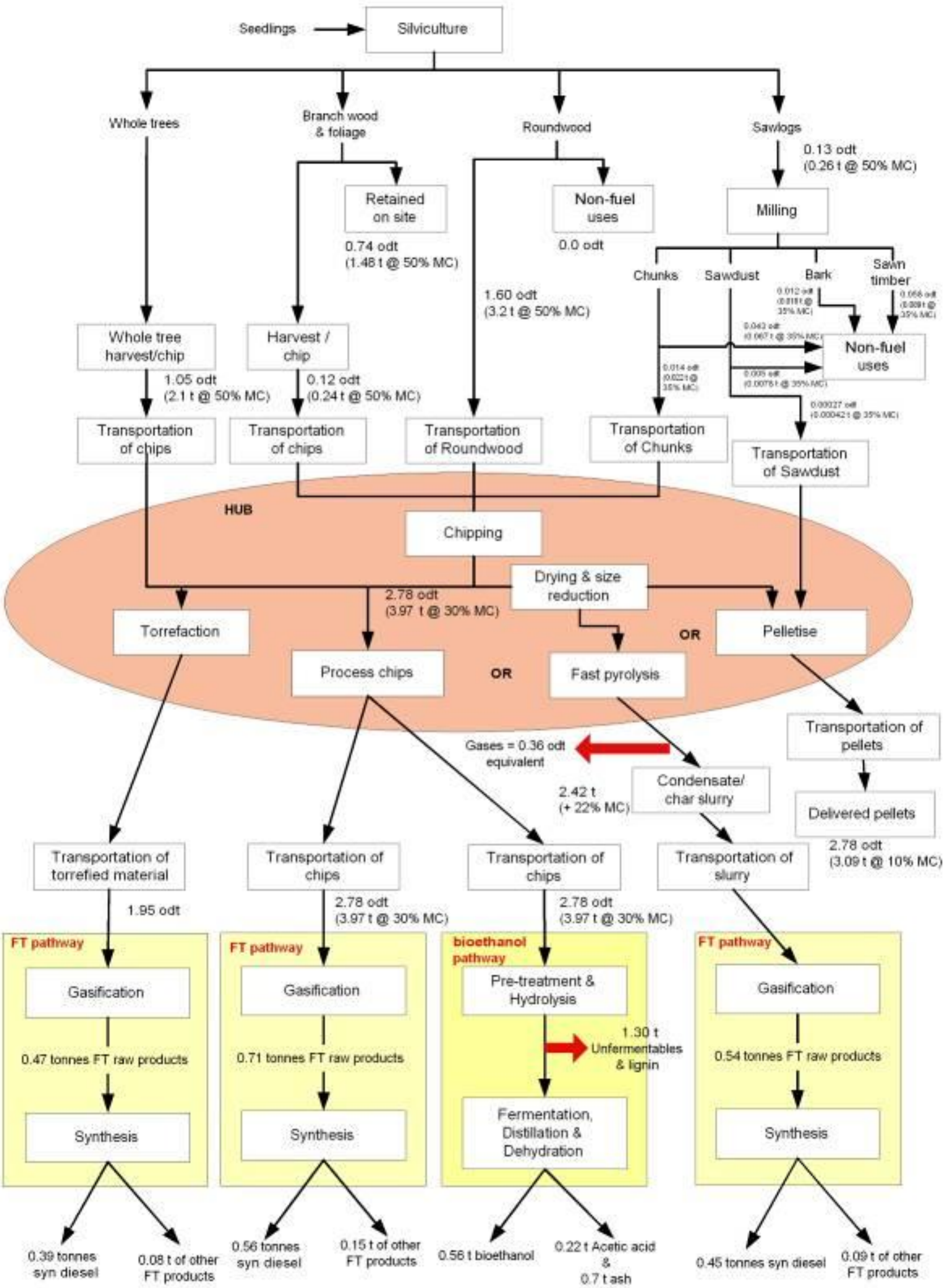
[1] Elsayed M.A, Matthews R., Mortimer N.D, (2003) Carbon and Energy Balances for a range of Biofuel Options. Department of Trade and Industry (DTI) report B/B6/00784. http://www.berr.gov.uk/files/file14925.pdf

[2] Smith T.C, Kindred D.R, Bosnam J.M, Weightman R.M, Shepherd M, Sylvester-Bradley R. (2004). Wheat as a Feedstock for Alcohol Production. HGCA Research Review No 61.
http://www.lowcvp.org.uk/assets/reports/HGCA%20RR61%20Wheat%20for%20alcohol.pdf

[3] Punter G., Rickeard D., Larive J., Edwards R., Mortimer N., Horre R., Baven A. and Woods J. (2004). Well-to-Wheel Evaluation for the Production of Ethanol from Wheat. A report for the LowCVP Fuels Working Group, WTW Sub-Group.
http://www.lowcvp.org.uk/assets/viewpoints/Biofuels%20WTW%20final%20report.pdf

Appendix V: Ligno-cellulose from the management of broadleaved forestry for the production of ethanol/synthetic diesel - mass flow and assumptions used

Broadleaf high forest (Sycamore, YC 5)



Assumptions used in forest management element

- Thinnings are taken every 5 years from well established woodland
- General yield class 5 woodland.
- Wood density of 490 kg/m^3.
- Branch wood estimates based on output of BSORT biomass partitioning model[1].
- Whole trees from early thinnings go to woodfuel.
- 86% of branchwood is retained on site.
- All roundwood goes to fuel.
- Sawlogs are processed into Chunks (75% to non-fuel uses), Sawdust (95% to non-fuel uses), Bark and Sawn timber (all of which goes to non-fuel uses).

Assumptions used in conversion to synthetic diesel element

- Fast pyrolysis product yield by mass = 75% liquid (of which 25% is water), 12% char, 13% gas[2].
- Ratio of 4.5:1 condensate/char slurry to raw FT product and 1.2:1 raw FT product to syn-diesel[3] taken from Karlsruhe Institute of Technology (2008).
- Ratio of 5:1 wood to syn diesel assumed[4] (based on data from Baitz *et al*. 2004) during the gasification and FT synthesis of woodchips.

Assumptions used in conversion to bioethanol element

- Ratio of 5:1 wood to ehtanol assumed (based on data from NERL[5], Iogen[6] and van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf[7]

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[1] Matthews, R. W. and Duckworth, R. R. (2005) BSORT: a Model of Tree and Stand Biomass Development and Production in Great Britain. In: Imbabi, M.S. and Mitchell, C.P. (eds.) Proceedings of World Renewable Energy Congress (WREC 2005), 22-27 May 2005, Aberdeen, UK. Elsevier: Oxford, 404-409.

[2] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[3] Dinjus, E (2008) Synthetic Fuels from Biomass. Logistics, Technology and Economics. Karlsruhe Institute of Technology. Presentation to the 6th European BioFuels Forum, January 2008, Rotterdam, Netherlands. http://www.europoint-bv.com/events/?biofuels2008/72

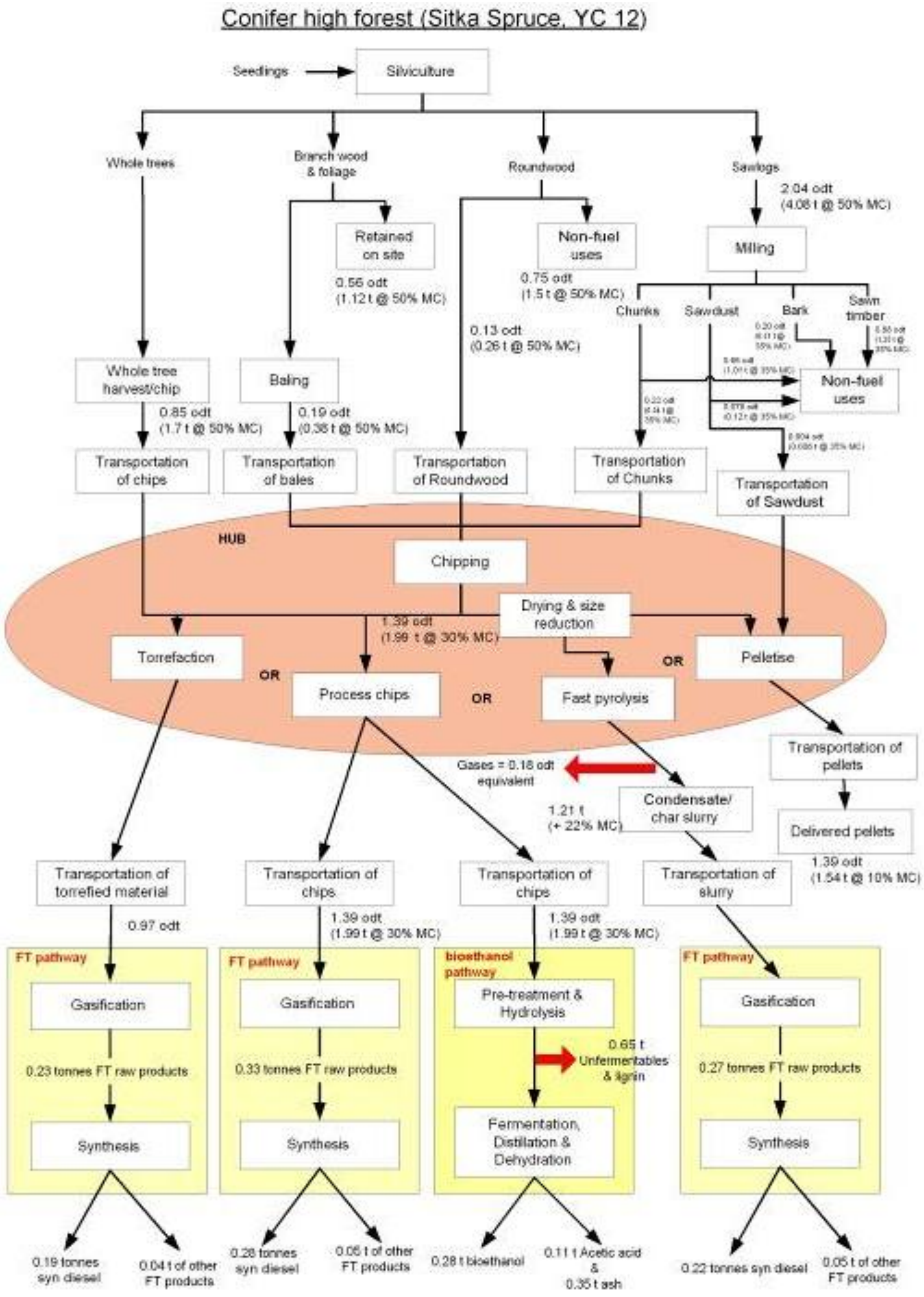
[4] Baitz, M., Binder, M., Degen, W., Deimling, S., Krinke, S., Rudloff, M. (2004) Comparative life cycle assessment for SunDiesel (Choren Process) and conventional diesel fuel. Report to Volkswagen AG and DaimlerChrysler Ag www.choren.com/dl.php?file=2005-01-21_Exec_Summ_LCA_Choren_englisch.pdf

[5] NERL (2007) Research Advances. Cellulosic Ethanol. http://www.nrel.gov/biomass/pdfs/40742.pdf

[6] www.iogen.ca

[7] van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf

Appendix VI: Ligno-cellulose from the management of coniferous forestry for the production of ethanol/synthetic diesel - mass flow and assumptions used



Assumptions used in forest management element

- Thinnings are taken every 5 years from well established woodland
- General yield class 12 woodland.
- Wood density of 350 kg/m^3.
- Branch wood estimates based on output of BSORT biomass partitioning model[1].
- Whole trees from early thinnings go to woodfuel.
- 75% of branchwood is retained on site.
- 85% of roundwood goes to non-fuel uses.
- Sawlogs are processed into Chunks (75% to non-fuel uses), Sawdust (95% to non-fuel uses), Bark and Sawn timber (all of which goes to non-fuel uses).

Assumptions used in conversion to synthetic diesel element

- Fast pyrolysis product yield by mass = 75% liquid (of which 25% is water), 12% char, 13% gas[2].
- Ratio of 4.5:1 condensate/char slurry to raw FT product and 1.2:1 raw FT product to syn-diesel[3] taken from Karlsruhe Institute of Technology (2008).
- Ratio of 5:1 wood to syn diesel assumed[4] (based on data from Baitz *et al*. 2004) during the gasification and FT synthesis of woodchips.

Assumptions used in conversion to bioethanol element

- Ratio of 5:1 wood to ehtanol assumed (based on data from NERL[5], Iogen[6] and van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf[7]

The complexities of production from commercial forestry systems have already been mentioned in [chapter/section] 2 of this report, with particular regard to the long rotations and range of product types which are consumed in varying fractions by processing streams. The biomass flow charts for conventional forestry systems attempt to account for these complexities and constraints on production as shown in Appendices 4 and 5. As discussed in [chapter/section] 2, initially total biomass production, broken down into the major components was estimated using the BSORT forest biomass model (Matthews and Duckworth, 2005). The results over a characteristic rotation for a forest stand were

[1] Matthews, R. W. and Duckworth, R. R. (2005) BSORT: a Model of Tree and Stand Biomass Development and Production in Great Britain. In: Imbabi, M.S. and Mitchell, C.P. (eds.) Proceedings of World Renewable Energy Congress (WREC 2005), 22-27 May 2005, Aberdeen, UK. Elsevier: Oxford, 404-409.

[2] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[3] Dinjus, E (2008) Synthetic Fuels from Biomass. Logistics, Technology and Economics. Karlsruhe Institute of Technology. Presentation to the 6th European BioFuels Forum, January 2008, Rotterdam, Netherlands. http://www.europoint-bv.com/events/?biofuels2008/72

[4] Baitz, M., Binder, M., Degen, W., Deimling, S., Krinke, S., Rudloff, M. (2004) Comparative life cycle assessment for SunDiesel (Choren Process) and conventional diesel fuel. Report to Volkswagen AG and DaimlerChrysler Ag www.choren.com/dl.php?file=2005-01-21_Exec_Summ_LCA_Choren_englisch.pdf

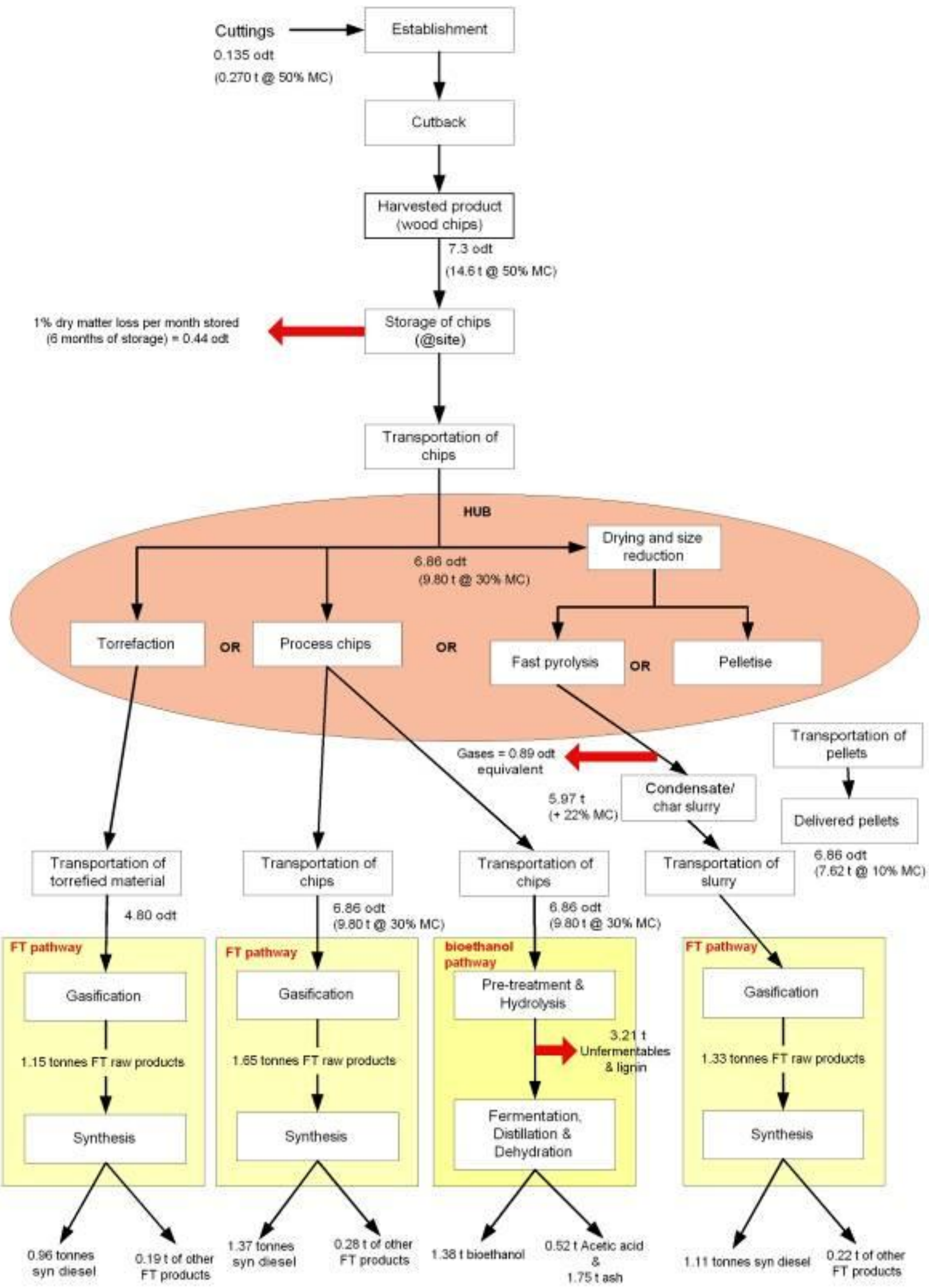
[5] NERL (2007) Research Advances. Cellulosic Ethanol. http://www.nrel.gov/biomass/pdfs/40742.pdf

[6] www.iogen.ca

[7] van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf

expressed on an annualised basis to provide the main inputs to the biomass flowcharts. For production from broadleaf high forest (Appendix 4) calculations were based on a yield model and BSORT calculations for sycamore of yield class 5 managed on a 48 year rotation (plus two fallow years) and involving periodic silvicultural thinnings (Edwards and Christie, 1981). This involved averaging estimates for yield classes 4 and 6. For production from conifer high forest (Appendix 5) calculations were based on a yield model for Sitka spruce of yield class 12 and a 50 + 2 year rotation involving periodic silvicultural thinnings (Edwards and Christie, 1981).

Appendix VII: Ligno-cellulose from SRC for production of ethanol/synthetic diesel - mass flow and assumptions used



Assumptions used in crop management element

- Cutting dry weight of 9g (taken from unpublished data held by FR)
- Planting density of 15,000 stools per hectare
- Long term yield of 7.3 oven dry tonnes per hectare per year, based on data used for Defra 'Energy Crop opportunity maps'[1] http://www.defra.gov.uk/farm/crops/industrial/energy/opportunities/index.htm and allowing for one unproductive year prior to stool 'cut back' and one unproductive year for destumping between crop rotations.
- Shoots are cut from stools and chipped in a single operation
- All above ground biomass enters the fuel supplychain
- Dry matter loss of 1% per month occurs in stored chips[2] (Garstang *et al.,* 2002).
- Three year interval between harvests
- 22 year crop life span (one year establishment and seven harvests)
- Moisture content of harvested chips falls from 50% to 30% during storage

Assumptions used in conversion to synthetic diesel element

- Fast pyrolysis product yield by mass = 75% liquid (of which 25% is water), 12% char, 13% gas[3] (Dti Global Watch, 2006).
- Ratio of 4.5:1 condensate/char slurry to raw FT product and 1.2:1 raw FT product to syn-diesel[4] taken from Karlsruhe Institute of Technology (2008
- Ratio of 5:1 wood to syn diesel assumed[5] (based on data from Baitz *et al*. 2004) during the gasification and FT synthesis of woodchips.

Assumptions used in conversion to bioethanol element

- Ratio of 5:1 wood to ehtanol assumed (based on data from NERL[6], Iogen[7] and van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf[8]

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[1] http://www.defra.gov.uk/farm/crops/industrial/energy/opportunities/index.htm

[2] Garstang, J., Weekes, A., Poulter, R. and Bartlett, D. (2002) Identification and characterisation of factors affecting the large scale, non ventilated bulk storage of woodchips and the development of best storage practices. Report to DTI, FES B/W2/00716/REP/DTI/pub URN02/1535 www.berr.gov.uk/files/file14947.pdf

[3] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[4] Dinjus, E (2008) Synthetic Fuels from Biomass. Logistics, Technology and Economics. Karlsruhe Institute of Technology. Presentation to the 6th European BioFuels Forum, January 2008, Rotterdam, Netherlands. http://www.europoint-bv.com/events/?biofuels2008/72

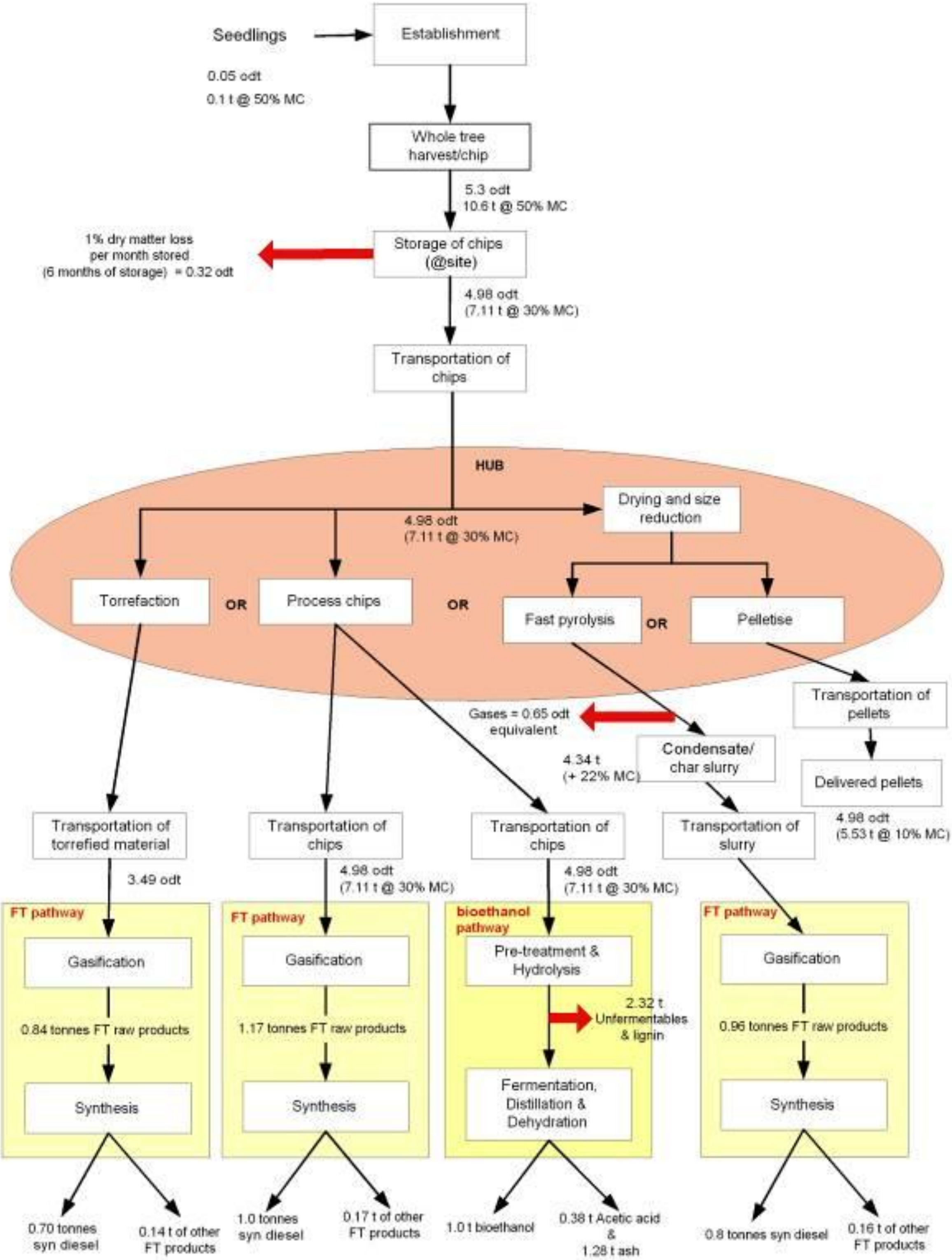
[5] Baitz, M., Binder, M., Degen, W., Deimling, S., Krinke, S., Rudloff, M. (2004) Comparative life cycle assessment for SunDiesel (Choren Process) and conventional diesel fuel. Report to Volkswagen AG and DaimlerChrysler Ag www.choren.com/dl.php?file=2005-01-21_Exec_Summ_LCA_Choren_englisch.pdf

[6] NERL (2007) Research Advances. Cellulosic Ethanol. http://www.nrel.gov/biomass/pdfs/40742.pdf

[7] www.iogen.ca

[8] van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf

Appendix VIII: Ligno-cellulose from SRF (whole tree harvesting) for the production of ethanol/ synthetic diesel - mass flow and assumptions



Assumptions used in crop management element

- Seedling weight of 20g
- Species planted alder, ash, birch, poplar and sycamore
- Planting density of 2500 trees per hectare
- Yield of 5.3 oven dry tonnes per hectare based on Hardcastle, 2006[1] and allowing for one unproductive harvesting year and one unproductive site preparation year between rotations.
- Rotation length of 15 years
- All above ground biomass enters the fuel supplychain following harvest
- Dry matter loss of 1% per month occurs in stored chips (Garstang *et al.,* 2002)[2].
- Six months chip storage time assumed
- Chip storage takes place in forest, by road side
- Moisture content falls from 50% to 30% during storage

Assumptions used in conversion to synthetic diesel element

- Fast pyrolysis product yield by mass = 75% liquid (of which 25% is water), 12% char, 13% gas (Dti Global Watch, 2006)[3].
- Ratio of 4.5:1 condensate/char slurry to raw FT product and 1.2:1 raw FT product to syn-diesel taken from Karlsruhe Institute of Technology (2008)[4]
- Ratio of 5:1 wood to syn diesel assumed (based on data from Baitz *et al*. 2004)[5] during the gasification and FT synthesis of woodchips.

Assumptions used in conversion to bioethanol element

- Ratio of 5:1 wood to ehtanol assumed (based on data from NERL[6], Iogen[7] and van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf[8]

[1] Hardcastle, P.D. (2006) A review of the potential impacts of short rotation forestry. Report to Forestry Commission and Defra. www.forestry.gov.uk/pdf/SRFFinalreport27Feb.pdf/$FILE/SRFFinalreport27Feb.pdf

[2] Garstang, J., Weekes, A., Poulter, R. and Bartlett, D. (2002) Identification and characterisation of factors affecting the large scale, non ventilated bulk storage of woodchips and the development of best storage practices. Report to DTI, FES B/W2/00716/REP/DTI/pub URN02/1535 www.berr.gov.uk/files/file14947.pdf

[3] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[4] Dinjus, E (2008) Synthetic Fuels from Biomass. Logistics, Technology and Economics. Karlsruhe Institute of Technology. Presentation to the 6th European BioFuels Forum, January 2008, Rotterdam, Netherlands. http://www.europoint-bv.com/events/?biofuels2008/72

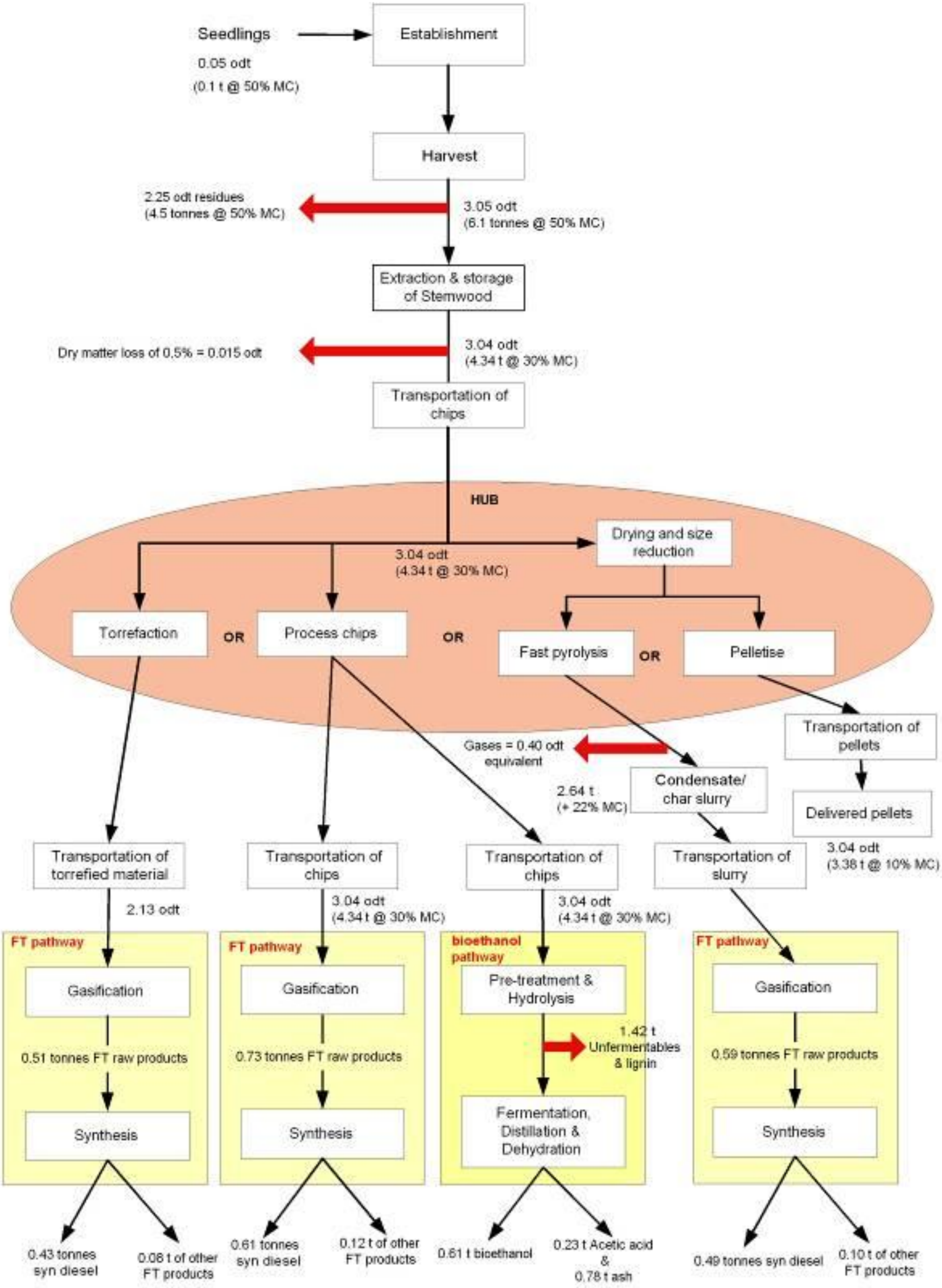
[5] Baitz, M., Binder, M., Degen, W., Deimling, S., Krinke, S., Rudloff, M. (2004) Comparative life cycle assessment for SunDiesel (Choren Process) and conventional diesel fuel. Report to Volkswagen AG and DaimlerChrysler Ag www.choren.com/dl.php?file=2005-01-21_Exec_Summ_LCA_Choren_englisch.pdf

[6] NERL (2007) Research Advances. Cellulosic Ethanol. http://www.nrel.gov/biomass/pdfs/40742.pdf

[7] www.iogen.ca

[8] van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf

Appendix IX: Ligno-cellulose from SRF (small round wood) for the production of ethanol/ synthetic diesel - mass flow and assumptions



Assumptions used in crop management element

- Seedling weight of 20g
- Species planted alder, ash, birch, poplar and sycamore
- Planting density of 2500 trees per hectare
- Yield of 5.3 oven dry tonnes per hectare based on Hardcastle, 2006[1] and allowing for one unproductive harvesting year and one unproductive site preparation year between rotations.
- Rotation length of 15 years
- All stem wood enters the fuel supplychain following harvest
- Small branches and tip are left on site for nutrient cycling
- Dry matter loss of 1% per month occurs in stored chips (Garstang *et al.,* 2002)[2].
- Six months chip storage time assumed
- Chip storage takes place in forest, by road side
- Moisture content falls from 50% to 30% during storage

Assumptions used in conversion to synthetic diesel element

- Fast pyrolysis product yield by mass = 75% liquid (of which 25% is water), 12% char, 13% gas (Dti Global Watch, 2006)[3].
- Ratio of 4.5:1 condensate/char slurry to raw FT product and 1.2:1 raw FT product to syn-diesel taken from Karlsruhe Institute of Technology (2008)[4]
- Ratio of 5:1 wood to syn diesel assumed (based on data from Baitz *et al*. 2004)[5] during the gasification and FT synthesis of woodchips.

Assumptions used in conversion to bioethanol element

- Ratio of 5:1 wood to ehtanol assumed (based on data from NERL[6], Iogen[7] and van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf[8]

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[1] Hardcastle, P.D. (2006) A review of the potential impacts of short rotation forestry. Report to Forestry Commission and Defra. www.forestry.gov.uk/pdf/SRFFinalreport27Feb.pdf/$FILE/SRFFinalreport27Feb.pdf

[2] Garstang, J., Weekes, A., Poulter, R. and Bartlett, D. (2002) Identification and characterisation of factors affecting the large scale, non ventilated bulk storage of woodchips and the development of best storage practices. Report to DTI, FES B/W2/00716/REP/DTI/pub URN02/1535 www.berr.gov.uk/files/file14947.pdf

[3] DTI Global Watch (2006) Second generation transport biofuels – a mission to the Netherlands, Germany and Finland. Global Watch Mission Report to DTI http://www.oti.globalwatchonline.com/online_pdfs/36610MR.pdf

[4]

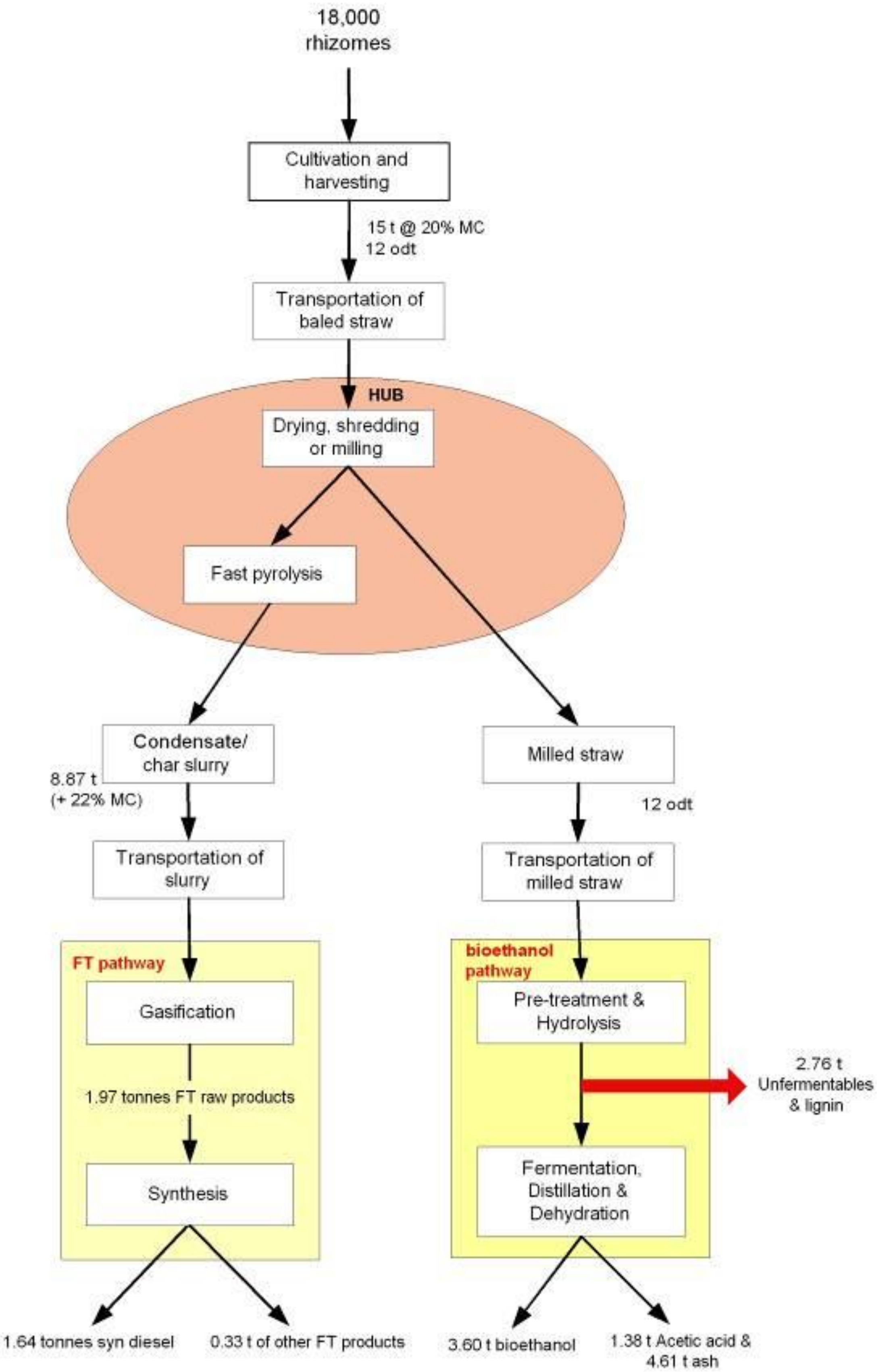
[5] Baitz, M., Binder, M., Degen, W., Deimling, S., Krinke, S., Rudloff, M. (2004) Comparative life cycle assessment for SunDiesel (Choren Process) and conventional diesel fuel. Report to Volkswagen AG and DaimlerChrysler Ag www.choren.com/dl.php?file=2005-01-21_Exec_Summ_LCA_Choren_englisch.pdf

[6] NERL (2007) Research Advances. Cellulosic Ethanol. http://www.nrel.gov/biomass/pdfs/40742.pdf

[7] www.iogen.ca

[8] van Zessen, E., Weismann, M., Bakker, R.R., Elbersen, H.W., Reith, J.H. and den Uil, H., (2003) Ligno-cellulosic ehtanol. A second Opinion. Report 2GAVE003.11. Netherlands Agency for Energy and Environment. http://www.ecn.nl/fileadmin/ecn/units/bio/Overig/pdf/Publications2.pdf

Appendix X: Ligno-cellulose from Miscanthus for production of ethanol/synthetic diesel - mass flow and assumptions used



Miscanthus straw (lignocellulose) to Bioethanol

- Flow chart is based on the wheat mass flow charts produced by Elsayed et al (2003)[1]
- Release of CO_2 by the fermentation of sugars is a related to that taken in by the plant during photosynthesis and hence not included.
- Assumes that pentose sugars are also broken down in fermentation as in the process used by the company Iogen.
- Figures for bioethanol yield show a best case scenario. A low yield scenario could be 60% of the values indicated here.
- 300kg bioethanol yield/tonne of dried straw (0%mc) assumed.
- Miscanthus yield of 12 dried tonnes (0%mc) .
- 1271 litres of bioethanol in 1 metric tonne.

Miscanthus straw (lignocellulose) to Pyrolysis Oil

- Data is based on report by Mohen D. et al (2005)[2]
- Yield of straw 12 odt.
- Yield/tonne of dried straw = 700kg, Char 20kg and gases 10kg.
- Straw needs to be dried to around 10%mc content with a particle size of approx 5 mm based on report by Christou M (2004).[3]
- Assumed that once shredded straw moisture would be around 6%.
- Bio-oil water content 23% based on report by Coulson M[4].

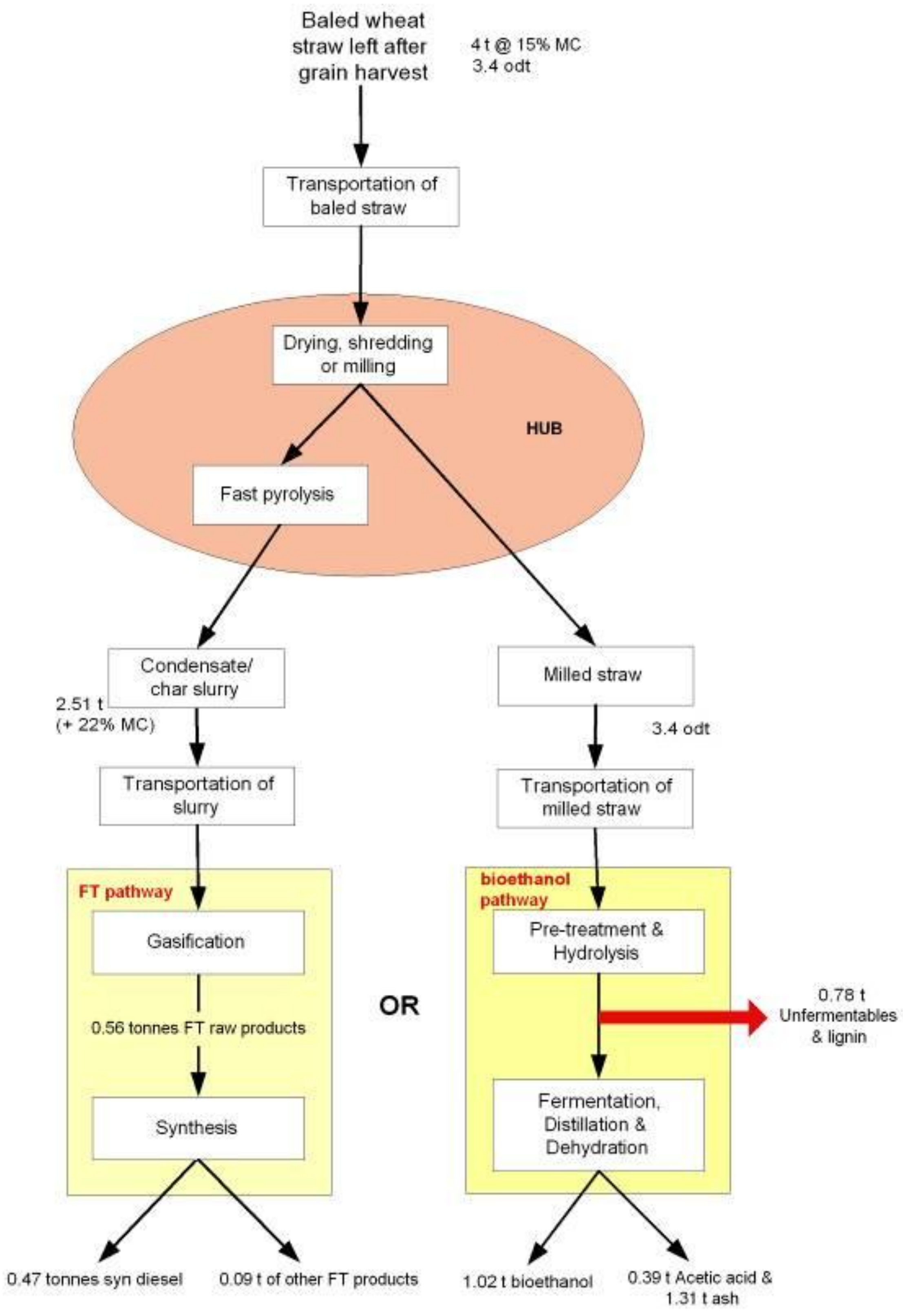
[1] Elsayed M.A, Matthews R., Mortimer N.D, (2003) Carbon and Energy Balances for a range of Biofuel Options. Department of Trade and Industry (DTI) report B/B6/00784. http://www.berr.gov.uk/files/file14925.pdf

[2] Mohan D., Pittman C.V, Jr., and Steele P.H. (2005) Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy and Fuels 2006, 20, pgs 849-889.

[3] Christou M. (2004). Bioenergy chains from perennial crops in Europe. EU-China Workshop on Liquid biofuels 2004. http://europa.eu.int/comm/research/energy/gp/gp_events/china/article_1738_en.htm

[4] Coulson M. Pyrolysis of Perennial Grasses from Southern Europe. PyNe issue 20. http://www.pyne.co.uk/docs/ThermalNet%20(July%2006)%20PyNe.pdf

Appendix XI: Ligno-cellulose from straw for production of ethanol/synthetic diesel - mass flow and assumptions used



Winter wheat straw (lignocellulose) to Bioethanol

- Flow chart is based on mass flow charts produced by Elsayed et al (2003)[1]
- Straw yield of 3.4 odt /ha.
- Release of CO_2 by the fermentation of sugars is a related to that taken in by the plant during photosynthesis and hence not included.
- Assumes that pentose sugars are also broken down in fermentation as in the process used by the company Iogen.
- Figures for bioethanol yield show a best case scenario. A low yield scenario could be 60% of the values indicated here.
- 300kg bioethanol yield/tonne of dried straw (0%mc) assumed.
- 1271 litres of bioethanol in 1 metric tonne.

Winter wheat straw (lignocellulose) to Pyrolysis Oil

- Data is based on report by Mohen D. et al (2005)[2]
- Yield of straw 3.4 odt.
- Yield/tonne of dried straw = 700kg, Char 20kg and gases 10kg.
- Straw needs to be dried to around 10%mc content with a particle size of approx 5 mm based on report by Christou M (2004).[3]
- Assumed that once shredded straw moisture would be around 6%.
- Bio-oil water content 23% based on report by Coulson M

[1] Elsayed M.A, Matthews R., Mortimer N.D, (2003) Carbon and Energy Balances for a range of Biofuel Options. Department of Trade and Industry (DTI) report B/B6/00784. http://www.berr.gov.uk/files/file14925.pdf

[2] Mohan D., Pittman C.V, Jr., and Steele P.H. (2005) Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review. Energy and Fuels 2006, 20, pgs 849-889.

[3] Christou M. (2004). Bioenergy chains from perennial crops in Europe. EU-China Workshop on Liquid biofuels 2004. http://europa.eu.int/comm/research/energy/gp/gp_events/china/article_1738_en.htm

Appendix XII: GLOSSARY OF TERMS AND ABBREVIATIONS

Terms

Carbon ratio: The ratio of carbon (C) contained in biomass upon delivery to the power station, to C (in CO2) emitted as a result of operations during all phases of growing the crop.
Chipping: The comminution of woody materials to particles of length 4-50 mm.
Comminution: The process of fractionating woody material to a smaller particle size.
Cut back: The act of establishing a SRC stool by cutting the stem of a tree back to a small stump, one or two years after planting.
Cutting: A section of living stem material, approximately 25 cm in length, cut from poplar and willow SRC. Fresh cuttings are planted to establish new areas of SRC.
Cutting cycle: The number of growing seasons between successive harvests of poplar or willow SRC.
Drilling: The process of sowing seed in rows using agricultural machinery pulled by a tractor.
Energy balance: The difference between energy output and energy input.
Energy ratio: The ratio of energy contained in the biomass upon delivery to the power station to energy input to all phases of growing the crop.
Greenhouse effect: The process by which radiation from the sun is 'trapped' by gases in the earth's atmosphere.
Greenhouse gas: A gas present in the earth's atmosphere which has the capacity to 'trap' radiation from the sun.
Grub up: The act of killing and removing SRC stools from the ground in readiness for establishment of a new crop.
Rhizome: Underground storage stem, thickened and tuber shaped, possessing buds, nodes and scale-like leaves.
Rotation: The number of growing seasons from the planting of cuttings/seedlings and establishment of SRC/forest to grubbing up of the stool beds or clear cut of forest.
Seed: A fertilised ovule containing an embryo which forms a new plant upon germination.
Stump: The base part of a tree or SRC stool remaining above ground after harvesting of the stem wood.
Working life: The life-span of a machine expressed in terms of the total operating time of the machine during its life.
Work period: The time taken to carry out a specified operation (reciprocal of work rate).
Work rate: The speed at which a specified operation can be carried out.

Abbreviations

C elemental carbon

gCO2 grams carbon dioxide

Cl elemental chlorine

CO2-C the carbon component of carbon dioxide

GJ gigajoule =103 MJ or 109 J

ha hectare =10 000 m2

hp horsepower = 0.7457 kW

h hour

j joule

kgC kilograms carbon

kgCO2 kilograms carbon dioxide = 103 gCO2

kW kilowatt =106 J

kWh kilowatt-hour = 3.6 MJ

kWhe kilowatt-hours of generated electricity

m metre

M million

mg milligram =10-6 kg

MJ megajoule = 106 J

mm millimetre =10-1 cm = 10-3 m

MWe megawatts of generated electricity (usually as rating for power station)

N2O-N the nitrogen component of nitrogen oxide

odt oven dried tonnes = 1000 odkg

S elemental sulphur

s second

SO2 sulphur dioxide

t C tonnes carbon = 1000 kgC

t CO 2 tonnes carbon dioxide = 1000 kg CO 2

µg microgram = 10-9 kg

W watt

yr. year