Biofuels Review:

Greenhouse gas saving calculations

For the Renewable Fuels Agency

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1. Introduction

This note provides a brief summary of the methodology used to develop the following material which forms part of the main Gallagher Review report:

- Graphs illustrating the range of GHG savings which can be achieved by different biofuels if they did not cause indirect land use change
- Estimates of the GHG saving which could be achieved by biofuel policies in Europe and globally if they did not cause land use change
- Estimates of the variation in carbon payback time based on conversion of different types of land.

The purpose of this summary is to provide details on the assumptions made. It does not provide a rationale for these assumptions or illustrate, in detail, calculations carried out.

2. Range of GHG savings achieved by different biofuels

Two graphs illustrating the range of GHG savings which can be achieved by different biofuels were prepared.

2.1 Range of GHG saving from biofuels, by feedstock

The GHG savings of most biofuel chains were calculated using the methodology established for Carbon Reporting under the Renewable Transport Fuel Obligation (for further details, refer to: http://www.dft.gov.uk/rfa/reportsandpublications/carbonandsustainabilityguidance.cfm). However, the results given for the second generation biofuel chains (bioethanol from agricultural or forestry wastes; Fischer-Tropsch diesel from wood) were drawn from the JEC study (CONCAWE, EUCAR & JRC, 2006) – the results are broadly comparable as they use similar boundaries and co-product treatment methodologies.

High and low GHG saving scenarios were established for each feedstock, on the basis of actual or likely fuel chain configurations – rather than on technical possibility. The table below summarises the assumptions made for each scenario.

Fuel chain	**Low GHG saving scenario**	**High GHG saving scenario**
Bioethanol from wheat	Based on the RTFO default value for bioethanol produced from wheat sourced from France. Bioethanol plant located in the UK; uses a simple natural gas boiler to generate process heat	Based on the UK default value for bioethanol produced from wheat sourced from UK. Bioethanol plant located in the UK; uses a gas turbine to generate process heat and electricity – some of which is exported to the national grid

Fuel chain	**Low GHG saving scenario**	**High GHG saving scenario**
Bioethanol from sugar cane	Based on the RTFO default value for bioethanol produced from sugar cane in South Africa. This assumes coal is used as the fuel to provide process heat.	Based on the RTFO default value for bioethanol produced from sugar cane sourced in Brazil. In addition the bioethanol plant is assumed to export a small amount of electricity which displaces marginal baseload electricity generation (assumed to be natural gas-fired)
Bioethanol from molasses	Based on the RTFO default value for bioethanol produced from molasses in South Africa. This assumes coal is used as the fuel to provide process heat.	Based on the RTFO default value for bioethanol produced from molasses in the United Kingdom.
Bioethanol from corn	Based on the RTFO default value for bioethanol produced from corn in the USA. This assumes coal is used as the fuel to provide process heat, and that the bioethanol plant is based on a wet mill process.	Based on the RTFO default value for bioethanol produced from corn in the USA. However, it is assumed that natural gas replaces coal as the fuel used to provide process heat, and that it is used in a gas turbine which meets all internal process heat and electricity requirements (no export)
Biodiesel from oilseed rape	Based on the RTFO default value for biodiesel produced from oilseed rape grown in the Ukraine. In addition, it is assumed that coal is used as the fuel to provide process heat at the biodiesel plant.	Based on the RTFO default value for biodiesel produced from oilseed rape grown in Poland. In addition, it is assumed that the oil is crushed using a low-energy physical process rather than the default solvent extraction process. It is also assumed that the biodiesel plant uses waste biomass to generate heat.
Biodiesel from soya beans	Based on the RTFO default value for biodiesel produced from soya beans grown in Brazil. This assumes that the soya beans are transported from inland Brazil to the port using trucks. In addition, it is assumed that coal is used as the fuel to provide process heat at the biodiesel plant.	Based on the RTFO default value for biodiesel produced from soya beans grown in Argentina. In addition, it is assumed that the biodiesel plant uses waste biomass to generate heat.

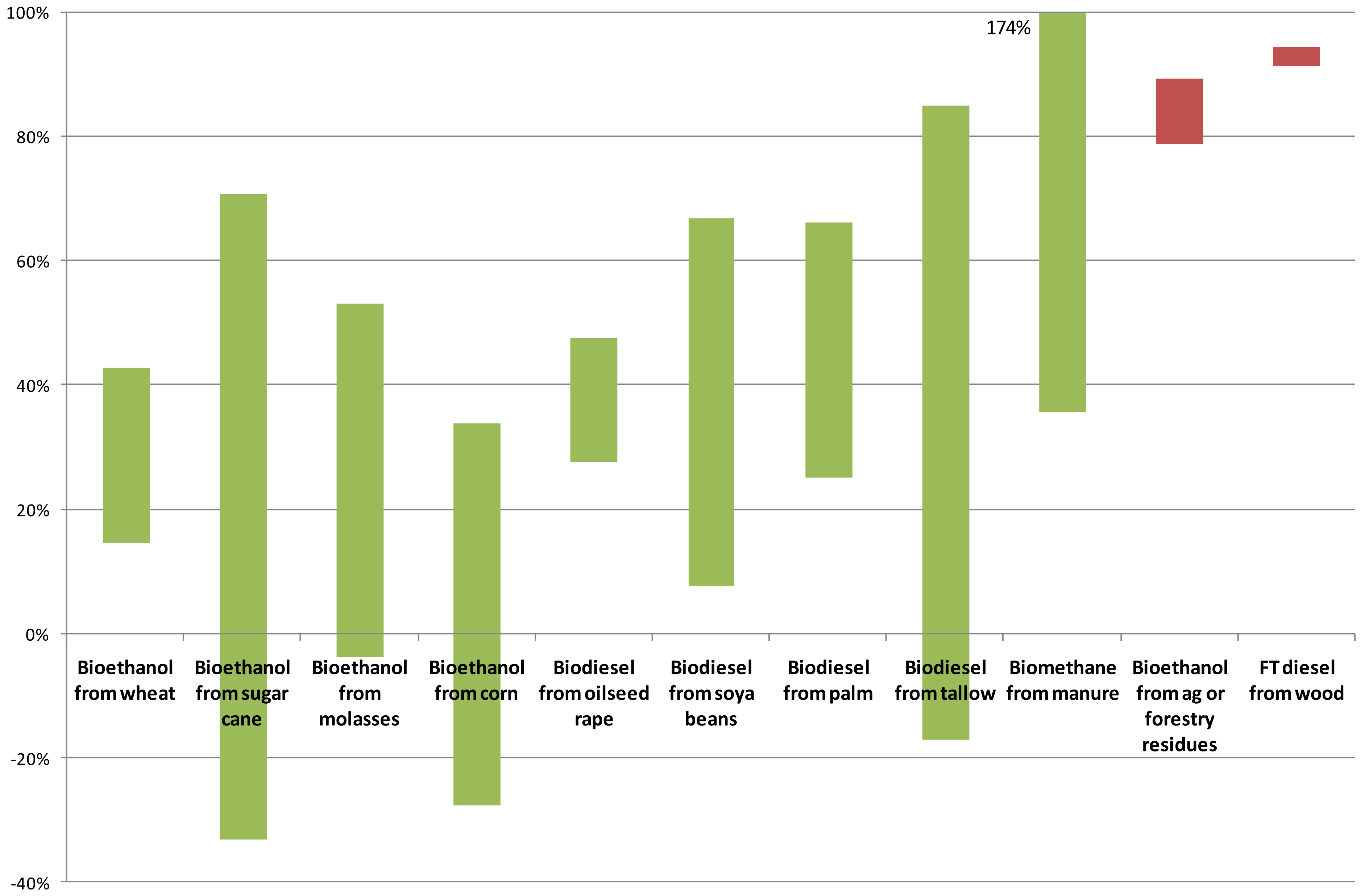
Fuel chain	**Low GHG saving scenario**	**High GHG saving scenario**
Biodiesel from palm	Based on the RTFO default value for biodiesel produced from palm grown in Malaysia. This assumes that the palm oil mill effluent anaerobically digests in open ponds, releasing methane to the atmosphere. In addition, it is assumed that heavy fuel oil is used to provide process heat at the mill, and coal is used to provide process heat at the biodiesel plant.	Based on the RTFO default value for biodiesel produced from palm grown in Indonesia. This assumes that the mill uses biomass wastes to provide heat and power at the mill. In addition, it is assumed that the palm oil mill effluent is digested in a closed system and flared. It is assumed that the biodiesel plant uses waste biomass to generate heat.
Biodiesel from tallow	Based on the RTFO default value for biodiesel produced from tallow sourced from the UK. In addition, it is assumed that the tallow used would previously have been burnt to provide process heat at the rendering plant, and is replaced by heavy fuel oil in this application. As a result, the GHG emissions from the heavy fuel oil are attributed to the biodiesel.	Based on the RTFO default value for biodiesel produced from tallow sourced from the UK.
Biomethane from manure	Based on the RTFO default value for biomethane produced from manure from the UK. In addition, it is assumed that the manure is trucked to the plant, on average, 100km.	Based on the RTFO default value for biomethane produced from manure from the UK. In addition, it is assumed that the biomethane plant receives a credit for the avoided methane emissions (based on: (CONCAWE, EUCAR & JRC, 2006)).
Bioethanol from ag or forestry residues	Based on (CONCAWE, EUCAR & JRC, 2006).	Based on (CONCAWE, EUCAR & JRC, 2006).
FT diesel from wood	Based on (CONCAWE, EUCAR & JRC, 2006).	Based on (CONCAWE, EUCAR & JRC, 2006).

2.2 Influence of technical fuel chain characteristics on GHG saving

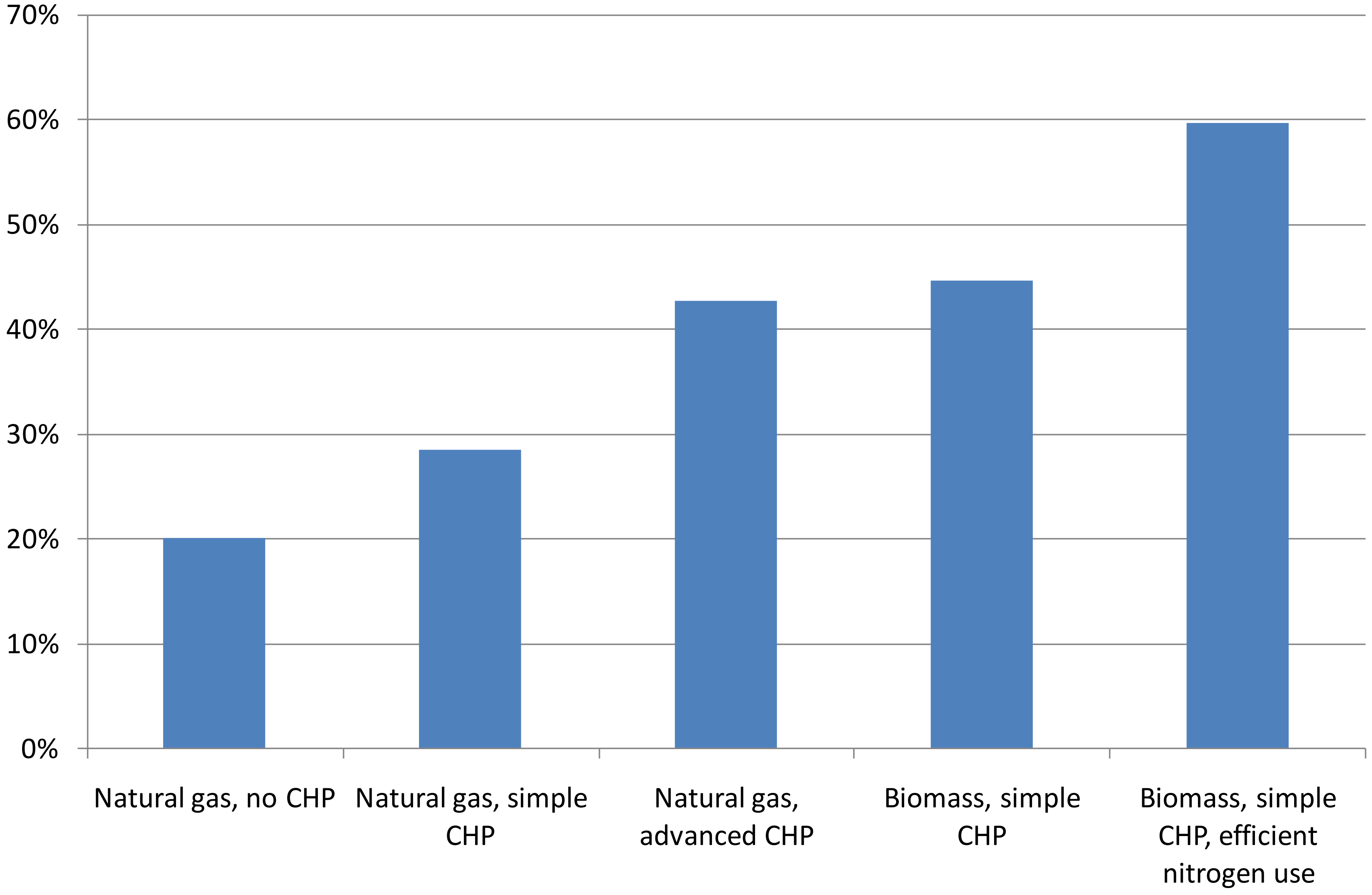
This graph shows how GHG savings from the wheat to bioethanol fuel chain can vary, based on technical characteristics of the chain. The GHG savings were calculated using the methodology established for Carbon Reporting under the Renewable Transport Fuel Obligation. The following assumptions were made:

- Natural gas, no CHP: process heat is provided by a simple boiler burning natural gas. All other values are based on the RTFO default fuel chain for bioethanol from UK wheat.
- Natural gas, simple CHP: process heat is provided by a natural gas-fired boiler and simple combined heat and power system (CHP) which generates sufficient electricity for internal plant needs but does not export any electricity. All other values are based on the RTFO default fuel chain for bioethanol from UK wheat.
- Natural gas, advanced CHP: process heat is provided by a natural gas turbine-based CHP system which results in export electricity. This exported electricity is assumed to displace marginal baseload electricity, assumed to be natural gas-fired.
- Biomass, simple CHP: process heat is provided by a biomass-fired boiler and simple CHP system which does not produce export electricity but meets internal plant needs. The biomass is assumed to be wheat straw, and its removal from fields is assumed to require additional fertiliser application (this is taken into account).
- Biomass, simple CHP, efficient nitrogen use: As above, however, it is assumed that fertiliser use has been optimised and higher yields of wheat have been achieved (e.g. through better timing of fertiliser application and improved wheat varieties). A yield of 13.5 t/ha is assumed, with a fertiliser application rate of 368 kg N (note: this fertiliser application rate allows for loss of nutrients due to removal of straw).

Graph 1 – Range of GHG saving from biofuels, by feedstock


100%
80%
60%
40%
20%
0%
-20%
-40%
174%
Bioethanol from wheat
Bioethanol from sugar cane
Bioethanol from molasses
Bioethanol from corn
Biodiesel from oilseed rape
Biodiesel from soya beans
Biodiesel from palm
Biodiesel from tallow
Biomethane from manure
Bioethanol from ag or forestry residues
FT diesel from wood

Graph 2 – Influence of technical fuel chain characteristics on GHG saving – bioethanol from UK wheat


70%
60%
50%
40%
30%
20%
10%
0%
Natural gas, no CHP
Natural gas, simple CHP
Natural gas, advanced CHP
Biomass, simple CHP
Biomass, simple CHP, efficient nitrogen use

3. GHG saving from biofuel policies

This section describes the estimation of potential GHG savings from biofuel policies in Europe and globally, assuming they have not caused any indirect land use change.

3.1 GHG saving from European biofuel policies

The savings resulting from the European Union 10% (by energy content) target are estimated to be approximately 54 – 68 million tonnes CO_2e.

The following assumptions were made:

- The feedstock mix was based on analysis carried out by the European Commission (see http://ec.europa.eu/agriculture/analysis/markets/biofuel/impact042007/text_en.pdf for further details) - details are provided in the table below.

- The GHG saving achieved by a biofuel chain was based on the best performing feedstock / origin default value from the UK RTFO default values. The lower estimate assumes that there is no improvement over time in the GHG saving of first generation biofuels, while the higher estimate assumes that there will be a 20 percent improvement.

Fuel chain	**Quantity of biofuel**	**Low per unit GHG saving**	**High per unit GHG saving**	**Low total GHG saving**	**High total GHG saving**
	Mtonne	**kg CO2e / GJ**	**kg CO2e / GJ**	**Mt CO2e**	**Mt CO2e**
Bioethanol from cassava	3	34.4	44.5	3	4
Bioethanol from wheat	18	25.6	37.4	12	18
Bioethanol from sugar beet	0	34.4	44.5	0	0
Bioethanol from sugar cane	44	60.0	64.9	70	76
Bioethanol from sorghum	1	60.0	64.9	2	2
Bioethanol from maize	22	35.6	45.4	21	27
Biodiesel from soya beans	10	38.8	48.3	15	19
Biodiesel from palm	10	39.6	48.9	14	18
Biodiesel from sunflower	0	41.2	50.2	1	1
Biodiesel from jatropha	7	39.6	48.9	10	13
Biodiesel from rapeseed oil	14	41.2	50.2	22	26
Lignocellulosic ethanol from bagasse	9	68.9	68.9	17	17
Lignocellulosic ethanol from wood residues	20	68.9	68.9	37	37
Lignocellulosic ethanol from agricultural residues	40	68.9	68.9	73	73
FT (or syn) diesel from bagasse	0	83.5	83.5	0	0
FT (or syn) diesel from wood residues	8	83.5	83.5	29	29
FT (or syn) diesel from Agricultural residues	3	83.5	83.5	12	12
TOTAL	**209.7**	**-**	**-**	**338**	**371**

3.2 GHG saving from global biofuel policies

The savings resulting from the global biofuel policies are estimated to be approximately 338 – 371 million tonnes CO_2e.

This estimate is based on the “2020 scenario 2” detailed further in the report “*Biofuels Review: Scenario development*”. This scenario explores the impact of volume based targets that different regions may put in place by 2020 and how these targets might be met if second generation biofuels are available.

Fuel chain	**Quantity of biofuel**	**Low GHG saving**	**High GHG saving**	**Low GHG saving**	**High GHG saving**
	Mtonne	**kg CO2e / GJ**	**kg CO2e / GJ**	**Mt CO2e**	**Mt CO2e**
Bioethanol from cassava	0.0	34.4	44.5	0	0
Bioethanol from wheat	12.4	25.6	37.4	8	12
Bioethanol from sugar beet	0.2	34.4	44.5	0	0
Bioethanol from sugar cane	2.0	60.0	64.9	3	3
Bioethanol from sorghum	0.0	60.0	64.9	0	0
Bioethanol from maize	4.5	35.6	45.4	4	6
Biodiesel from soya beans	3.4	38.8	48.3	5	6
Biodiesel from palm	0.6	39.6	48.9	1	1
Biodiesel from sunflower	1.3	41.2	50.2	2	2
Biodiesel from jatropha	0.0	39.6	48.9	0	0
Biodiesel from rapeseed oil	19.9	41.2	50.2	31	37
Lignocellulosic ethanol from bagasse	0.0	68.9	68.9	0	0
Lignocellulosic ethanol from wood residues	0.0	68.9	68.9	0	0
Lignocellulosic ethanol from agricultural residues	0.0	68.9	68.9	0	0
FT (or syn) diesel from bagasse	0.0	83.5	83.5	0	0
FT (or syn) diesel from wood residues	0.0	83.5	83.5	0	0
FT (or syn) diesel from Agricultural residues	0.0	83.5	83.5	0	0
TOTAL	**44.3**	**-**	**-**	**54**	**68**

4. Estimates of the variation in carbon payback time based on different types of land use conversion.

The following table illustrates the impact on carbon payback times of converting different types of land to biofuel production.

Fuel chain	**Assumed country of origin**	**GHG saving excluding the impacts of land use change**	**Carbon payback (years)**	
		%	**Grassland**	**Forest**
Palm to biodiesel	Malaysia	46%	2 - 39	65 - 138
Soya to biodiesel	USA	33%	51 - 350	655 - 1763
Sugarcane to bioethanol	Brazil	71%	11 - 37	56 - 144
Wheat to bioethanol	UK	28%	72 - 123	293 - 514

Calculation of the carbon payback time requires knowledge of both:

- The GHG saving of the biofuel (compared with fossil fuels) excluding any land use change impacts, and
- The GHG emissions resulting from land use change.

RTFO fuel chain default values were used for the GHG saving of the biofuel. The GHG emissions resulting from land use change were based on the RTFO land use change default values (which are calculated following the IPCC guidelines[1], but the most influential underlying parameters were varied to obtain best and worst case scenarios for land use change emissions in each of the countries considered. In the case of conversions from grassland, the most important assumption is the soil carbon stock of the land use before it is converted (based on soil type). In the case of conversions from forest land, there are two factors which are important: the initial biomass carbon stock (i.e. the type of trees) and the soil carbon stock prior to conversion.

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[1] see (IPCC, 2006) and http://www.dft.gov.uk/rfa/reportsandpublications/carbonandsustainabilityguidance.cfm

5. References

CONCAWE, EUCAR & JRC. (2006). *Well to wheels analysis of future automotive fuels and powertrains in the European context.* CONCAWE, EUCAR & JRC.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme (H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.) Japan.: IGES.