Carbon Life Cycle Calculation for Biodiesel

Report elaborated in the framework of the Carbon Labelling Project

Deliverable D3

Intelligent Energy – Europe (IEE)

September 2008

Home Grown Cereals Authority

Caledonia House

223 Pentonville Road

London N1 9HY

United Kingdom

Carbon Labelling (Contract No. EIE/06/015) is supported by:

Contents

1 Introduction

As part of the EU Carbon Labelling Project, Home Grown Cereals Authority elaborated this report on “Carbon Life Cycle Calculation for Biodiesel”. This report is based on research funded by HGCA and undertaken by Jeremy Woods, Gareth Brown, Alfred Gathorne-Hardy (Imperial College, London), Roger Sylvester-Bradley, Daniel Kindred (ADAS) and Nigel Mortimer (North Energy Associates). The scientific background reports are available on the HGCA website (www.hgca.com):

- Facilitating carbon (GHG) accreditation schemes for biofuels: feedstock production (2008)
- Understanding and managing uncertainties to improve biofuel GHG emissions calculations (2008)

2 Summary

Road transport contributes around one fifth of European Union (EU) greenhouse gas emissions and its share and gross emissions continue to grow, unlike other energy sectors. The growing share of emissions from transport coupled to its increasing dependence on oil, have provided powerful drivers for biofuel production growth over the last few years. The Carbon Labelling Project aims to reduce carbon emissions within the European road transport sector by promoting the use of biodiesel. This report is concerned with research on quantification of savings in greenhouse gas (GHG) emissions that can be achieved through use of biodiesel in road transport fuel. It demonstrates that substantial reductions in GHG emissions are possible from biodiesel fuel manufactured from oil seed rape when substituting for mineral diesel.

The work outlined here has also shown that it is possible to develop and apply the robust and transparent monitoring and calculation methodologies needed to derive credible GHG balances for biodiesel. **A biodiesel (and bioethanol) GHG calculator has been produced (www.hgca.com/biofuelcalc) using standardised methodologies and this has been coupled with on-farm audits.** The aim is to provide estimates of GHG emissions for individual batches of UK-biofuel feedstocks and to enable farmers to understand and manage those factors which are most sensitive to the GHG emissions (see Carbon Labelling Report on “Farming measures for improved CO_2 life cycles of biofuels”).

Based on the evidence-base derived from the farm audits and detailed life-cycle assessment studies from which the GHG calculator has been developed, we calculate that it is possible to produce biodiesel in ways that can result in substantially lower GHG emissions than their fossil fuel surrogates. **For rape to biodiesel, GHG reductions of between 18 and 39% are calculated[1].**

The GHG calculator highlights the main areas that farmers need to focus on to deliver low carbon feedstocks for biofuel production, in particular the need to manage nitrogen fertiliser inputs by optimising requirements per unit of output whilst maintaining high yields. Thus:

- Feedstock production accounts for between 50 to over 80% of the total GHG emissions of the biofuel supply chains covered, and is therefore the dominant source of emissions in a biofuel supply chain.
- For biodiesel from rape, nitrogen inputs account for over 90% of the on-farm GHG emissions. Nitrous oxide (N_2O) alone accounts for over 60% of those farm-based GHG emissions.
- Nitrogen management choices for farmers include sourcing fertiliser from manufacturing plants with nitrous oxide abatement which can reduce feedstock-based emissions by 25-30% (ammonium nitrate) and selection of varieties which have lower nitrogen requirements and are inherently more suited to biofuel production e.g. low protein / high oil rape.

In contrast to nitrogen fertiliser-related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions and some gains could be made here, for instance, by minimising cultivation operations. Other areas which could have a significant impact on farm emissions are land-use history, soil type and drying operations.

It is important to note that substantial uncertainties exist in calculating the GHG emissions arising from land-based biological production systems. For biofuels, these uncertainties result from both the complexity of potential supply chains and in the scientific understanding of some of the mechanisms that result in the production of greenhouse gases. This uncertainty is not unique to biofuel production and applies to all forms of land use including for food, materials and timber production. A major report, explaining and clarifying the nature and extent of the uncertainties surrounding the calculation of biofuel GHG balances has been produced in parallel to this report (Kindred et al, 2008).

Much of the reduction potential in GHG emissions from UK-biofuels results from the way energy is produced and used in the biofuel conversion plants. The most substantial reductions in emissions result where co-products are used to produce heat and surplus electricity. However, much work is still to be done to clarify the GHG impacts of alternative uses of co- and by-products, particularly when used as animal feed. Despite this uncertainty, as energy use and GHG emission efficiencies are raised in the conversion plants, pressure will mount on farmers to deliver lower GHG-emission feedstocks.

[1] The options considered here do not include biodiesel plants powered by CHP.

The work carried out in this project has delivered a standardised, transparent and clear methodology for calculating both farm and whole-chain biofuel supply GHG balances. It has developed an integrated GHG calculator for biodiesel from rape (and bioethanol from wheat) and a new electronic questionnaire for farm audits. By carrying out these activities, a major step towards on-farm GHG certification has been taken and near-term future developments should lead to a simple, robust and transparent audit questionnaire for direct use in biofuel feedstock assurance and certification.

3 GHG Calculator: basic approach and methodology

The HGCA Biofuels Greenhouse Gas Calculator (www.hgca.com/biofuelcalc) describes oilseed rape to biodiesel and wheat to bioethanol production chains.

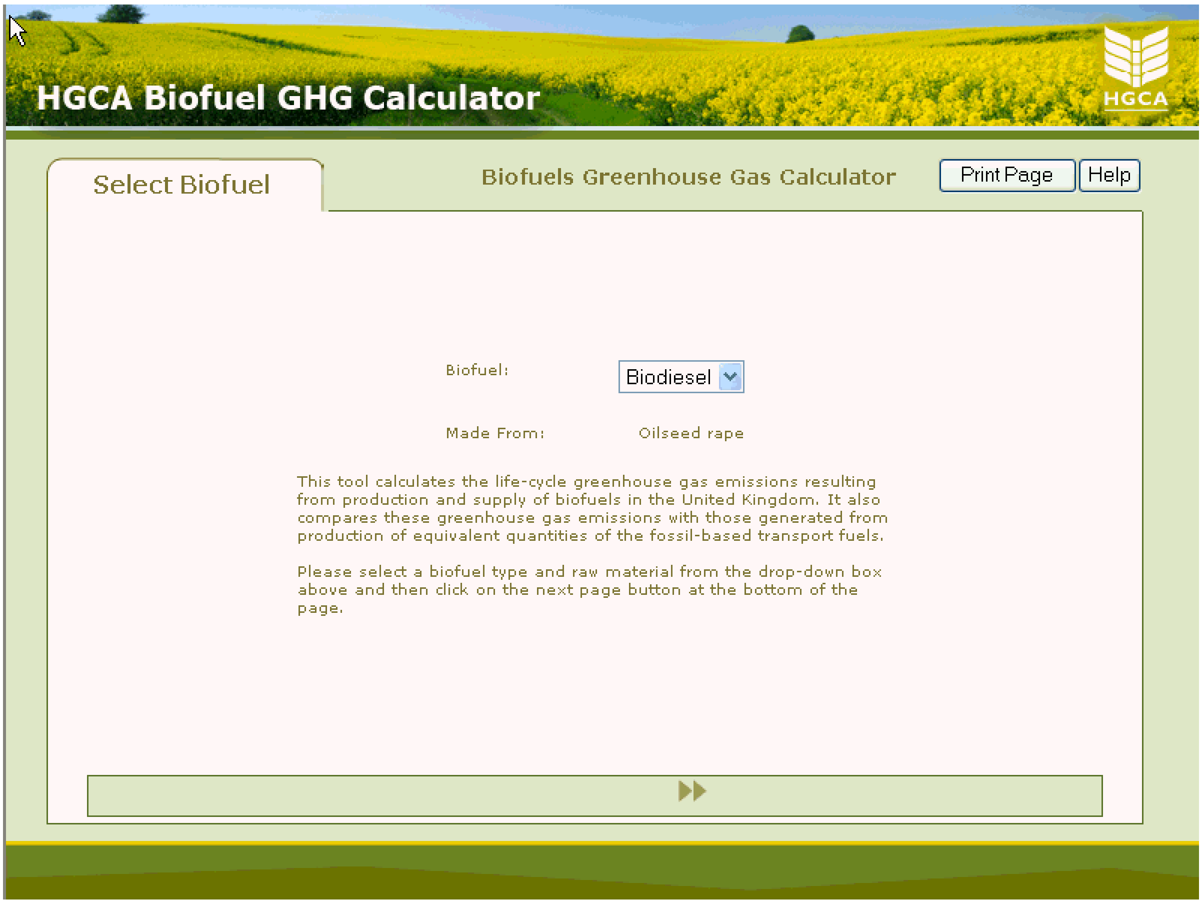

Figure 1: HGCA Biofuels Greenhouse Gas Calculator start sheet

The Biofuels GHG calculator is a spreadsheet-based tool for calculating the GHG emissions resulting from the production and use of rapeseed biodiesel (and wheat-based bioethanol) in the United Kingdom. It uses input data describing the entire production chain for any given batch of these biofuels, calculates the GHG emissions associated with that batch and compares the emissions with those produced from the production and use of an equivalent quantity of diesel (or petrol). It is based on standard life-cycle analysis (LCA) principles, using user input or default data to produce inventories of inputs, outputs and GHG emissions for all supply chain stages from farming to delivery of produced fuel for use in vehicles. The resulting well-to-tank (WTT) emission figures allow appropriate comparisons between different biofuels and between biofuels and fossil fuels.

The biodiesel section of the Biofuels Calculator uses basic data and assumptions primarily from two studies by a leading European Life Cycle Assessment group and partner in this project, North Energy Associates (Mortimer and Elsayed, 2006 and Mortimer, et al., 2003).

For each WTT calculation, the calculator guides the user through a set of steps in a life cycle inventory, before presenting the results and allowing for examination of the detailed calculations. Each step of the calculations is presented on a separate page, so that users may more easily focus on those steps of most interest to them and simply accept defaults for those steps of less interest or over which they have little control. Thus a farmer can focus on analysing the GHG impacts of farm level choices (Figure 3), while simply accepting suggested defaults for fuel production plant and other supply chain parameters.

3.1 Underlying emission factors

Greenhouse gas emission calculations consider emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), and global warming potentials used are the IPCC 100-year factors (Table 1). Based on these global warming potentials, total GHG emissions are expressed in units of kilograms of carbon dioxide equivalent (kg CO_2eq).

Table 1: 100-year global warming potentials

Gas	CO_2	CH_4	N_2O
Global Warming Potential	1	23	296

For calculations of greenhouse gas emissions resulting from energy use in the production and distribution of biofuels, the calculator uses representative emission factors for fuels, electricity and transport as shown in the following sections.

3.2 Fossil fuels and electricity

For all consumption of fossil fuels and electricity from the grid, the GHG emission factors shown in Table 2 are used (LowCVP, 2004).

Table 2: GHG emissions factors for fossil fuels and electricity

	GHG Emissions (kg CO_2eq/GJ)
Diesel	87
Gasoline	86
Natural Gas (EU-mix)	61
Grid Electricity (UK-mix)	160

3.3 Transport

Calculations of GHG emissions resulting from transport of biofuel feedstock and finished product are based on the GHG emissions factors shown in Table 3.

Table 3: GHG emissions factors for freight transport

Transport Mode	GHG Emissions Factor (kgCO_2eq/t.km)
Road	0.081
Rail	0.027
Sea	0.007

The road transport mode option assumes that fossil diesel is used. The GHG emissions factor is based on diesel consumption for road freight of 0.936 MJ/t.km (JEC, 2007) and the GHG emissions factor for diesel burning of 87 kg CO_2eq/GJ as given in Table 2. The diesel consumption for road freight includes an allowance for an empty return trip after delivery of feedstock or fuel over the specified one-way distance. Emissions factors for rail and sea are based on JEC, 2007.

4 Oilseed rape-to-biodiesel calculations

The oilseed rape-to-biodiesel production chains in the Biofuels GHG Calculator are based mainly on production chains described in two recent studies by North Energy Associates (Mortimer and Elsayed, 2006 and Mortimer, et al., 2003). Analyses of areas of uncertainty and of the Calculator’s applicability to future accreditation systems have informed the methodology and default characteristics adopted for the rape methyl ester calculations. Those methodologies and default characteristics are described below.

4.1 Basis of calculations

Greenhouse gas emissions resulting from a given oilseed rape-to-biodiesel production chain are calculated by summing the total direct and indirect emissions from all sections of that production chain and subtracting credits for GHG emissions avoided as a result of the biodiesel co-products substituting for other GHG-generating products and processes. The two studies which provided most of the basic data for the development of the rape methyl ester calculator did not use this substitution method for attributing total emissions to all co-products, but instead used allocation by price. It was therefore necessary to extract the raw data from these studies and develop a new life cycle inventory for the calculator. Because both of the North Energy studies presented their methodologies and background data in very transparent ways, it was relatively easy to extract the necessary data on inputs, outputs, efficiencies and other characteristics of the different steps in the oilseed rape-to-biodiesel production chain, and to use these to develop new life cycle inventories. However, a substitution-based LCA required assessments of the likely displacement impacts of the biodiesel co-products, and determination of life-cycle emissions of the products displaced.

4.1.1 Agricultural inputs

The GHG emissions factors used for agricultural inputs are given in Table 4. The factors for fertilisers and pesticides are taken from LowCVP (2004) and those for seeds and lime from Mortimer et al (2003).

Table 4: GHG emission factors for fertilisers, seeds and pesticides

Agricultural Input	GHG Emissions (kg CO_2eq/kg)
Nitrogen fertiliser (as N)	6.69
Phosphate fertiliser (as P)	0.71
Potash fertiliser (as K)	0.46
Lime	1.80
Pesticides (as active ingredient)	5.37
Seed material	0.61

The nitrogen fertiliser emission factors are based on ammonium nitrate, the most commonly used nitrogen fertiliser in the UK (DEFRA, 2007). Once transparent and reliable figures for urea and other nitrogen fertilisers are available, these can be incorporated into the Calculator. Pesticides include all insecticides, herbicides and fungicides and are reported as kg of active substance.

4.1.2 Effects of straw removal

In the calculator, selection of either of the option buttons for “straw ploughed in” or “straw removed” provides information to help describe the farming practices employed, but currently has no effect on the calculations. It may be appropriate to use this information in calculations of N_2O emissions from crop residue, although this would also require data on the fraction of total straw returned, and would strictly require quantification of impacts of straw removal on soil organic matter.

4.1.3 Credits for rape meal

Rape meal has value as an animal feed, and may also be used as a fuel for co-firing in coal power stations. The Calculator allows for a choice between these two options for the use of rape meal co-product and then calculates credits for GHG emissions avoided through displacement of equivalent amounts of animal feed production elsewhere or electricity generation as per UK-grid.

Imported soya bean meal from the USA is chosen as the animal feed product that is substituted by rape meal in calculations of animal feed credits. Each kilogram of rape meal is considered to substitute for 0.90 kg of soya bean meal, on the basis of relative protein content. Production in the USA and transport to the UK of each kilogram of soya bean meal result in emissions of 0.46 kg CO_2eq.

For rape meal used as fuel in co-firing for electricity production, a credit of 825 kg CO_2eq per tonne of rape meal is applied. This is based on the assumptions that:

- Rape meal is assumed to have a lower heating value (LHV) of 16.1 GJ/t
- Rape meal is converted to electricity at the UK average rate of 0.325 GJ of electricity output per GJ of primary energy input.
- Rape meal is transported 150 km by road to a power plant
- The electricity generated from rape meal substitutes for other electricity generation with GHG emissions equal to the UK average of 160 kg CO_2eq/GJe (Table 2).

4.1.4 Credits for glycerine

The Calculator allows for credits to be assigned for the production of glycerine as a co-product of esterification. The credits depend on the destination of the glycerine. Glycerine has several uses in the pharmaceutical, food and other markets. Therefore, when it is sold as a raw material in the chemical markets, it is difficult to assign a destination. Determining the substitution impacts of glycerine (as well as whether they even exist) is therefore difficult. Nevertheless, the Calculator provides three choices for glycerine destination and its resultant impacts on GHG credit calculations. These utilisation options have not yet been fully characterised in the academic literature, but are seen as possible scenarios:

- **Glycerine used as a bulk chemical**, **displacing production of propylene glycol**. A credit of -6.16 gCO_2eq/MJ biodiesel is assigned for displacing production of propylene glycol, and a cost of 2.63 gCO_2eq/MJ biodiesel is added for purification of the crude glycerine co-product. This equates to a net credit of -1299 kgCO_2eq/t crude glycerine. These GHG credits and costs are based on analyses reported in JEC, 2007.

- **Glycerine used as animal feed**, **replacing wheat feed**. A credit of -0.84 gCO_2eq/MJ biodiesel is assigned for displacing production of wheat grain, and a cost of 2.63 gCO_2eq/MJ biodiesel is added for purification of the crude glycerine co-product. This equates to a net GHG cost of 659 $kgCO_2eq/t$ crude glycerine. This analysis is also based on JEC, 2007.
- **Glycerine co-fired in power plant.** This involves GHG emissions of 13 $kgCO_2eq/t$ glycerine for transporting the glycerine 150km to a power plant and includes further direct emissions during burning in the power plant. At the time of writing, no reliable data was available on GHG emissions from glycerine combustion, so the equivalent value for rape meal burning, 38 $kgCO_2eq/t$ (Mortimer and Elsayed, 2006), was used.

4.1.5 Credits for potassium sulphate

Potassium sulphate is another co-product of some biodiesel plants. Potassium sulphate may be used as a fertiliser, displacing potassium sulphate fertiliser. In order to calculate the credits to be assigned for production of potassium sulphate, a life cycle inventory was carried out for production of potassium sulphate fertiliser in Europe via the Mannheim process using potassium chloride and sulphuric acid. The credit was calculated as 457 $kgCO_2eq/t$ potassium sulphate produced.

4.1.6 Set-aside credit

In the Calculator, all oilseed rape for biodiesel production is assumed to be grown on rotational set-aside, and a credit of 922 MJ/ha (equivalent to 26 l/ha of diesel fuel) is applied for avoidance of maintenance of set-aside land. When oilseed rape farming replaces land use other than set-aside, the set-aside credit does not apply and the emissions associated with the alternative reference land use need to be calculated.

4.2 Default biodiesel production chains

In order to illustrate typically expected inputs, yields and resultant GHG emissions of different biodiesel production chains, all production chain sub-sections in the Calculator have a “Set Default Values” button that allows for setting of all data values and process characteristics to representative values. The default values used for the oilseed rape-to-biodiesel production chain are described below.

4.2.1 Basic oilseed rape-to-biodiesel pathway

The basic non-energy inputs and yields of the different processes in the biodiesel production chain are shown in Figure 2.

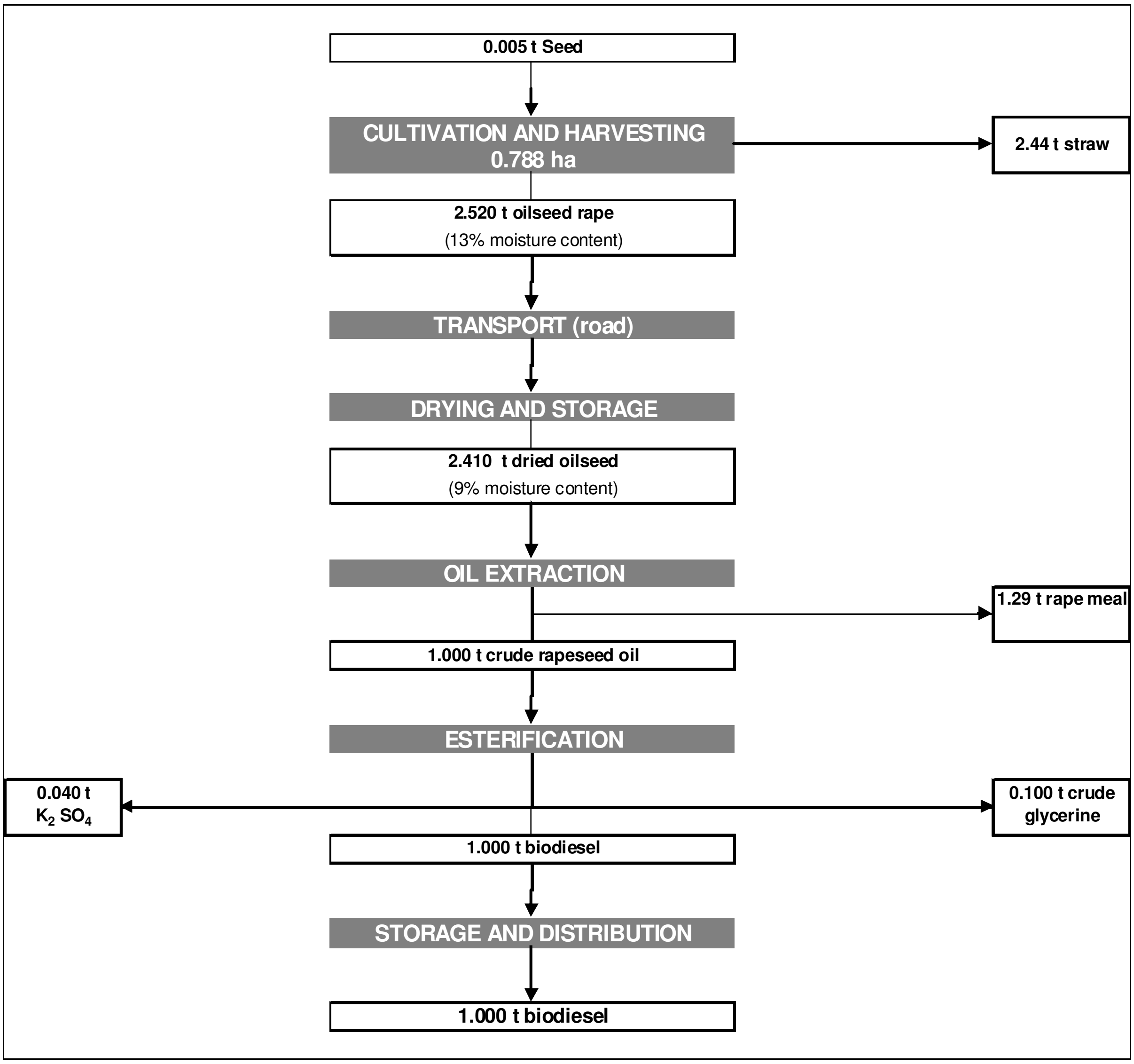

Figure 2 Basic assumptions for default rape to biodiesel pathways (Mortimer & Elsayed, 2006)

4.2.2 *Farming inputs and yields*

For the calculation of default GHG emissions from the farming component of the biodiesel production chain, the used values are shown in

Table 5: Default farming inputs and yields

Inputs	Defaults
Diesel fuel, l/ha	67
K fertiliser (as K), kg/ha	40
P fertiliser (as P), kg/ha	22
N fertiliser (as N), kg/ha	196
Pesticides (as active ingredient), kg/ha	2.8
Seed material, kg/ha	5
Yields	**Defaults**
Rapeseed, t/ha	3.1
Straw, t/ha	3.0

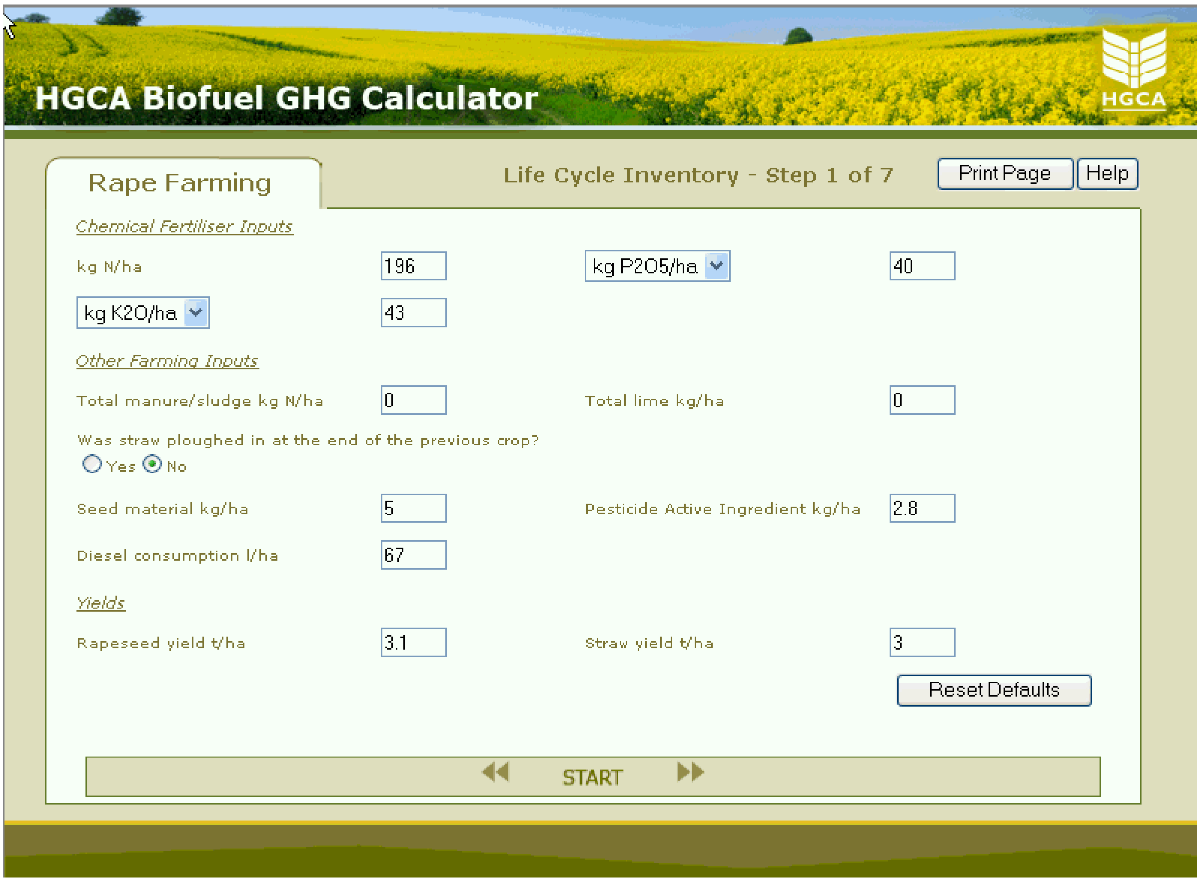

Figure 3: Farming inputs and yields sheet of the HGCA online calculator

4.2.3 *Oilseed transport*

In all default production chains, rapeseed is assumed to be transported by road in diesel-fuelled trucks over an average distance of 50 km from the farm to a central drying facility.

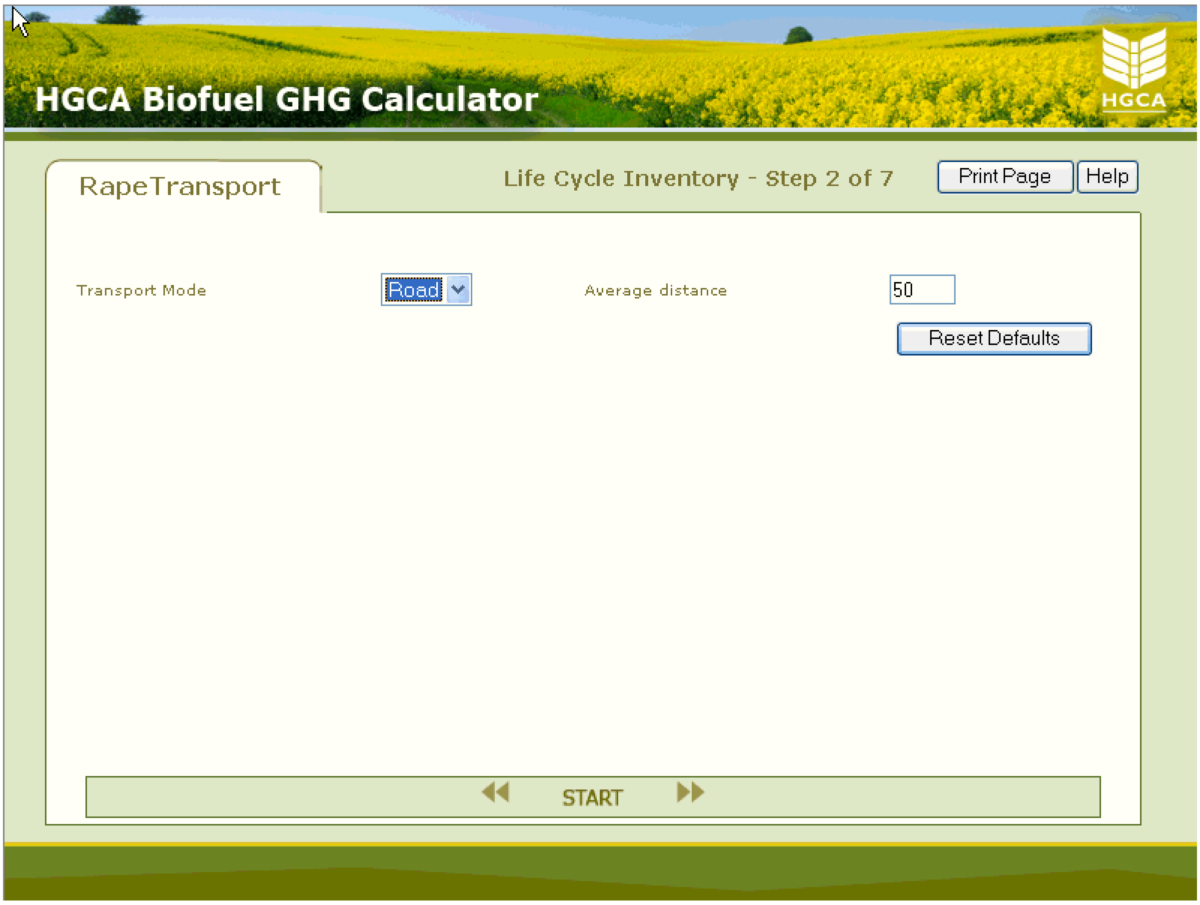

Figure 4: Rapeseed transport distance sheet of the HGCA online calculator

4.2.4 *Drying and storage*

For the default case, rapeseed is assumed to be harvested at 13% moisture and dried to 9% moisture before delivery to the crushing plant. The drying and storage of the rapeseed consumes 3.8 litres of diesel fuel and 5 kWh of electricity per tonne of dried oilseed.

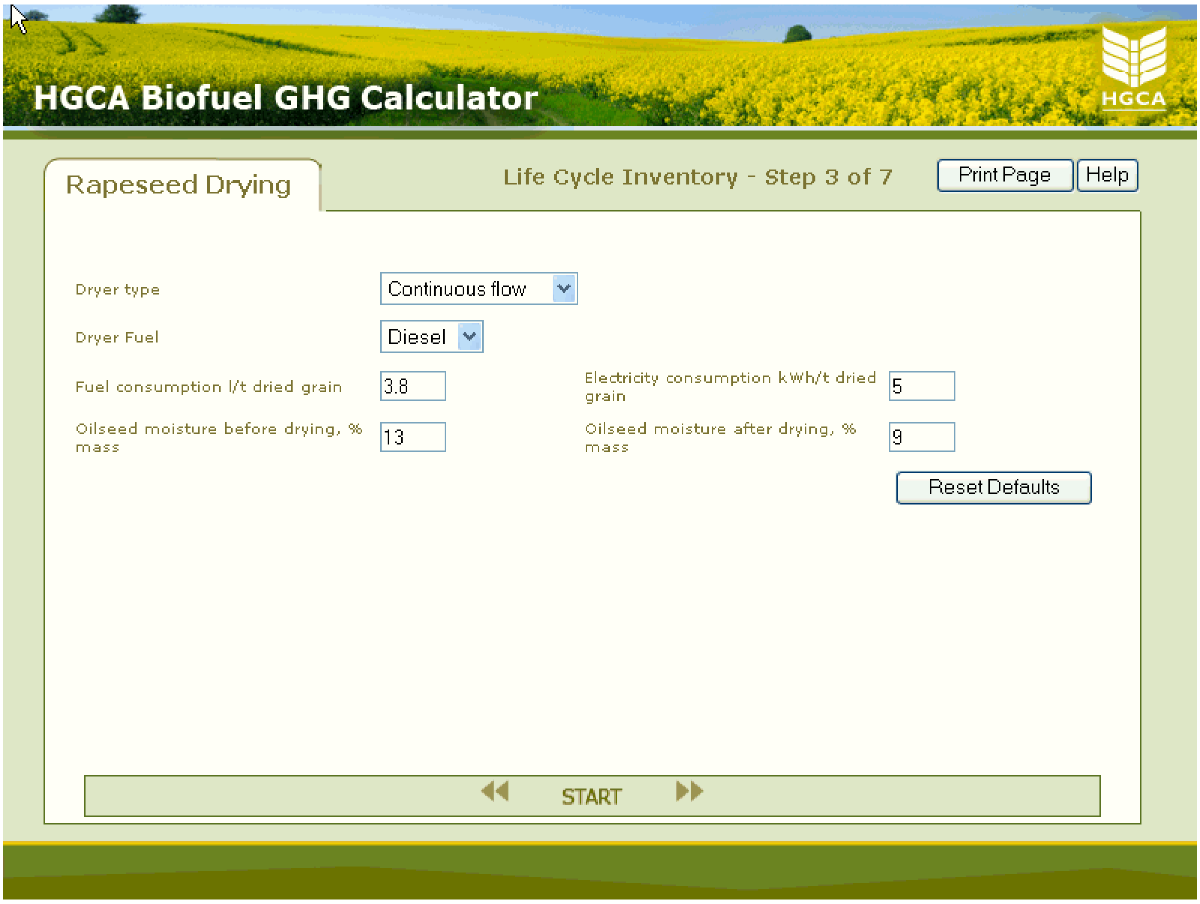

Figure 5: Rapeseed drying sheet of the HGCA online calculator

4.2.5 Oil extraction

The default oil extraction plant yields 0.41t of crude rapeseed oil per tonne of dried rapeseed. Additionally, 0.54t of rape meal is produced per tonne of dried rapeseed. The oil extraction process requires 2.78 GJ of heat and 0.46 GJ of electricity per tonne of crude rapeseed oil produced. The calculator does not provide for different energy supply options in the esterification plant as it does for the bioethanol plant. This is because an analysis of a range of such options at relevant scales has not yet been carried out. Thus, the only energy supply considered is one using a natural gas-fired boiler to generate the necessary heat and imported electricity from the grid.

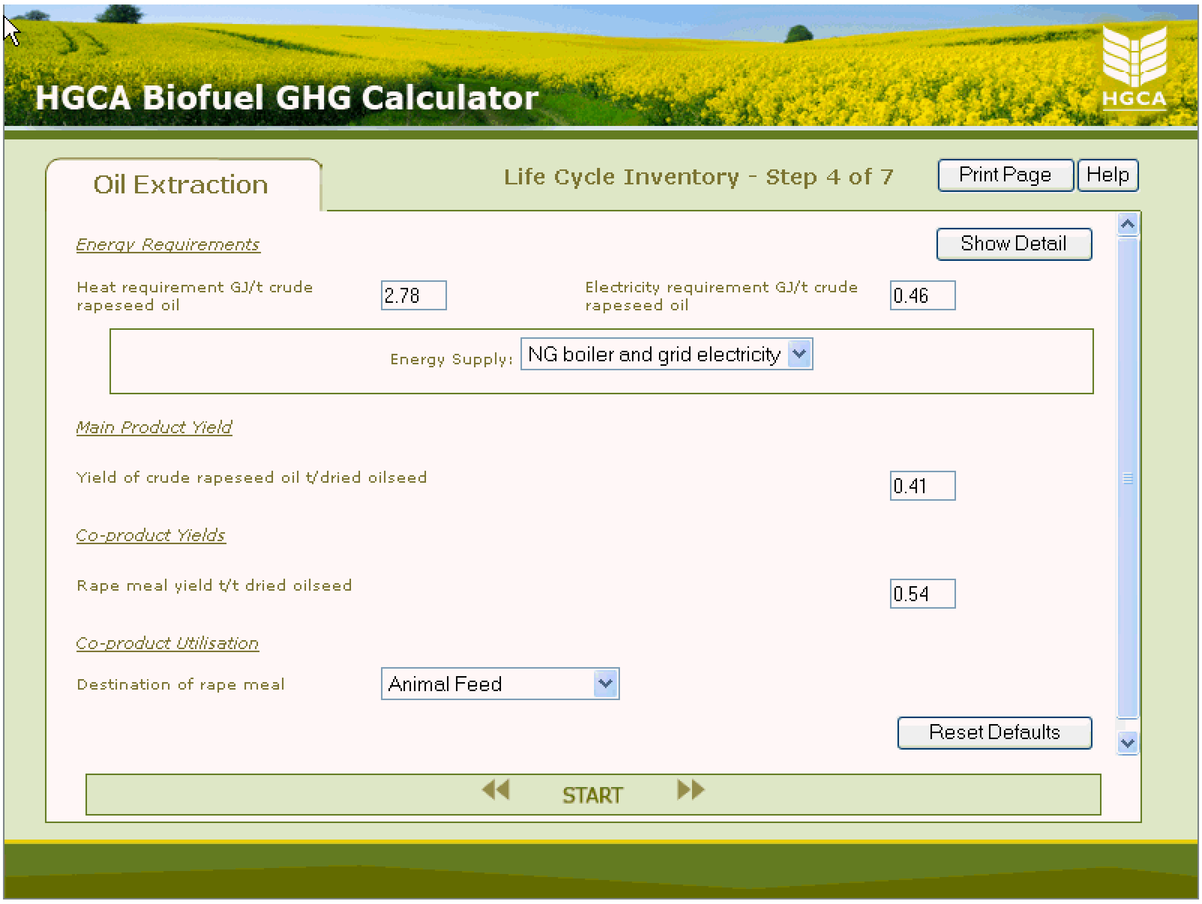

Figure 6: Rape oil / meal extraction and yield sheet of the HGCA online calculator

4.2.6 Esterification

The default esterification plant yields 1.0t of biodiesel per tonne of crude rapeseed oil. Additionally, 0.10t of glycerine and 0.04t of potassium sulphate are produced for every tonne of biodiesel produced. The entire production process at the plant requires 2.85 GJ of heat and 0.33 GJ of electricity per tonne of biodiesel produced. The calculator does not provide for different energy supply options in the esterification plant as it does for the bioethanol plant. This is because an analysis of a range of such options at relevant scales has not yet been carried out. Thus, the only energy supply considered is one using a natural gas-fired boiler to generate the necessary heat and imported electricity from the grid.

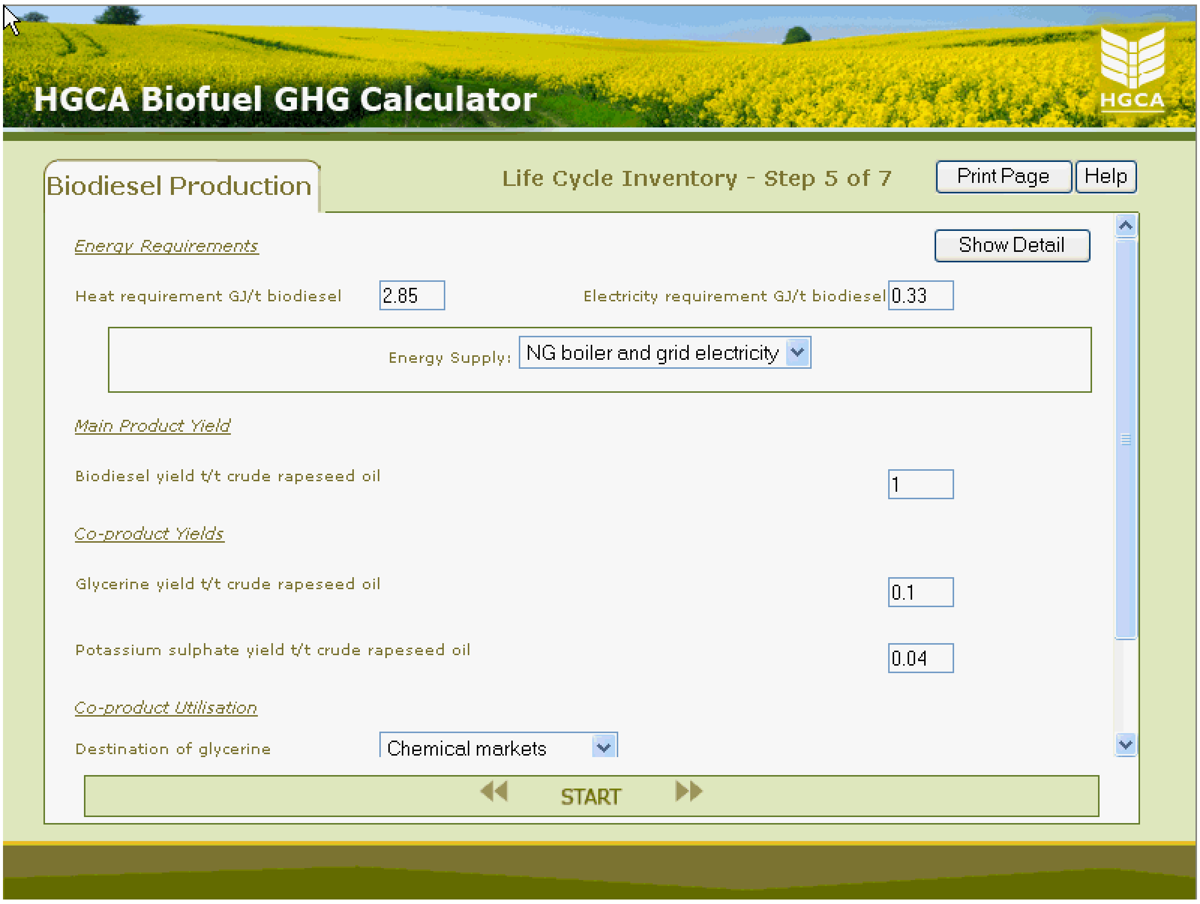

Figure 7: Biodiesel production and yield sheet of the HGCA online calculator

4.2.7 Transport to end use

In all default production chains, biodiesel is assumed to be transported by road in diesel-fuelled trucks over an average one way distance of 150 km from biodiesel plant to fuel blending/distribution site.

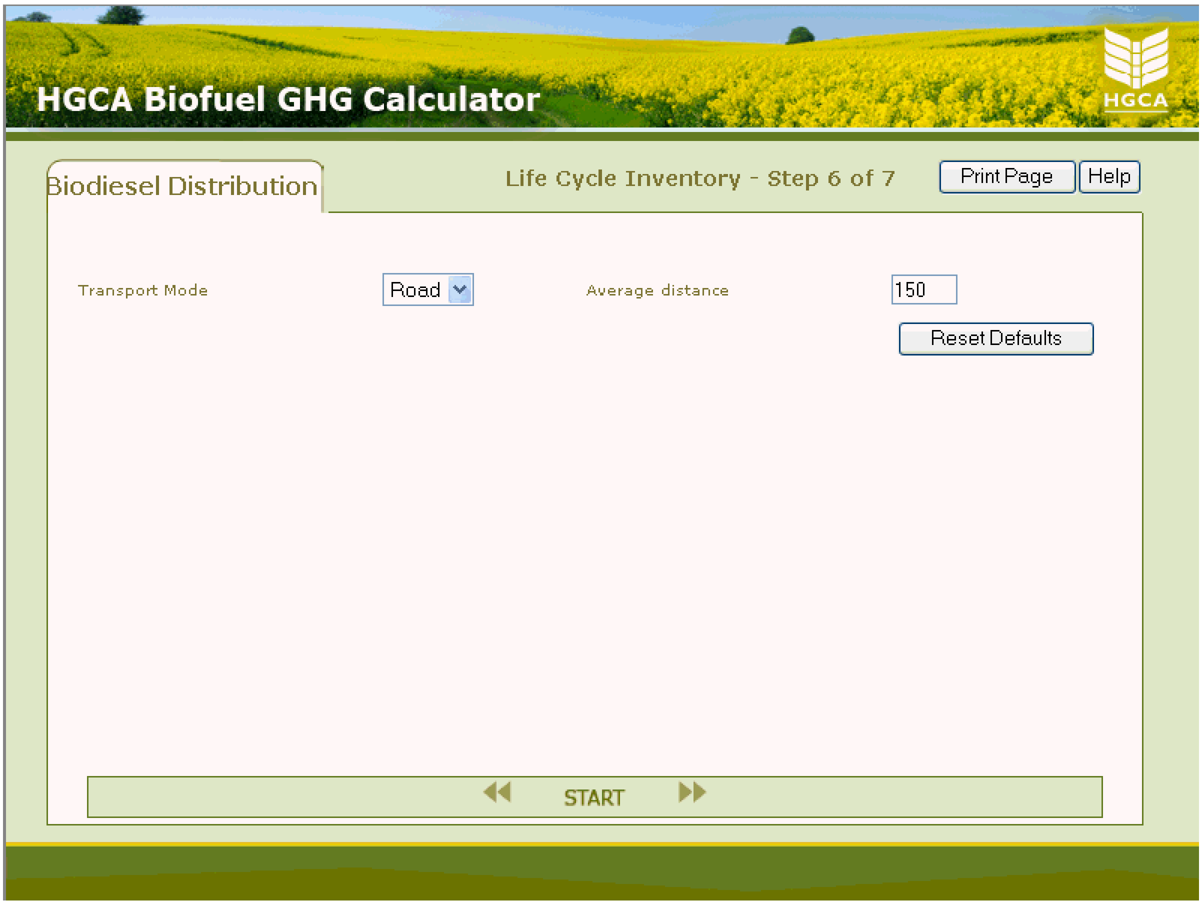

Figure 8: Biodiesel transport distance of the HGCA online calculator

4.3 Summary calculations

The calculator details a summary table of the GHG emissions (in kg CO_2 equivalent / t biodiesel) associated with each of the sections of the production chain.

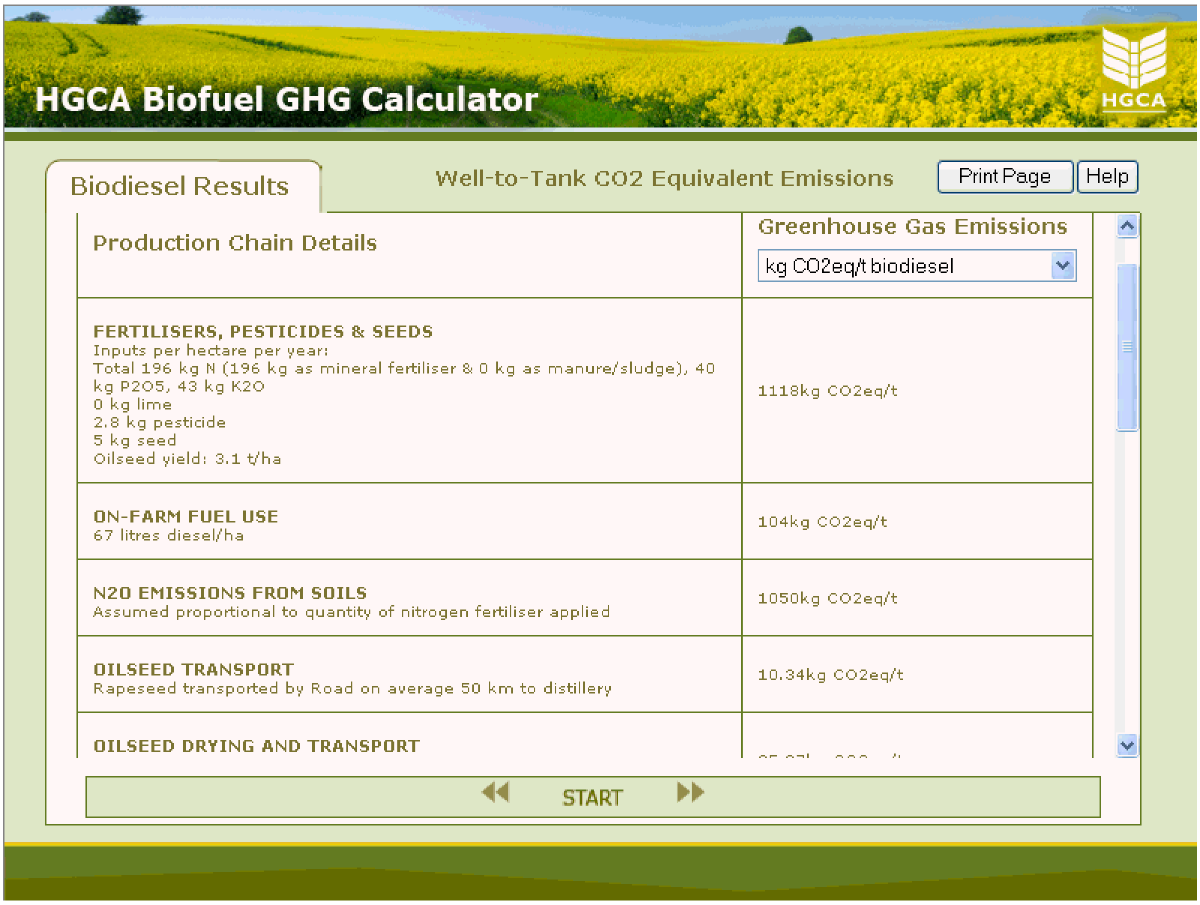

Figure 9: Summary sheet of GHG emissions through the biodiesel production chain of the HGCA online calculator

A summary bar chart of GHG emissions associated with each section of the biodiesel production supply chain is shown. The chart serves to graphically highlight the major GHG-emitting areas of the supply chain. The summary also states the percentage GHG savings of the calculated biodiesel supply chain with respect to the corresponding fossil fuel (diesel).

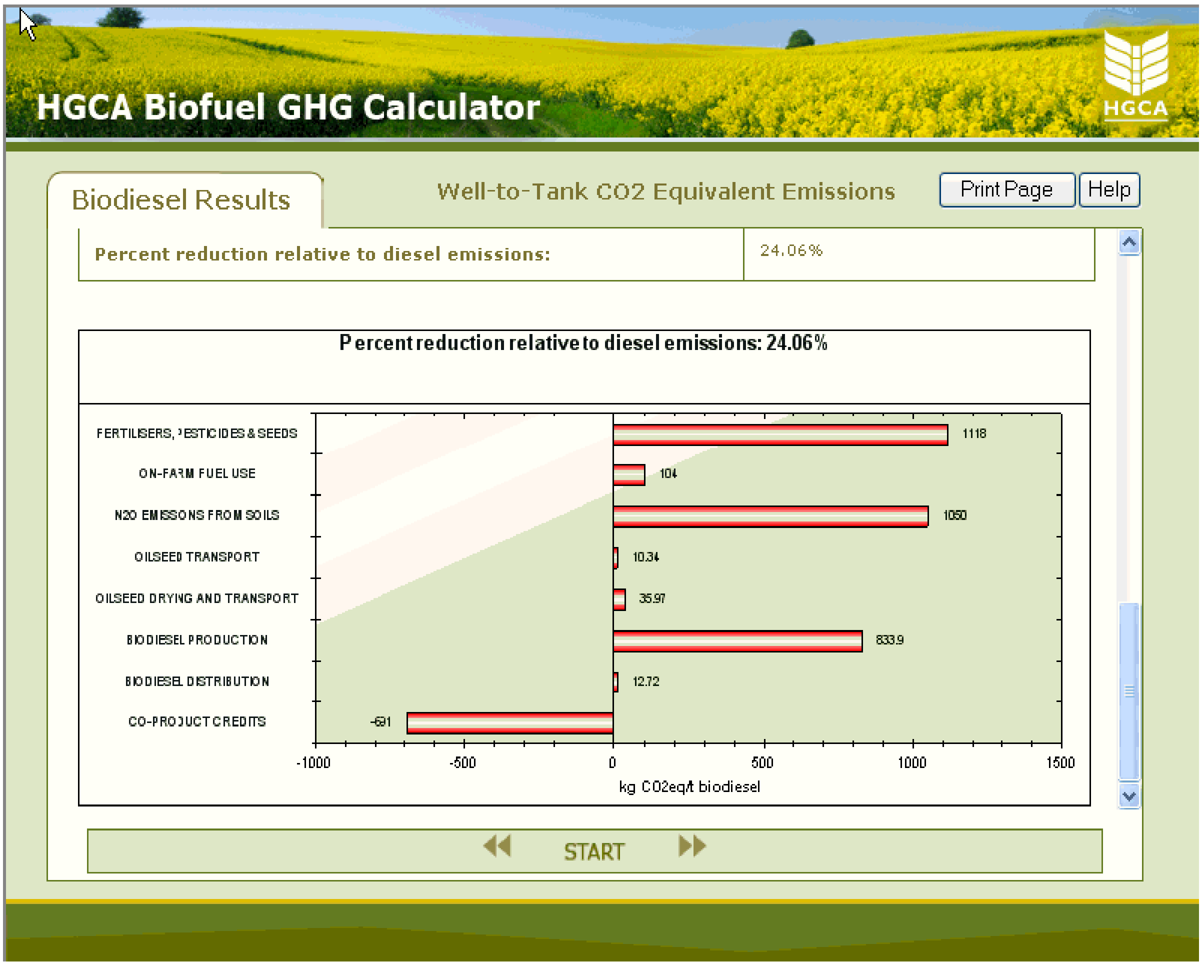

Figure 10: Bar chart summary sheet of GHG emissions in the biodiesel production chain of the HGCA online calculator

5 Farm audits

Farm audits have been developed with the aim of allowing the GHG emissions associated with the feedstock production for biofuels to be calculated at the farm-level. To date, two years of audits have been carried out by auditing body CMi using questionnaires developed in collaboration with Imperial College London. An overview of the rationale and key findings from the farm audits is presented in WP7 Farmer / Processor Best Practices Report.

The farm audits have been developed with two questions in mind, what information we would *like* from farmers, and what information can reasonably be *collected* from farmers. The audits have demonstrated that the majority of the desired information from farmers is readily available, but the problem has been interpreting this data. A wide variety of different practices are carried out on farms, and this has been easily recorded. However what influences these practices and what the GHG implications resulting from them are, is less certain.

The most influential GHG emissions factor, N fertiliser application rate, is highly variable, for example from 100 to 270kg/ha for oil seed rape. There is a pattern that, for organic soils, N fertiliser rates are significantly reduced, possibly due to the higher N levels present in the soil. However, the gains from the resulting lower emissions may need to be offset by increased carbon-based emissions resulting from the oxidation of the SOC in these high-organic-matter soils.

Cultivation options show no apparent relationship between soil or crop type, but are likely to be determined by previous cultivations, as well as local preferences / situations / habits. Using present GHG emission calculations, cultivation has relatively low emission factors, but further research on the role of cultivation in soil CO_2 and N_2O fluxes might alter this.

When more accurate information on the implications of different cultivation regimes, soil types and fertilisers is available, the audit system, together with the calculator, will allow accurate GHG assessments of each feedstock tonne. With this in mind, the next two steps are to allow farmers to 'virtually' farm their land, experimenting with different practices to create the lowest possible 'carbon tonne' of feedstock fuel, and also to potentially widen the scope of the audit system to include the whole farm, as discussed in Kindred, et al (2008).

6 The role of agriculture

The arrival of the UK Renewable Transport Fuels Obligation (April 2008) and the EU Renewable Energy Directive has focused attention on the need for farmers to supply the feedstocks needed to deliver low-GHG biofuels. EU farmers will have an opportunity to play major role in supplying the feedstocks and in demonstrating the methodologies needed to deliver low-GHG biofuels.

The Greenhouse Gas calculator highlights the main areas that farmers need to focus on to deliver those feedstocks. In particular, the most urgent need is to manage nitrogen fertiliser inputs by optimising the nitrogen requirements per unit of output whilst at the same time maintaining high yields. Part of delivering decreased nitrogen-use intensity could be achieved by selecting varieties that are inherently more appropriate for biofuel production and with lower nitrogen requirements e.g. high oil rapeseed or high-starch wheat (see WP7 for details). Additionally, choosing nitrogen fertiliser supplies that come from fertiliser manufacture plants with nitrous oxide abatement, and an increasing number of such plants are deploying this technology, could reduce feedstock-based GHG emissions by 25 to 30%[2].

In contrast to nitrogen fertiliser related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions; some gains could be made here, particularly by minimising cultivation operations. Other areas that could have a

[2] Assumes all the farm's nitrogen fertiliser use is as ammonium nitrate

substantial impact on each farm's emission factor include: land-use history, soil type, timing of field-operations, particularly nitrogen fertiliser applications and any drying operations.

Agriculture has an important role to play in ensuring that biofuels can provide a robust tool for climate change mitigation. However, to be credible, simple, practical and verifiable, tools that allow farmers to focus on the main components of biofuel supply chains over which they have control are urgently needed. The work carried out in this project aims to deliver a standardised, transparent and clear methodology for calculating both farm and whole-chain biofuel supply GHG balances. It has developed an integrated GHG calculator for biodiesel from rape (and bioethanol from wheat) and a new electronic questionnaire for farm audits. A major report, explaining and clarifying the nature and extent of the uncertainties surrounding the calculation of biofuel GHG balances has been produced in parallel to this report (Kindred et al, 2007c). By carrying out these activities, a major step towards on-farm GHG certification has been taken and near-term future developments should lead to a simple, robust and transparent audit questionnaire for direct use in biofuel feedstock assurance and certification.

7 Future research requirements

The research outlined in this report and in the parallel report on the uncertainties associated with such GHG calculations for biofuels (Kindred et al, 2008) highlights a number of important issues for the farming sector. It concludes that real gains are possible in reducing GHG emissions from UK feedstock-derived biofuels (biodiesel from rape and ethanol from wheat). Such gains are however, sensitive to location (including soil type and climate) and to management practices. In turn, this means that tools that are able to adequately monitor and account for these factors should allow farmers to target the main areas that will cost-effectively enable them to reduce the GHG emissions associated with biofuel feedstock provision.

On current evidence, biofuels can be produced in the UK in ways that result in substantially lower GHG emissions than the fossil fuel alternatives:

- For rape-to-biodiesel, reductions of between 18 and 39% are calculated by the GHG calculator.
- For wheat-to-ethanol, reductions of between 10 and 95% are calculated by the GHG calculator using UK-average agricultural factors.

The more efficient the conversion processes become in turning the feedstock into biofuels, the greater the share of the whole chain emissions will be from the feedstock production unless commensurate gains in efficiency are also seen in farming. Feedstock production is currently projected to account for between 50 to over 80% of the total GHG emissions of the biofuel supply chains covered, and is therefore the dominant source of emissions. The requirement for nitrogen emerges as the dominant source of GHG emissions from feedstock production:

- For biodiesel from rape, nitrogen inputs account for over 90% of the on-farm GHG emissions; nitrous oxide (N_2O) alone accounts for over 60% of those emissions.
- In contrast to nitrogen fertiliser related emissions, on-farm fuel, pesticide and seed supply-based emissions account for about 20% of the total farm-emissions.

It is important to note that substantial uncertainties exist in calculating the GHG emissions arising from land-based biological production systems. For biofuels, these uncertainties result from both the complexity of potential supply chains and in the scientific understanding of some of the mechanisms that result in the net production of greenhouse gases. This uncertainty is not unique to biofuel production and applies to all forms of land use including for food, materials and timber production. The systems needed to manage the uncertainty are being developed and include the GHG Calculator developed through this work.

Much of the potential reduction in GHG emissions for UK-sourced biofuels highlighted above, results from the way energy is produced and used in a biofuel conversion plant. The most substantial reductions in emissions result where co-products are used to produce heat and surplus electricity. As noted above, as emissions are reduced in the industrial sector the focus of emissions reduction will change to the farming sector. Here, savings from optimised use of N fertilisers in particular, location including soil type, and on management practices (particularly drying), will become increasingly important.

8 Conclusions

In order to maximise the potential benefits of an EU biofuels industry, and in particular to maximise GHG savings, there is a need to promote farm-level reporting of GHG emissions. The aim of this reporting would be to allow a share of the value arising from avoided GHG emissions to be retained by growers and to incentivise continued improvements in GHG intensity of biofuel crop production. The parallel development of the science-base and the practical tools necessary to implement farm-level GHG auditing are also required.

This work has shown that whilst there are a range of important issues that remain to be resolved before farm-level GHG (carbon) reporting can become basic farming practice, these issues are not insurmountable. The farm audit trials and development of the calculator show that it is possible to use data obtained directly from farms to get credible individual GHG intensities. The resulting improved levels of accuracy of reported GHG emissions will be incentivised in the UK RTFO through adoption of conservative default values for GHG intensities (E4Tech, 2006).

Issues of approach, such as co-product allocation procedures, have implications on the final carbon intensities and potentially on behaviour, though ultimately any approach adopted should accurately reflect reality without entailing excessive bureaucratic or regulatory burdens (see Kindred et al, 2008 for details). There is a need for consensus-building across stakeholders and the LCA community in the approaches adopted. Before such consensus emerges, a number of areas that cause the greatest uncertainty in GHG balance calculations need to be resolved. These are outlined below.

8.1 GHG calculator development

A GHG calculator has been developed through this work and it demonstrates that the integration of multiple biofuel supply chains is possible within a single, standardised methodology for GHG accounting for biofuels. Where possible and relevant, the same default factors and procedures have been used making cross-comparison between the chains possible. The calculator includes wheat-to-ethanol and rape-to-biodiesel options and other biofuel supply chain options could also be included.

The work confirms that substantial reductions in GHG emissions are possible through compound efficiency gains along 'conventional' biofuel supply chains in the UK.

Also highlighted is the need to continue research to reduce the uncertainty associated with current GHG balance calculations and to overcome the remaining obstacles to developing directly coupled farm auditing and GHG calculations.

8.2 Farm audit developments

During 2007, a second set of farm audits was carried out by CMi following on the audits carried out in 2006, providing an additional 100 audits to the 57 available from the previous year.

To our knowledge, the 2006 audits were the first example of this kind of auditing attempted anywhere in the world. The audits this year were developed using a simple questionnaire implemented in electronic spreadsheet format. They aimed to build on the success of the previous year by:

- Focusing the questions to be more tightly coupled to an integrated audit and GHG balance calculation
- Learning through feedback and by engaging with a wider farmer-base
- Developing a simple interactive interface
- Developing more accurate fossil fuel and soil factors

The audits have highlighted the large diversity in management approaches, input requirements and monitoring activities that occur on UK-farms. Despite this diversity it is possible to obtain most, if not all, of the relevant data required to calculate a robust GHG balance for biofuel feedstocks. Furthermore, a number of factors which affect the accuracy and confidence in the calculations are outside the capacity or control of farmers to influence and will require alternative mechanisms to gather and analyse the data required. Such factors include indirect land-use and direct and indirect nitrous oxide emissions.

Future audits should directly couple the GHG calculator to questionnaire but caution must be used in interpreting the results until a number of the uncertainties are resolved (see below).

8.3 Reducing and managing uncertainties

The uncertainties implicit in GHG accounting can be divided into those that predominantly stem from the approach taken (what actually happens), and those that are more technical in nature (e.g. scientific uncertainty in key emission factors and in indirect impacts). Much of the uncertainty lies in attempting to understand what level of detail is required in the monitoring and accounting procedures to provide a valid average for a field or farm level operation. There are also issues of fundamental scientific uncertainty where insufficient knowledge is available to provide an adequate level of precision. Despite these uncertainties sometimes being possibly large enough to change the outcome of the GHG balance, considerable knowledge will be gained through learning-by-doing. Indeed, it may not be possible to gain sufficiently broad data sets through any other means. The coupling of the GHG Calculator's development to the development of the farm audits has already helped to identify the nature and scope of the uncertainties and practical methods to account for and ameliorate a wide range of these factors as detailed in Kindred et al, 2008.

The biggest uncertainty surrounding GHG intensity concerns **N_2O emissions**. The IPCC approach advocated in the proposed RTFO Carbon reporting methodology (DfT 2007) provides the simplest, most transparent and defensible basis for quantifying N_2O emissions and may be suitable in the first instance. It is appropriate that emissions are driven by N fertiliser application. However, emissions from organic N sources (manures/compost/sludge), organic soils and crop residues are currently ignored. Accounting for N_2O emissions from these sources using an adapted IPCC approach seems likely to allow the fastest progress.

Regard will have to be given to potential consequences, intended or not, of on-farm practices that could result from untried accounting procedures. These issues will need to be reviewed before economic incentives are derived from low carbon intensities, or perverse practices could be encouraged.

In terms of producing a conservative methodology for dealing with N_2O emissions, it is recommended here that:

- Organic additions are accounted for using the IPCC approach on the basis of *available* N content rather than *total* N content.
- Crop residues are accounted for using the IPCC approach assuming a modest N addition that is included irrespective of yield, N fertiliser and whether or not straw is removed.
- That appropriately large emissions should be assumed for cropping on organic and humose soils.

There is a need to reconcile the IPCC approach to N_2O emissions, DNDC outputs and findings from recent work e.g. Crutzen *et al*. 2007. Whilst the work of Crutzen *et al.* (2007) suggests that real N_2O emissions from biofuel cropping may be higher than calculated from the IPCC approach, there is considerable evidence from field experimentation and modelling that the IPCC approach may significantly *overestimate* the real N_2O emissions from cropping in the UK. In this case, biofuel production in the UK could be unfairly penalised. Given the markedly different conditions and climates in different countries of production there is a need to evaluate whether using the same IPCC default emission factors for all countries is appropriate, or even for regions within a country. It would be possible to advocate a regional approach to N_2O emissions, using DNDC to calculate emissions from crop types in specific regions for specific soil types assuming certain N fertiliser and manure inputs. However, GHG emissions from farms producing crops with lower nitrogen inputs and hence, reduced N_2O emissions would not be fairly accounted for. Thus activities to reduce N_2O emissions would not be properly incentivised.

The most promising approach for the future for quantifying N_2O emissions on a farm-by-farm basis will be to use different emission factors for different scenarios, e.g. soil types, climates, regions, etc, as per Tier 2 of the IPCC methodology. Such emission factors could be derived using UK-DNDC in combination with experimental and field validation.

Generally, it will be important that changes to the approach used for quantifying N_2O emissions in carbon reporting methodologies can be made as more accurate approaches and emission factors are developed.

There is significant uncertainty over the **emission factors used for nitrogen fertiliser manufacture**. The different emission factors assumed in the RTFO draft Carbon Reporting methodology (Department for Transport, 2007) give substantially higher emission factors for ammonium nitrate manufacture over that of urea (6.8 versus 2.9 kg CO_2eq/kg N respectively). Such a difference potentially penalises countries where ammonium nitrate is predominantly used to provide nitrogen to crops, against other parts of the world. Given that many of the N fertiliser manufacturing plants in Western Europe are installing N_2O abatement technologies, there is a need to assess the difference in the GHG emissions of different N fertiliser products, to ensure that appropriate emission factors are used. Emerging data suggests that choosing nitrogen fertiliser supplies that come from fertiliser manufacture plants with nitrous oxide abatement could reduce feedstock-based GHG emissions by 25%[3].

It is also important that if the use of urea is effectively incentivised by carbon reporting methodologies that full consideration is given to the likely impacts on national and global ammonia emissions.

[3] Assumes all the farm's nitrogen fertiliser use is as ammonium nitrate

This research project also finds that there may be significant additional CO_2 emissions associated with the acidification of lime and chalk that have hitherto been ignored. The IPCC methodologies assume that CO_2 release only occurs from applied materials, and not from chalky soils. Calculations of CO_2 emissions on emission factors related to the acidifying nature of the nutrients applied may be needed in future. There is a need for further work to clarify this issue.

There is a good deal of uncertainty over the most appropriate default values to use for grain drying. There is also uncertainty surrounding the diesel used in farm cultivations, with the true benefits of minimal cultivation techniques on fuel use being unclear and difficult to quantify.

8.4 Identified research requirements

There are two broad areas of research needed with regard to developing the direct quantification of farm-level biofuel-based GHG balances. They can be split into issues that are solely relevant to biofuels and those that are required to understand the GHG impacts of agricultural production systems in general.

► ***Establish direct coupling between the farm audit questionnaire and the GHG calculator. The main areas to be resolved are:***

- Derive robust land-use change indicators (direct and indirect).
- Adequately quantifying actual energy use in cultivations.
- Develop methodologies for estimating energy use in grain drying.
- Fertiliser requirements and plant-available nutrient estimates throughout a rotation.
- Develop new combined audit and calculator.

The following issues are relevant to biofuels but also to any agricultural production system.

► ***Fertiliser management (mainly nitrogen) and impact assessments:***

- Provide detailed analyses of in-field N_2O emissions. Evaluate the appropriateness of the IPCC emission factors for N_2O emissions from EU arable biofuel cropping. Approaches for dealing with organic manures, crop residues, organic soils and baseline emissions from non-cropped land need to be developed and evaluated. Given the relative paucity of published data on N_2O emissions from arable soils, and the large expense of experimental N_2O measurement, the UK-DNDC model will be useful in answering these questions.

- There is a need to evaluate the most appropriate emission factors for fertiliser manufacture for ammonium nitrate and other N fertiliser products in the EU. The variation in manufacturing emissions between products, manufacturing plants and country of origin needs to be assessed.
- Exploration of how N fertiliser rates could be optimised for GHG savings could be very instructive for the agricultural and biofuels industry. The N fertiliser rates that maximise GHG savings should be determined, and the economic costs of optimising GHG savings should be assessed.
- The potential for using grain N% (or grain protein) as a 'signature' for GHG emissions from nitrogen needs to be evaluated.

► ***Quantify the CO_2 emissions resulting from the acidification of lime or calcareous soils. The current understanding in the literature needs to be reviewed, and there may be a need for experimentation.***

► ***Develop globally agreed standardised allocation procedures for co-products***

► ***Develop and employ standardised comparative reference systems – requires the development of a global land use inventory***

► ***Gain a better understanding of the links between investment in biofuel feedstock production with crop productivity***

8.5 Future developments

Whilst it is not possible to predict all the future developments likely to face the arable industry in the coming years, or to predict the possible ramifications of the emerging biofuel industry and carbon reporting, it is clear that given the right incentives, growers and the wider agricultural industry could make changes that would improve the GHG intensity of crops and the resulting biofuels. In order for these improvements to be made it will be important that the carbon / GHG reporting methodology allows for these changes to be fully accounted for. In turn, farmers need to know the conditions (climate, soils and management) under which the least-cost gains can be made.

Crop breeding and changes to fertiliser manufacture and application to land appear to provide the biggest and most immediate opportunities for improving GHG intensities. Whilst changes to yield and N fertiliser input can easily be accounted for in the GHG reporting methodology, as they are key input values; more subtle effects on biofuel processing efficiency are less easily accounted for.

Most of the changes that improve the GHG intensity of biofuel crops are equally applicable to reducing GHG emissions from arable cropping in general. It is possible that economic incentives to farmers could transpire through carbon trading mechanisms. The potential for this is being investigated in Defra project SFF0602.

For farmers to gain from the emerging policies directed at reducing GHG emissions on a national basis e.g. the Renewable Transport Fuels Obligation (RTFO) and the UK and European Emissions Trading Schemes (ETS), the sector needs to demonstrate transparent and practical methodologies for accounting for GHG emissions. The work highlighted here provides a pathway for delivering such an accounting system.

References

Crutzen, P. J. Mosier, A. R. Smith, K. A. & Winiwarter, W. (2007). N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics Discussions* 7, 11191–11205.Defra (2000). Energy use in organic farming systems (OF0182). Defra.

Defra (2007). The British Survey of Fertiliser Practice. Fertiliser Use on Farm Crops for Crop Year 2006, Defra, York, 2007.

Department for Transport (2007) “Carbon Reporting: Default Values and Fuel Chains” by A. Bauen, P. Watson and J. Howes, Version 1.2 for the Department for Transport, London, United Kingdom, 2 May 2007.

E4tech Bauen, A. Watson, P. & Howes, J. (2006). Methodology for Carbon Reporting under the Renewable Transport Fuel Obligation.

JEC (2007). *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context WELL-TO-TANK Report Version 2c, March 2007*

Kindred, D. Smith, T. C. Sylvester Bradley, R. Ginsburg, D. & Dyer, C. (2007a). Optimising nitrogen applications for wheat grown for the biofuels market. In *Project Report No. 417*. HGCA, London

Kindred, D. Weightman, R. Verhoeven, T. Swanston, J. S. & Brosnan, J. (2007b). Effects of variety and fertiliser nitrogen on alcohol yield, grain yield, starch and protein content, and protein composition of winter wheat. *Journal of Cereal Science*. In press: doi:10.1016/j.jcs.2007.07.010

Kindred, D. Mortimer, N. Sylvester-Bradley, R. Brown, G. & Woods, J. (2008). Understanding and managing uncertainties to improve biofuel GHG emissions calculations. HGCA, London.

LowCVP Punter, G. Rickeard, D. Larive, J. Edwards, R. Mortimer, N. Horne, R. Bauen, A. & Woods, J. (2004). WTW Evaluation for production of ethanol from wheat. In *FWG-P-04-024*: Low Carbon Vehicle Partnership.

Mortimer, N. D. Cormack, M. Elsayed, M. & Horne, R. (2003). Evaluation of the comparative energy, global warming and socio-economic costs and benefits of biodiesel. Resources Research Unit, Sheffield Hallam University.

Mortimer, N. D. & Elsayed, M. (2006). North East Biofuel Supply Chain Carbon Intensity Assessment. North Energy Associates.

Woods, J., Brown, G., Gathorne-Hardy, A., Sylvester-Bradley, R., Kindred, D. & Mortimer, N. (2008). Facilitating carbon (GHG) accreditation schemes for biofuels: feedstock production. Project 435, HGCA. London