Session 3B

Crops for Biofuel and Bioenergy

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Session Organiser:	Dr Alison Hamer *The National Non-Food Crops Centre, York, UK*
Platform Papers:	3B-1 to 3B-4
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The bio-based economy – plant protection considerations with expanding non-food cropping

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There is a growing commercial interest in use of plant-derived feedstocks for energy and other industrial uses. This is being driven by a number of political and commercial drivers. The gradual increase in oil price since the late 1990's from around \$15-20/barrel to current levels of around \$70-80/barrel has significantly shifted cost differentials between fossil-derived and plant-derived technologies. Given that around 90% of oil is used, in one form or another, as an energy source, there is particular interest in utilisation of alternative and renewable fuel technologies; including those utilising plant-derived feedstocks; to try and diversify sources of energy supplies, reduce reliance on imports and control energy costs. These alternative technologies can reduce greenhouse gas emissions, stimulate rural economies and provide export markets for developing nations.

The drivers for developing bioenergy may differ between countries, but the development of the bioenergy market sector, driven by political imperatives in the main, will have a significant and increasing impact on the types of crop grown and how land is managed in the future. In common with the US, the EU has set out its own 'renewable energy roadmap'. The EC aims to ensure 20% of Europe's energy mix is derived from renewable sources by 2020, which is likely to lead to incentives to stimulate greater use of biomass resources for heat, power and transport. Though there are no specific targets for use of plant-derived biomass, in the EU's Biomass Action Plan, biomass in its wider sense (solid biomass, biogas, biofuels and renewable waste streams) is expected to contribute 150 Mtoe to European energy demand by 2010 (12% of total consumption). As part of the drive to stimulate use of plant biomass, the Commission has proposed a mandatory target for 10% of transport fuels to be derived from biofuels by 2020 (agreed in principle by EU Energy Ministers earlier this year under the Biofuels Directive (2003/30/EC)). Member States will have to produce National Action Plans to explain how they will deliver these targets. In response, in the UK, the Renewable Transport Fuel Obligation will start in April 2008, whereby transport fuel suppliers will be mandated to supply initially 2.5% of their fuel sales (by volume) from biofuels, rising to 3.75% by 2009/10 and 5% thereafter. All of the above drivers will act to stimulate a very significant market demand for crop-derived feedstocks. Looking at the near future alone, the predicted potential impacts on resource demand across the EU are significant (Table 1), and demand will continue to rise thereafter.

Table 1. Anticipated EU plant biomass feedstock consumption forecasts
([1] European Commission, [2] EuroObserver)

	Current	2010
Biofuel demand [1]		
Cereals	5.5 Mt	10.7Mt
Oilseeds	10.1Mt	15.5Mt
Sugar	1.1Mt	1.6Mt
Biomass demand [2]		
Solid biomass	58.8 Mtoe	78.6 Mtoe

In terms of impact, 1 Mtoe of biomass equates to around 173,000 ha of biomass energy crop (Miscanthus or short-rotation willow coppice). As part of the EU's analysis of impacts of the current Biofuel Directive, to deliver the 2010 target of 5.75% substitution of transport biofuels, under the most likely scenario, around half of the required feedstocks will be sourced within the EU, from expansion of the cereal and oilseed area by some 4.1m hectares (4% of EU arable area) and redirection of a further 4.2m hectares of existing production (for export markets or sugar production) into biofuel markets.

Expansion of both conventional crops to meet biofuel demands and biomass crops to meet heat and power demands in the near term, and fuel demands in the longer term as we move to so-called 'second generation' technologies (based on fermentation of cellulosic biomass to produce ethanol, and pyrolysis, gasification then gas to liquid conversion to diesel) will result in significant pressures on land use and its management. Crops grown for energy markets will have to be managed sustainably, to ensure the most favourable energy and greenhouse gas balances are delivered while minimising any other impacts on the agri-environment. Fertilizer and pesticide inputs will need to be carefully managed to deliver minimal external impacts. However, the financial pressure to shorten rotations and increase intensity of cropping of cereals and, more likely, oilseed rape could lead to problems. Soil and trash-borne plant pathogens are likely to increase. Diseases such as club-root, *Sclerotinia*, and *Phoma* are likely to become more prevalent as rotations shorten, and in the case of club-root could limit oilseed rape production, as a break from susceptible crops is the only effective means of control. Given that current temperate arable rotations are optimized towards cereal production, there are fewer opportunities to intensify production without significantly compromising yield and returns over the rotation, however any further intensification is likely to lead to problems with diseases such as take-all, eyespot, *Septoria* and *Fusarium*. While the latter can be effectively controlled chemically, this would increase pressure on inputs. For take-all, the only means of management is by effective breaks from cereal cropping. In addition, there are also likely to be indirect effects on neighbouring food crops through increases in the inoculum pool, for example increasing *Septoria* and rust in cereals. Erosion of the efficacy of fungicide activity, through disease and pest resistance, may also occur where a limited number of active ingredients are used over an increasing crop area. Pest problems are likely to be similarly affected, with increasing incidence of damage from pollen beetle, seed weevil and pod midge anticipated in oilseed rape.

Short rotation willow coppice (SRC) and Miscanthus are relatively new biomass crops in the arable landscape. They are currently well dispersed; consequently disease and pest pressure is relatively low. However, SRC suffers from very damaging rust infestations and invasions of willow beetle. While breeding has developed better rust-tolerant lines, as a perennial crop it is difficult to take advantage of such developments. Chemical control of both pests and disease is also difficult in biomass crops, both in practical terms and through a limited availability of approved chemical controls. As a non-native in Europe, *Miscanthus* to date has few reported pest and disease problems. However, genetic diversity in the current population is very limited which increases the risk should pests and diseases emerge. In addition to indigenous risks, risk assessments conducted by CSL on imported *Miscanthus* identified at least five invertebrates and 18 pathogens that could be imported that would pose a threat to *Miscanthus* and potentially other Gramineae species in the EU. Clearly there are a number of potential pest and disease issues that will deserve attention as energy cropping develops more widely across the EU.

Crop rotation systems for sustainable energy farming

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The increasing numbers of biogas plants in Germany cause a rising demand for energy crops as a feedstock in the anaerobic digestion process. Nowadays, the tendency is to minimise the area of fallow land and expand the cultivation of maize (*Zea mays*) for energy farming. Maize is an efficient photosynthetic C_4-plant with a high capacity for biomass production and a high potential for methane formation. Moreover, the agricultural production of maize is highly developed and cultivation knowledge is widespread among farmers. Owing to the concurrent promotion of environmentally sound agricultural production, methods securing plant health, soil fertility and yield as well as conserving the natural habitat are of particular importance. Sustainable energy cropping systems should have characteristics like high yields, low production inputs and high energy values to make the production of energy from biomass even more economically efficient and to optimise the environmental benefits. Thus, whole crops are harvested instead of only grain in conventional cropping systems with one main crop. A new concept is the double cropping system in which one summer main crop follows one winter crop resulting in two harvests per year. In this context the optimum harvest time – as well as preservation and storage methods – is of particular interest. There is also a focus on the suitability of species mixtures like forage plant mixtures with emphasis on perennial species and varieties. Minimal tillage, reduced plant protection measures and low fertiliser-use play an important part, too. An open question concerns whether overhead irrigation is necessary or economic. In order to establish crop rotation systems for sustainable energy farming in 2005 a comprehensive joint project "EVA" (2005–2008) was initiated in Germany. In this network field experiments were established at 7 sites under different soil and climate conditions. Crops are grown within 5 rotation systems at each site (Table 1). At two marginal sites in Saxony and Brandenburg rye (*Secale cereale*) will be cultivated instead of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*). The monitoring programme includes economic and ecological assessments.

Table 1: Defined crop rotations (**whole crop as substrate for biogas**, usage of grain only)

	Crop rotation				
Year	1	2	3	4	5
2005	**spring-barley** **fodder radish/rape**	**Forage sorghum**	**maize**	**spring-barley** with **underseed alfalfa or clover grass**	**Oat**
2006	**maize**	**forage rye** **maize**	**forage rye** **forage sorghum**	**alfalfa or clover grass**	**winter triticale**
2007	**winter triticale** **sweet sorghum**	Winter triticale	**winter triticale** **annual ryegrass** (intercrop)	**alfalfa or clover grass**	winter rape
2008	winter wheat	winter wheat	winter wheat	winter wheat	winter wheat

Dry matter yields obtained over all sites for the period 2005 and 2006 reveal that the C_4-crop rotations (2 and 3) are the best, followed by the C_4/C_3-crop rotation (1). Data determined for crop rotation 4 (cereals and forage mixtures) and 5 (cereals only) clearly depict lower dry matter yields in comparison to the first three rotations. Considering biogas and methane yields from different species, results confirm maize as the energy crop with highest methane yield per hectare (Table 2).

Table 2: Biogas and methane yields of different plant species based on batch anaerobic digestion test (source: C Herrmann *et al.* (2007), modified by K Gödeke)

species (n)	Whole crop yield [t odm/ha]	biogas yield [m³/ha, rounded]	methane yield [m³/ha, rounded]
maize (12)	18.5	16 000	8 354
spring-barley/ -rye (29)	6.9	5 207	2 901
oat (8)	7.6	5 188	2 895
forage sorghum (12)	12.8	8 639	4 664

odm = organic dry matter

Focusing on the economic aspect the more detailed site-specific evaluation shows that maize is the favourite energy crop with reasonable substrate cost if cultivated at for maize advantageous sites (Bavaria, Baden-Württemberg, Mecklenburg-Western Pomerania). Data determined at sites characterised by moderate soil and climate conditions (Thuringia, Saxony, Lower Saxony) indicate economically significant advantages of cultivating whole crop winter triticale (*X Triticosecale*) as a biogas crop. The most favourable plant species on sandy soil and under dry climate condition (Brandenburg) is forage sorghum (*Sorghum sudanense*) cultivated as main crop. First results of the ecological evaluation show that species compositions of spiders, ground beetles and pollinators are completely different in stands of maize, winter wheat and crop mixtures (oat (*Avena sativa*) combined with false flax (*Camelina sativa*)) as well as forage sorghum. Thus, maize should not be excluded from rotation systems, plant species diversity is necessary for insect species diversity. At present, there is an ongoing discussion on using energy crops as a fuel and concerning the humus depletion in soil by the removal of biomass. Our recent calculations show a positive humus balance assuming that the part of energy crop within the rotation is 30% and the digested slurry is used as organic fertiliser in this rotation.

Up to now rotation systems investigated show optimal results when C_4- and C_3-plants were grown in combination. Therefore, it may be concluded, that future economical and ecological energy crop rotation systems for biogas production should include both C_4– and C_3-plants with variable parts or modified by other C_4– and C_3-species depending on site-specific conditions.

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Identifying and addressing the challenges of oilseed rape cultivation for biodiesel production

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Demand for biofuel production and effect on oilseed rape production

Development of biofuel production within the UK has been slow compared with the rest of Europe, and it is of note that sales of biofuel in the UK amounted to just 0.53% in 2006. There have, however, been considerable recent increases in capacity for biodiesel and bioethanol production. The UK government's Renewable Transport Fuel Obligation (RTFO) will give further encouragement to the development of biofuels.

If the entire UK RTFO for diesel were to be met from rapeseed it would require around 3 million tonnes of rapeseed and 0.8 m ha of arable land. Current UK rapeseed production totals around 2.0 mt but much of this is already being utilised for human consumption. In practice, it is expected that a wide range of vegetable oils will be utilised for biodiesel production in the UK, with imports of oils such as palm and soya. However, even supplying a share of this additional demand will have consequences for production of the oilseed rape crop in the UK.

Although seed yields of new varieties in trial have risen over time, indicating greater genetic potential, yields of the commercial crop in the UK have remained close to the present mean of 3.2 t/ha. A continuing lack of yield improvement for the farm crop would present a significant challenge to meeting the increased demand for rapeseed for biodiesel production.

A major reason for the lack of yield improvement of the commercial oilseed rape crop in the UK was found to be inadequate disease control, highlighting an area requiring attention in addressing the challenge of increased demand. As seed yield remains a key component in maximising efficiency of production of rapeseed for biodiesel as it is for food production, agronomy requirements of the rapeseed crop for biodiesel will be similar.

Implications for cropping

The expected increase in demand for oilseed rape will put pressure on rotation length. Good agronomic practice recommends that oilseed rape be grown in a rotation of no more than once in four years. It is known however, that shorter rotations are already being implemented, with the frequency of commercial crops grown one year in three rising from 8% in 1990 to 23% in 2003 (Spink, 2005). A number of major disease problems have already been encountered where oilseed rape has been grown on short rotations.

Clubroot (*Plasmodiophora brassicae*) has been the most notable problem and has shown an alarming increase in oilseed rape throughout the UK over the last two years (Harling & Oxley, in press). It can have a considerable impact on yields (with a Swedish study showing 50% yield loss when 100% of the crop was affected (Wallenhammer, 1998)) and complete crop loss may also occur. Although previously a problem of specific areas particularly where brassicas such as turnips, swedes or calabrese, have been grown in the past, it has been observed more widely in the UK and Europe recently (P Gladders; C Padley, personal communications, 2007). This is thought to be linked to warm, wet autumns in the last two sowing seasons. Once established, clubroot is a long term problem with resting spores remaining viable in the soil for 20 years or more. Short rotations can also lead to the build up of sclerotinia (*Sclerotinia sclerotium*) in the soil. The anticipated withdrawal of older fungicides, such as vinclozolin, which provided persistence for effective control, will lead to increasing pressure from sclerotinia and provides impetus for development of new products.

Tackling the challenges

Growers should attempt to maintain a rotation with non-cruciferous crops and make every effort to prevent clubroot infection of uncontaminated land and. Good soil drainage and aeration will also reduce the clubroot pathogen which needs moisture to spread. Only one commercially available variety of oilseed rape, Mendel, shows resistance to clubroot, although its growth will maintain clubroot in the soil. Since Mendel represents the only variety choice for known clubroot infected fields, there is a need to maintain its level of resistance and to develop a strategy for variety management. Early sowing into warm, moist soils encourages disease; delayed drilling can help, but care is needed in northern regions with winter-kill which may offset any advantages. There is interest in fluazinam as a potential agrochemical option for clubroot control, but its use may be more appropriate for high value horticultural brassicas, where soil drenches may be applied. Lime application decreases clubroot via the addition of calcium ions and raising soil pH. The cost effectiveness and practicalities of clubroot reduction in oilseed rape using several lime products is being evaluated in current work.

There are proposals to incorporate a reduction of the carbon footprint of biofuels within the RTFO scheme. Details are as yet unclear, but use of energy involved in growing and processing a biofuel crop is an important part of its carbon footprint. Analysis of the energy balance for biodiesel production in UK conditions shows that nitrogen fertiliser accounts for the largest portion, one-third, of all energy inputs. Agrochemical use has a comparatively minor impact. Consequently, appropriate agrochemicals to ensure good foliar disease control and maintain yield can be applied with little deleterious effect on energy balance.

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Grass and woody biomass species – agronomic requirements learnt from 15 years field experimentation

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Introduction

After many years of research, perennial energy crops are starting to become a commercial reality. In the UK two species are currently being planted on a large scale, Miscanthus (*Miscanthus x giganteus*) and short rotation coppice (SRC) willow (*Salix* spp.). To fulfil the demand for renewable energy, partly led by the Renewables Obligation and the Road Transport Fuels Obligation, the UK Biomass Strategy, 2007 (DEFRA, 2007) proposes that the land used for production of perennial energy crops should increase by some 350 000 ha by 2020.

Miscanthus is native to south east Asia; it is a naturally occurring inter-specific hybrid, and has to be propagated vegetatively from rhizome pieces. Until the late 1990's it was not grown on a field scale in Europe. Because of this, it is unsurprising that the species is not suffering serious pest or disease problems in the UK to date. However, with time, and areas planted increasing, it is of concern that problems may arise. Adding to this concern is the potential problem that there is very little genetic difference between the planting stock being used. It is believed that most commercial plantings are of clonal material. In contrast, willow is native to the UK, and does suffer from some pest and disease problems. However, there is great genetic diversity, both within and between species, and breeding programs are aimed at tackling some of the pest and disease problems, as well as increasing yield.

In this paper we review the agronomic requirements of the crops, and also discuss two other species of interest as temperate perennial biomass crops – SRC poplar (*Populus* spp.) and switchgrass (*Panicum virgatum*).

***Miscanthus*:** *Miscanthus* has been grown in various small plot experiments across Europe since 1992. Barley Yellow Dwarf Virus (BYDV) was first identified in miscanthus in 1993 at Rothamsted. In studies on *M. sinensis* (a parent of *Miscanthus x giganteus*), Lamptey *et al*. 2003, concluded that yield losses of 20% could result from infection, but that the threat of *M. sinensis* being a source of infectious aphids was small. One species of aphid, *Melanaphis sorini* is known to use *Miscanthus* spp. as their host but have only been identified in *M. sinensis* imported to a UK nursery (DEFRA 2006). Halbert (2002) states that infestations of this aphid can cause severe damage and death of Miscanthus. In the UK the only other aphid recorded feeding on miscanthus is *Rhopalosiphum maidis* (Fitch). Miscanthus Mealybug, *Miscanthiococcus miscanthi*, has not been observed in the UK but it is reported from the US to distort and stunt plant growth. Common rustic moth, *Mesapamea secalis* has been observed infrequently across several UK field trials; the larvae can damage and kill young stems. Other insects and diseases reported in Miscanthus are Miscanthus blight, also called leaf spot (*Stagonospora sp.*), rust (*Puccinia miscanthi*) and ergot (*Claviceps panicoidearum*), but none of these are known to have occurred in the UK. A number of other insects have been noted on UK Miscanthus, but not at a significant level.

SRC willow: Willow beetles, the chrysomelid beetles *Phratora vulgatissima* (blue willow Beetle), *P. vitellinae* (brassy willow beetle) and *Galerucella lineola* can cause severe leaf damage from feeding. Genetic variation in susceptibility to blue willow beetle was identified by Peacock *et al.* (2002). They also showed yield differences between cultivars in response to defoliation, cultivars such as Tora being more tolerant than most to loss of leaf area. Aphids, *Tuberolachnus salignus* (Giant Willow aphid) and *Pterocomma salicis* (Black Willow aphid) can cause severe feed damage which in combination with other stresses (e.g. drought) can kill individual stools. There are no known problems with viruses in SRC willow. However, two rust species, *Melampsora epitea* and *M. capraearum*, are common in willow plantations, with *M. epitea* being most predominant. Rust defoliates susceptible plantings prematurely and reduces yields by as much as 40%. Severe rust predisposes plants to infections by secondary pathogens which often lead to death of the plants. Willow dieback also occurs in SRC plantations. Planting mixtures of genotypes within a field has been shown to reduce pest and disease problems with SRC.

SRC poplar: This can also be severely affected by rust, *Melampsora larici-populina*.

Switchgrass: This is a C4 perennial grass from the North American prairies. It has been identified in the US as a potential biomass crop species, and has been grown in EU field experiments since 1993. It is grown from seed, and as a result is far cheaper than SRC or *Miscanthus* to establish. It yields slightly less than *Miscanthus*. Sharp Eyespot, *Rhizoctonia cerealis* (observed occasionally in UK field trials) was first identified in field trials at Rothamsted (BSPP, 2001). Other diseases that occur in the US are *Phoma* (*Phoma spp*) (as in the UK), rust (*Puccinia* spp.), smuts (*Tilletia maclaganii*), anthracnose (*Colletotrichum graminicola*), leaf spot (*Elsinoë panic*), Helminthosporium spot blotch (*Helminthosporium sativum*), Fusarium root rot (*Fusarium* spp.) and Panicum mosaic virus (PMV).

Conclusions

Experience of growing these crops has shown no significant pest or disease problems in *Miscanthus* and switchgrass, and other authors have made the same point (e.g. Lewandowski, 2003). However this paper has brought together information showing that pest- and disease-causing organisms occur which could become problematic. Problems in SRC willow are known, and control strategies have been developed to minimise detrimental effects.

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The impact of crop management on the life cycle assessment for biofuels

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UK biodiesel production plants are in operation and bioethanol plants are in construction. The Renewable Transport Fuels Obligation (RTFO) coming into force in 2008 will secure a limited market for UK biofuels; incorporation into road transport fuel is set at 2.5% (by volume) for 2008 and 5% by 2010. Production is also increasing in other countries as they produce fuel from agricultural resources to reduce greenhouse gas (GHG) emissions and secure their national fuel supply. Understanding the environmental impacts of agronomic practices in the biofuels industry enables maximum benefits to be gained from biofuels and allows for the production of feedstock with optimal efficiency. It also enables communication of the pros and cons of biofuel production from different feedstocks, allowing effective biofuel expansion strategies to be developed.

Awareness of the whole supply chain of biofuel manufacture is important. The 'cradle to grave' life cycle assessment (LCA) approach stretches from feedstock production, transport and processing through to delivery and use in vehicles. LCA brings an understanding of agricultural inputs and their impact to manufacturers and policy makers. LCAs range from simple overviews to detailed quantitative studies. In some instances, overly conservative outputs can result through the use of assumptions or omissions instead of accurate data.

We report findings of a Defra-funded project which aimed to quantify the impact of agricultural and other inputs on GHG emissions savings achieved by UK biofuels. The effects of fertilisers and pesticides on crop yield and GHG emissions were taken into account. We find that including appropriate pesticide treatments in a growing programme has little impact on GHG emissions savings achieved by the resulting biofuel. These treatments contribute less than 1% of GHG emissions across the life cycle of a typical biofuel (bioethanol or biodiesel, Ashley *et al*, 2007). In contrast, fertiliser has a large impact on total life cycle GHG emissions (Table 1, Ashley *et al*, 2007).

Table 1 Relative contributions (%) of cultivation practises to GHG emissions from biofuels

Process	Contribution to total lifecycle emissions (%)		
	OSR/ biodiesel	Wheat/ bioethanol	Sugar beet/ bioethanol
Cultivation	73.3	74.9	44.2
Fuel and machinery	31.8	14	30.3
Seed, fertiliser, soil treatments	39.7	34.5	18.82
Pesticide	0.15	0.13	0.07
Soil emissions (N_2O)	11.86	34.6	8.26
Maintained set-aside	-10.24	-8.3	-5.01
Processing and transport	26.6	25	55.8

Approximately 35% to 38% of total GHG emissions from biofuel production can be attributed to the use of nitrogen fertilisers in feedstock production (Ashley *et al*, 2007), coming largely from fertiliser production using natural gas. Further emissions arise when nitrous oxide is emitted from cultivated soils; a further 6-28% of total GHG emissions.

There is scope for the reduction of fertiliser use in biofuel feedstock production. The protein content of harvested produce is not as critical for fuel production as it is for food; therefore there is a possibility that fertiliser application can be reduced without affecting fuel yield. It has been suggested that optimum GHG emissions savings per hectare might be achieved when nitrogen fertiliser is reduced by around half, from 180 kg/ha to 80-90 kg/ha when growing oilseed rape for biodiesel production. This reduces the yield of oilseed rape by around 9%, but increases GHG emissions savings by around 19% across the lifecycle of the biofuel produced (Mortimer and Elsayed, 2006).

If oilseed rape is in short supply, there might be a necessary compromise between producing the maximum quantity of fuel and producing less fuel at increased GHG emissions savings. Without effective carbon and sustainability accreditation for fuel crops, such as those proposed under the RTFO, and given the limited supply of UK biomass, yield may take priority over GHG emissions savings.

The exclusion of pesticide treatment would be expected to reduce crop yield. This in turn would have an impact on the GHG emissions savings achieved by the resulting biofuel. Although pesticide production is energy (and therefore GHG) intensive, relatively small quantities are applied per hectare compared with fertilisers. Therefore, the use of appropriate levels of pesticides and herbicides in the cultivation of crops for biofuel production may be regarded as beneficial from a net GHG emissions savings perspective. This poster does not assess the potential impact of different biofuel agronomic regimes on other factors such as biodiversity and eutrophication; here we assess the impact of agricultural inputs on GHG emissions only.

Future technologies are likely to use lower input biomass crops instead of food crops. For example, 2nd generation biofuel production will use lignocellulosic feedstocks and biomass crops such as short rotation coppiced willow or miscanthus require fewer chemical inputs. LCA studies for these new technologies show significant improvements in GHG emissions savings over existing crops and processes. The Well-To-Wheels LCA (Edwards *et al*, 2007) shows GHG emissions savings of around 90% for these technologies when compared with fossil fuels. The equivalent analysis for 1st generation biofuel processes shows savings of around 50% compared with fossil fuels.

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