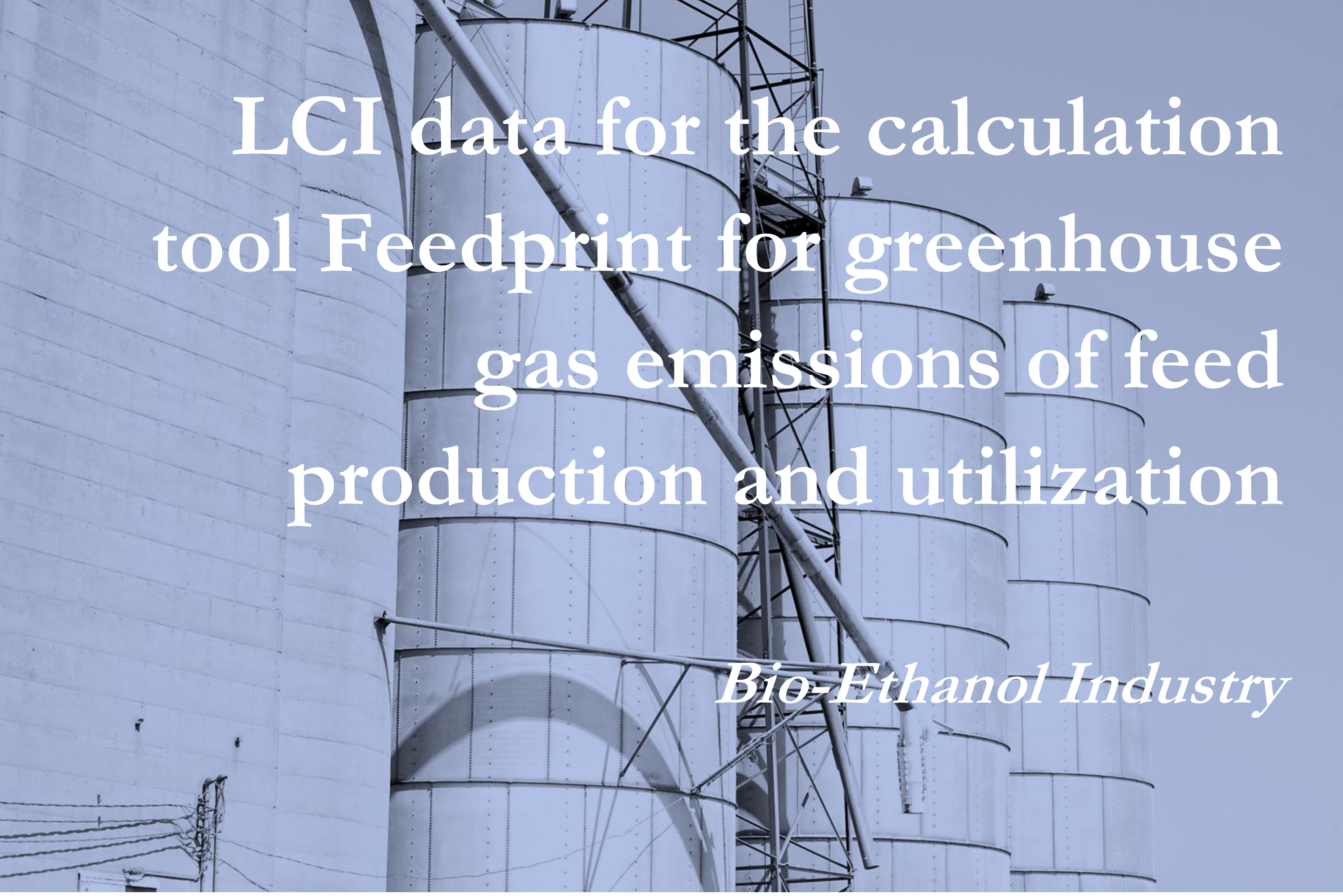

LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization

Bio-Ethanol Industry

W.J. van Zeist[1]

M. Marinussen[1]

R. Broekema[1]

E. Groen[1]

A. Kool[1]

M. Dolman[2]

H. Blonk[1]

[1] Blonk Consultants

[2] Wageningen University and Research Centre

November, 2012

blonk consultants

Blonk Consultants
Gravin Beatrixstraat 34
2805 PJ Gouda
the Netherlands
Telephone: 0031 (0)182 579970
Email: info@blonkconsultants.nl
Internet: www.blonkconsultants.nl

LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization

Bio-Ethanol Industry

W.J. van Zeist[1]
M. Marinussen[1]
R. Broekema[1]
E. Groen[1]
A. Kool[1]
M. Dolman[2]
H. Blonk[1]

[1] Blonk Consultants
[2] Wageningen University and Research Centre

November, 2012

blonk consultants

Table of contents

3.1 Introduction

3.1.1 Context of this document & reading guide

This document is part of the background documentation for the FeedPrint program and database. Background information of this project, underlying methodology and justification thereof, can be found in the 'FeedPrint methodology' document. These chapters focus only on the processing step of crops into the feed materials. Information on origin of crops is given, but details on cultivation and transportation (to and from the processing facility) are described in separate documents: the cultivation of each crop is described in the cultivation background reports similar to this one (Marinussen et al, 2012), whereas transportation is described in the Feedprint methodology report (Vellinga et al, 2012).

Each chapter can be read and interpreted as a standalone set of LCI data, which covers the country of crop cultivation, the country of processing, mass balances, energy inputs (and outputs, if applicable), as well as data needed for the allocation of the by-products. In some cases, multiple processes can follow one another with multiple allocation steps. In these cases, the data is entered into the database by following these specific processing steps consecutively. Usually (but not restrictively) the data entered are relative to an input of 1000 kg of crop product.

3.1.2 Overview of products and allocation principles

Each chapter in this document describes a bio-ethanol production process with different animal feed materials as by-products. The wet intermediate by-products are considered to be a residue and are treated according to allocation approach 3 (see chapter §5.3, Vellinga et al, 2012). A considerable amount of energy is required to dry these by-products, and the energy inputs will be specifically allocated towards the dried final products.

3.1.3 Structure of data

This document contains tables that reflect those data applied in the FeedPrint program. Additionally, tables with background data are supplied, which are often inventories of encountered literature. Only the tables that are used as data for the FeedPrint database and calculations are given a table number (see for an example Table 3.1.1). Other tables that are not used in the FeedPrint database are not numbered and have a simpler layout, see the example below.

Table 3.1.1 Example default inputs table for FeedPrint database.

Output	Values		Unit
	Best estimate	Error (σ_g^2)	
Electricity	88	1.4	MJ/ton
Natural gas	245	1.4	MJ/ton

Example of background data not directly used in FeedPrint database

Source	Data found	Remarks
Reference 1	80 MJ/ton	Older data from 1 processing facility.
Reference 2	90 MJ/ton	Newer data from multiple facilities.

There are a number of recurring types of tables, usually in the following order:

1) Definition of feed materials related to the process;
2) Estimation of countries of origin of the crop and countries of processing;
3) Mass balances for the process;
4) Energy or material inputs needed for the process;

5) Allocation factors for the outputs from the process.

Unless explained otherwise in a specific chapter, these five tables are present for each process. Additional sections or figures can give information on, for example, the definition of the process represented with a flowchart. Each section also contains the references for cited sources. The usual structure of a section is that first the default inputs for the FeedPrint database are presented, with the rest of the section explaining in detail which data sources were used and why.

There are a number of different types of error ranges that can be given for each data point, and these are applied for the energy and auxiliary inputs. More background information can be found in the overall methodology document (Vellinga et al. 2012), which also explains the decision process followed to arrive at the error ranges.

3.1.4 Glossary of terms

Below is a list of terms with definitions as applied in this document.

DMC	Dry matter content in g/kg.
GE	Gross Energy content in MJ/kg.

3.1.5 References

CVB-table: see appendix 1 in Vellinga et al. (2012)

European Commission. (2011). COMMISSION REGULATION (EU) No 575 / 2011 of 16 June 2011 on the Catalogue of feed materials. Official Journal of the European Union, (L 159), 25–65.

Marinussen et al (2012) Background data documents on cultivation. Blonk Consultants. Gouda, the Netherlands

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands.

3.2 Bio-ethanol from maize

3.2.1 By-products from bio-ethanol production from maize

Bio-ethanol is produced by fermentation of sugars. Every carbon hydrate chain can be used, where short chains can be fermented directly and complex chains have to be shortened firstly by hydrolysis. By historical, financial and practical reasons the most common sources for deriving bio-ethanol are sugar cane (South America, Brazil), maize (in USA more than 90% of bio-ethanol is derived from corn), wheat and sugar beet. In Dutch feed industry by-products from bio-ethanol produced in Europe derived from wheat, maize and sugar beet are most common. The feed raw material derived from bio-ethanol production from maize is Distillers Dried Grains and Solubles:

Table 3.2.1 Feed raw materials derived from bio-ethanol production from mazie in Europe according to the CVB.

name	DMC (g/kg)
Concentrated Distillers Solubles	200
Distillers solubles fresh	72
Dried Distillers Grains and Solubles	901

The by-product Distillers Grains and Solubles is mostly abbreviated as DGS. Before use as ingredient for compound feed the DGS is dried, resulting in Dried Distillers Grains and Solubles; DDGS. DGS can also be used as wet feed in rations for cattle. Concentrated distillers solubles is and intermediate form with a dry matter content ranging from 20 to 45 percent[1]. For allocation purposes it will be treated as a wet by product, similar to the fresh solubles. These can both be considered to be wet varieties of the DDGS.

3.2.2 Sourcing

The biggest bio-ethanol from maize producing country is by far the USA. Nevertheless imports of DDGS from the USA is very much limited because it originates from GMO-maize. In Europe the top three bio-ethanol producing countries in 2009 are France, Germany and Spain representing 2/3 of the total European bio-ethanol production of 3,7 billion litres (Epure, 2011). In the Netherlands a relatively small production plant (14 million litres, Nedalco in Bergen op Zoom) and one new plant in Rotterdam (Abengoa) with a capacity of 480 million litres are operational. Relatively close to the Netherlands in Wanze, Belgium another relatively big bio-ethanol plant is operational (BioWanze). This plant has a capacity of 300 million litres.

No detailed information is available about the countries and or specific plants from which the Dutch industry sources DDGS from bio-ethanol production out of maize. Because a big part of the European DDGS production is situated in surrounding countries as France, Germany and Belgium we assume that the majority of the DDGS from maize is also sourced from these countries.

Table 3.2.2. Estimated countries of origin of feed materials.

Processing in:	France	Belgium	Germany	Netherlands
percentage	30%	30%	30%	10%
Crop-country				
Germany			100%	
France	100%			

[1] See http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm or http://www.extension.org/pages/39513/what-are-corn-condensed-distillers-solubles

Belgium	100%	
Netherlands		100%

3.2.3 Mass balance

After milling the corn alcohol is produced (ethanol content of 8 - 10%) by hydrolysis and fermentation of the flour. A by-product of this stage is carbon dioxide, which is marketed in some cases. Distillation and dehydration results in the bio-ethanol. The stillage from distillation is considered as a wet intermediate is dried resulting in DDGS, which is used as feed component. Considering this, for the purpose of the LCI data, no mass balance is necessary, as we start the description of the process at the wet by-product.

3.2.4 Inputs

Below are the default energy input data for drying DDGS. As explained in the remainder of the text, the overall energy use of the bio-ehtanol production facility is not taken into account. Before the drying step, allocation takes places with the wet DGS having no upstream emission associated. After which the energy input for DDGS drying (Table 3.2.3) is specifically attributed to DDGS.

Table 3.2.3 Default input data for drying DDGS (expressed per ton dried DDGS as output)

	parameter	Best estimate	Min	Max	unit
Energy use (DDGS drying only)	natural gas	3750	3400	4800	MJ/tonne DDGS

Although LCI data for the production of bio-ethanol from maize is available (see the references section) none of these list energy costs specifically for the drying step. Because of this, the drying energy found for distillers grain from wheat processing was used. These values are mainly based on Punter et al, 2004, and are described in section 3.4.

3.2.5 Allocation

As prior to drying the wet DGS is considered a low value by-product according to appraoch 3 as described in the methodology document (see §5.3, Vellinga et al, 2012), which means that all upstream emissions are allocated towards Ethanol. After this allocation step, the drying of DDGS is to be attributed to this by-product specifically.

3.2.6 References

Anonymous 2006. An Assessment of the Potential for Energy Savings in Dry Mill Ethanol Plants from the Use of Combined Heat and Power (CHP). Energy and Environmental Analysis

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

Kim, S. & B.E. Dale 2009. Regional variations in greenhouse gas emissions of biobased products in the United States-corn based ethanol and soybeanoil. In: International Journal of Life Cycle Assessment vol. 14, pag. 540 – 546.

Kim, S. en B.E. Dale 2007. Life cycle assessment of fuel ethanol derived from corn grain via dry milling. Bioresource technology 99(12):5250-60.

Liska, A.J., H.S. Yang, V.R. Bremer, T.J. Klopfenstein, D.T. Walters, G.E. Erickson and K.G. Gassman 2008. Improvements in Life Cycle Efficiency and Greenhouse Gas Emissions of Corn-Ethanol. In: Journal of Industrial Ecology, Vol. 13, pag 58-74.

Malça, J. & F. Freire 2006. Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation. In: Energy, Vol 31, pag 3362 – 3380.

McAloon, A., F. Taylor, W. Yee, K. Ibsen and R. Wooley 2000. Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks. National Renewable Energy Laboratory, Colorado.

Mortimer, N. D., M. A. Elsayed and R. E. Horne 2004. Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet:, Resources Research Unit, Sheffield Hallam University. Final Report for British Sugar, Report No 23/1, January 2004.

Mueller, S. 2010 Detailed report: 2008 National Dry Mill Corn Ethanol Survey. Energy Resources Centre, University of Illinois, Chicago.

Mueller, S., K. Copenhaver and M. Wander 2008. The Global Warming and Land Use Impact of Corn Ethanol Produced at the Illinois River Energy Center. University of Illinois, Chicago.

Punter, G., D. Rickeard, J.F. Larivé, R. Edwards, N. Mortimer, R. Horne, A. Bauen and J. Woods 2004. Well-to-Wheel Evaluation for Production of Ethanol from Wheat. Low CVP Fuels Working Group.

Shapouri, H., J.A. Duffield and M. Wang 2002. The Energy Balance of Corn Ethanol: An Update. U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report No. 813.

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands.

Wu, M. 2008. Analysis of the Efficiency of the U.S. Ethanol Industry 2007. Center for Transportation Research, Argonne National Laboratory.

3.3 Bio-ethanol production from beet molasses

3.3.1 By-products from bio-ethanol production from beet molasses

Vinasse is a by-product of bio-ethanol production from sugar beets. Bio ethanol can be formed either from directly from the sugar beet (sugar thick juice) or from molasses which is a by-product from the sugar extraction from beets. Vinasse can be used as animal feed component or bio-fuel (vinasse can be used in digesters to produce biogas).

Table 3.3.1 Feed raw materials derived from bio-ethanol production from wheat in Europe according to the CVB and EU catalogue.

name	DMC (g/kg)
Vinasse Ruw Eiwit < 250	663
Vinasse Ruw Eiwit > 250	696

3.3.2 Sourcing and

The Dutch feed industry source the sugar products mainly from the countries listed in Table 3.3.2. The beet cultivation generally takes place in the same country of processing.

Table 3.3.2 Estimated countries of origin of feed materials.

Phase	the Netherlands	Germany
Processing	90%	10%
Crop cultivation in the Netherlands	100%	0%
Crop cultivation in Germany	0%	100%

3.3.3 Mass balance

Vinasse is produced during the ethanol production from either sugar beet directly, or from molasses originating from sugar production (see also the chapter on sugar production from sugar beet). Below is the default mass balance for bio-ethanol production. These values will be underpinned in the remainder of the text.

*Table 3.3.3 Mass balance for the production of Vinasse**

Input:	DMC (g/kg)	Mass (kg)
Molasses	820	1000
Output:		
Bio-ethanol	1000	245
Vinasse	680	525
Carbon dioxide	1000	~250

* Please note that, as the wet vinasse is considered a low value by-product, only the drying step of vinasse is taken into account, an no allocation between the products in this mass balance takes place.

The default mass balance is based on information found in the econinvent report on Life Cycle Analysis of Bioenergy (recalculated with vinasse set at 68% dry matter compared to 58% reported in ecoinvent). A number of different mass balances have been found which vary mainly due to differences in molasses and vinasse moistere and/or sugar content.

For sucrose, the relevant chemical reaction for the production of ethanol is as follows (included are molecular weights):

$C_{12}H_{22}O_{11}$ (*342.30*) + H_2O (*18.02*) → 4 C_2H_5OH (*46.07*) + 4 CO_2 (*44.01*)

From the chemical conversions of sugar into ethanol a theoretical maximum amount of ethanol produced can be deduced and this amounts to 538 kg ethanol from 1000 kg sucrose or 511 kg ethanol from 1000 kg glucose. These values are used as a comparison to various sources describing ethanol production. Using an approximate sucrose content of around 50% (see for example ecoinvent or van Razmovski & Vucurovic, 2012), this equates to 270 kg ethanol/t molasses. The amount of vinasse then produced can in principle be calculated from the remaining dry matter after ethanol production, but this is highly dependent on both the efficiency and initial dry matter and sugar content. It was decided to use the ecoinvent mass balance, which was the only mass balance encountered with a detailed dry matter content description.

Source	Vinasse yield	Ethanol yield (kg ethanol/t sugars (sucrose))	Ethanol yield per ton beet molasses (kg ethanol/t molasses)	% compared to maximum yield
Theoretical maximum yield		538	270	100%
Ecoinvent (2007)	614 (58% dm)		245	86%
Chul Park & Baratti (1992)		420 - 480		78% - 89%
Maung & Gustafson (2011)			260	96%
Shapouri et al. (2006)		464	232	86%
Olbrich (1963)			249	92%

3.3.4 Inputs

Below are the default energy input data for the drying step of vinasse. Since the intermediate wet molasses (the dry matter content of which is not exactly known and may vary) is considered a low value residue by-product, no upstream allocation takes place and only the drying step is taken into account.

Table 3.3.4 Energy input data for drying vinasse, values for 525 kg vinasse produced (680 g/kg dry matter content)

parameter	Best estimate	Min	Max	unit
Natural gas	2350	2000	3200	MJ/tonne molasses
Electricity	153	1.3 (error, lognormal)		MJ/tonne molasses

Ecoinvent describes processing of vinasse specifically as 42.6 kWh electricity and 2128 MJ heat required for the production of 614.3 kg of vinasse at 58% dry matter from 1 tonne of molasses. For heat produced at 90% efficiency this relates to approximately 2350 MJ of natural gas required. These values from ecoinvent are the only values encountered in public literature on drying of vinasse.

Common energies for drying food substances range from 3000 to 6000 MJ per tonne water evaporated. As there is still approximately 150 kgs of water to be evaporated in going from 58% to 68% dry matter, resulating in a maximum of 900 MJ in the most pessimistic scenario. This results in the maximum set at 3000 MJ while the minimum is set somewhat below this value.

3.3.1 Allocation

As prior to drying the vinasse is considered a low value by-product according to appraoch 3 as described in the methodology document (see §5.3, Vellinga et al, 2012), which means that all upstream emissions are allocated towards the other products. After this allocation step, the drying energy is attributed to this by-product specifically.

3.3.2 **Refereces**

Chul Park, S. & J.C. Baratti 1992. Continuous Ethanol Production from Sugar Beet Molasses Using an Osmotolerant Mutant Strain of *Zymomonas mobilis. In: Journal of Fermentation and Bioengineering, vol. 37, pag. 16-21.*

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

Econinvent, 2007. Background report 17 – Life cycle analysis of bioenergy. Swiss Centre for Life Cycle Inventories.

Epure 2012, website visited at 5 jan 2012: www.epure.org. Renewable Ethanol: Producing Food AND Fuel

Maung, T.A. & C.R. Gustafson 2011. The economic feasibility of sugar beet biofuel production in central North Dakota. In: Biomass and Bioenergy, vol. 35, pag. 3737 – 3747.

NFU Sugar UK Beet Sugar Industry Sustainability Report 2011

Olbrich, H. 1963 Molasses. Publish by Biotechnologie-Kempe GmbH (2006)

Razmovski, R. & V. Vucurovic 2012. Bioethanol production from sugar beet molasses and thick juice using *Saccharomyces cerevisiae* immobilized on maize stem ground tissue. In: Fuel, vol. 92, pag. 1 – 8.

Shapouri, H., M. Salassi & J. N. Fairbanks 2006. The economic Feasability of ethanol production from sugar in the United States. USDA.

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands.

3.4 Bio-ethanol from wheat

3.4.1 By-products from bio-ethanol production from wheat

Bio-ethanol is produced by fermentation of sugars. Every carbon hydrate chain can be used, where short chains can be fermented directly and complex chains have to be shortened firstly by hydrolysis. By historical, financial and practical reasons the most common sources for deriving bio-ethanol are sugar cane (South America, Brazil), maize (in USA more than 90% of bio-ethanol is derived from corn), wheat and sugar beet. In Dutch feed industry by-products from bio-ethanol produced in Europe derived from wheat, maize and sugar beet are most common. Feed raw materials derived from bio-ethanol production from wheat are summarized in Table 7-1:

Table 3.4.1 Feed raw materials derived from bio-ethanol production from wheat in Europe according to the CVB table.

name	DMC (g/kg)
Concentrated Distillers Solubles	
Distillers solubles fresh	72
Dried Distillers Grains and Solubles	901

The by-product Distillers Grains and Solubles is mostly abbreviated as DGS. Before use as ingredient for compound feed the DGS is dried, resulting in Dried Distillers Grains and Solubles; DDGS. DGS can also be used as wet feed in rations for cattle. The energy of concentrated distillers solubles is and intermediate form with a dry matter content ranging from 20 to 45 percent[2]. For allocation purposes it will be treated as a wet by product, similar to the fresh solubles. These can both be considered to be wet varieties of the DDGS.

3.4.2 Sourcing

In Europe the top three bio-ethanol producing countries in 2009 are France, Germany and Spain representing 2/3 of the total European bio-ethanol production of 3,7 billion litres (Epure, 2011). In the Netherlands a relatively small production plant (14 million litres, Nedalco in Bergen op Zoom) and one new plant in Rotterdam (Abengoa) with a capacity of 480 million litres is operational. Relatively close to the Netherlands in Wanze Belgium another relatively big bio-ethanol plant is operational (BioWanze). This plant has a capacity of 300 million litres.

No detailed information is available about the countries and or specific plants from which the Dutch industry sources DDGS. Because a big part of the European DDGS production is situated in surrounding countries as France, Germany and Belgium we assume that the majority of the DDGS from wheat is also sourced from these countries.

Table 3.4.2 Estimated countries of origin of feed materials.

Processing in:	France	Belgium	Germany
percentage	33%	33%	34%
Crop-country			
France	100%	50%	
Germany		50%	80%
Denmark			20%

[2] See http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm or http://www.extension.org/pages/39513/what-are-corn-condensed-distillers-solubles

3.4.3 Flowchart

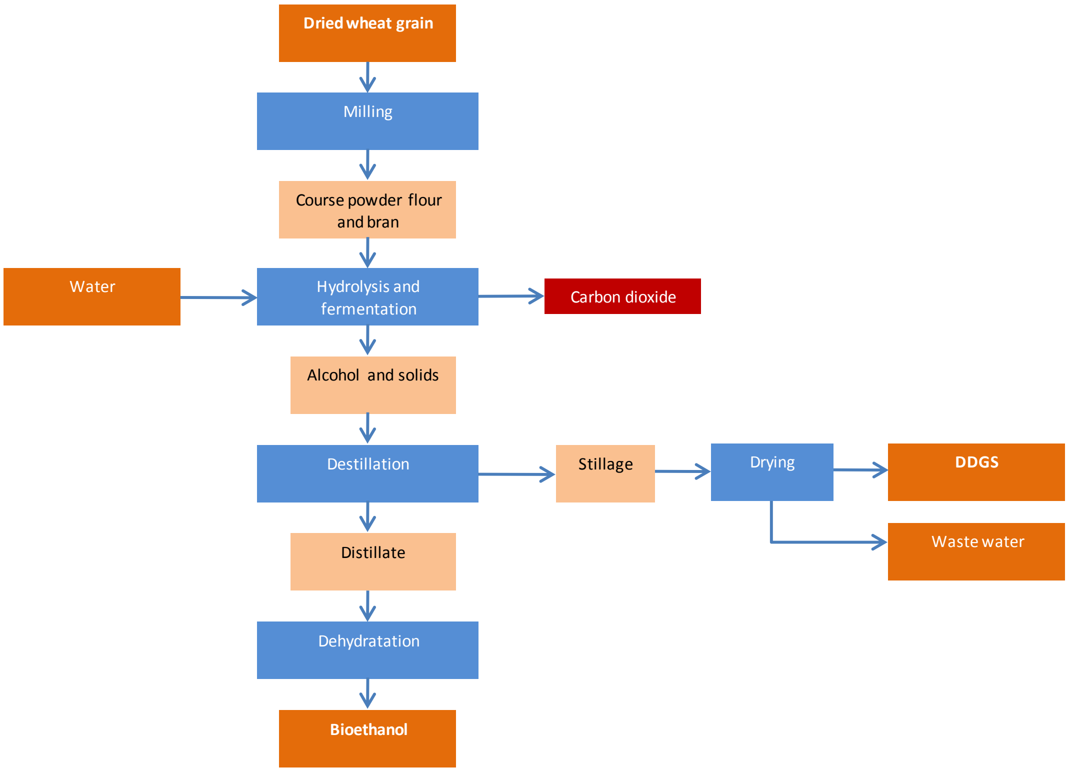

Figure 3.4.1 Flowchart of bio-ethanol production from wheat, reference: Mortimer ea (2004) and Punter ea (2004)

Wheat is dried at 3% water content before entering the bio-ethanol plant. After milling the wheat, alcohol is produced (ethanol content of 8 - 10%) by hydrolysis and fermentation of the flour. A by-product of this stage is carbon dioxide, which is marketed in some cases. The new bio-ethanol plant in Rotterdam, the Netherlands will export the produced CO_2 to greenhouses as CO_2 fertilizing.[3] However, in our current allocation methodology (no upstream emissions towards wet DGS), only the drying step is taken into account and for our current purposes this is of no consequence.

Distillation and dehydration results in the bio-ethanol. The stillage from distillation is dried resulting in DDGS, which is used as feed component. Drying of DGS is a particularly energy intensive part of the process.

3.4.4 Mass balance

Below is the default mass balance for bio-ethanol production. These values will be underpinned in the remainder of the text.

Table 3.4.3 Default mass balance

Input:	DMC (g/kg)	Mass (kg)
Dry wheat grain	970	1000
Output:		
Bio-ethanol	1000	330
DDGS	900	376

3 http://www. archief.degroentenenfruit.nl/groentenenfruit/2010/08/24/nummer-34/Bio-ethanolfabriek-is-tweede-bron-voor-Ocap.htm

The table below shows mass balances from various sources. Choices for the best estimates in the default mass balance are underpinned in the next section. Recalculated, the wet precursor (at 7.2 % dry matter, would have a mass of 4130 kg in the best estimate.

Mass balance of bio ethanol production from wheat according to different sources

	Product	Punter ea (2004)	Schepens (2009)	Malça & Freire (2006)
IN:	Dry wheat grain	1000 (97% dm)	1000 (unknown dm)	1000 (unknown dm)
	Water	3300		
OUT:	Bio-ethanol	330	300	279
	DDGS	376 (90% dm)	330 (92.5% dm)	377 (unknown dm)
	CO_2	301	290	
	Waste water	3281		

If we assume that the dry matter content of the used wheat in the mass balance of Schepens (2009) is 88%, the bioethanol production per ton dried wheat at 97% dry matter is 331 kg, which is comparable to the mass balance of Punter ea (2004). The production of DDGS per ton dried wheat (97% dry matter) is 331 kg product or 306 kg dry matter. This is less than the 376 kg product or 339 kg dry matter reported by Punter ea (2004). The dry matter content for wheat and DDGS is not given by Malça & Freire (2006).

The wet precursors of DDGS can be assumed to have similar outputs on a dry matter basis. Although there are some differences in composition (see http://www.ag.ndsu.edu/pubs/ansci/beef/as1242w.htm), there was no specific information encountered specifically on the processing of these wet by-products.

3.4.5 Inputs

Below are the default energy input data for drying DDGS. As explained in the remainder of the text, the overall energy use of the bio-ehtanol production facility is not taken into account. Before the drying step, allocation takes places with the wet DGS having no upstream emission associated. After which the energy input for DDGS drying is specifically attributed to DDGS.

Table 3.4.4 Default input data for drying DDGS (expressed per ton dried DDGS as output)

	parameter	Best estimate	Min	Max	unit
Energy use (DDGS drying only)	natural gas	3750	3400	4800	MJ/tonne DDGS

Energy use for drying DGS

The energy needed to dry DDGS is allocated to DDGS. The energy needed for the other processes is allocated to ethanol. In the table below the figures from literature are stated about the share of energy used for drying DDGS and the other processes, for which Punter et al. (2004) was the only direct source of information.

Input data for drying DDGS (expressed per ton dried wheat as input)

plant	process	parameter	Values	unit	Data analysis					Ref
			applied		Rel	Com	TRC	GSp	TeC	
Natural gas based	Drying DDGS	natural gas	1410	MJ/t	2	2	2	1	2	a
	Other processes	natural gas	2478	MJ/t	2	2	2	1	2	a
		electricity	479	MJ/t	2	2	2	1	2	a

a: Punter ea (2004).

The DDGS production from wheat is 376 kg/ton, which relates to 3750 MJ/ton DDGS of natural gas use. the following input for the amount of DDGS produced. The minimum and maximum are choses related to the minimum and maximum values taken for the overall processing industry (see below). The minimum, however, is chosen conservatively, as there is no reason to assume that process can or will be significantly more efficient.

Input data for drying DDGS (expressed per ton DDGS as output)

plant	process	parameter	Values			unit	Data analysis					Ref
			Best estimate	Min	Max		Rel	Com	TRC	GSp	TeC	
Natural gas based	Drying DDGS	natural gas	3750	3400	4800	MJ/t	2	2	2	1	3	a

a: Punter ea (2004).

Energy use in overall bio-ethanol production

The data below were gathered for the overall production of bio-ethanol. Although these data are not directly included (as only the drying step is taken into account) they are applied in determining the error range of the drying energy, which should be correlated with the overall distribution of energy values encountered in literature.

Punter ea (2004) describes bio-ethanol production from wheat through several scenarios of different techniques. In this study the most conservative scenario (Scenario A) is chosen as reference. This scenario is based on a simple model in which electricity from the grid and natural gas is used. Punter et al. (2004) also describes scenarios with an optimized fossil fuelled plant and a plant fuelled by straw.
The optimized fossil fuelled plant scenarios are:
- scenario B1: a natural gas boiler is combined with a backpressure steam turbo-generator which produces electricity and the exhaust steam can be used in the process.
- scenario B21 a natural gas-fired gas turbine produces electricity, an unfired heat recovery steam generator (HRSG) using the exhaust from the gas turbine to produce high pressure steam and a backpressure steam turbine producing more electricity and low pressure steam suitable to drive the ethanol production process
- scenario B22, as scenario B21 including a fired HRSG producing additional heat

The amount of bio-ethanol and DDGS produced in these scenarios does not differ to the basic scenario as described in the Tables above. The difference concerns a higher usage of natural gas usage, no electricity usage from the grid but own production and export of surplus electricity to the grid. In these scenarios the export of surplus electricity t the grid is an additional by-product.

Energy inputs and outputs for bio-ethanol production per ton dried wheat for four scenarios of increasing optimized fossil fuelled bio-ethanol plant, based on Punter ea (2004)

product		Unit	Scenario A	Scenario B1	Scenario B21	Scenario B22
Input:						
Natural gas		MJ/ton	3893	4734	8963	5996
Electricity from the grid		kWh/ton	132.9	0	0	0
Output:						
Electricity to the grid		kWh/ton	0	131.1	833.3	485.4

Recently BMA derived information from the Dutch feed industry about the manufacturing process of DDGS and bio-ethanol from wheat (Schepens, 2009). Although these data come from the industry the origin is not clear so the reliability is ranked relatively low. The data about yield of bio-ethanol and DDGS are comparable to Punter ea (2004), the data on energy use and especially electricity use differs a lot from Punter ea. (2004). The yield of bio ethanol and DDGS and energy use given by Malca & Freire (2006) differ from the data given by Punter ea (2004) and Schepens (2009). Furthermore the origin of these data is not explained by Malca & Freire (2006). The data from these source are thus not used in the best estimates. The applied values for yield of bio ethanol and DDGS and energy use are based on the figures for the conservative scenario from Punter ea (2004) because these are more reliable then the data from Schepens (2009). The minimum reported for the defaults was chosen as a slightly more efficient version of Punter, while the maximum is the average of Schepens (2009) and Malca & Freire (2006).

The energy use and yield of bio ethanol and DDGS (per ton dried wheat as input) for the processing of bio ethanol from wheat in Europe from different sources, the quality of data analysed by the Pedigree score and the applied value.

Product	parameter	Values		unit	Data analysis					Ref
		Best estimate	sources		Rel	Com	TRC	GSp	TeC	
Energy use	Natural gas	3893	3893	MJ/t	2	2	2	1	2	a
			4209	MJ/t	4	2	1	1	2	b
			5760	MJ/t	?	?	?	?	?	c
	electricity	132.9	132.9	kWh/t	2	2	2	1	2	a
			686	kWh/t	4	2	1	1	2	b
			448	kWh/t	?	?	?	?	?	c
Bio ethanol	Yield	330	330	Kg/t	2	2	2	1	2	a
			331	Kg/t	4	2	1	1	2	b
			279	Kg/t	?	?	?	?	?	c
	gross energy content	26.7	26.7	GJ/t	2	2	2	1	2	a
DDGS	Yield	376	376	Kg/t	2	2	2	1	2	a
			331	Kg/t	4	2	1	1	2	b
			377	Kg/t	?	?	?	?	?	c
	gross energy content	18.2	18.2	GJ/t	2	2	2	1	2	a

a: Punter ea (2004) b: Schepens (2009) c: Malca & Freire (2006)

Output data for the production process of bio ethanol from wheat (expressed per ton dried wheat as input)

product	parameter	Values	unit	Data analysis					Ref
		applied		Rel	Com	TRC	GSp	TeC	
Bio ethanol	Amount	330	kg	2	2	2	1	2	a
	dry matter content	1000	kg/t						
	gross energy content	26.7	GJ/t	2	2	2	1	2	a
DDGS	Amount	376	kg	2	2	2	1	2	a
	dry matter content	900	kg/t	2	2	2	1	2	a
	gross energy content	18.2	GJ/t	2	2	2	1	2	a

a: Punter ea (2004)

3.4.6 Allocation

As prior to drying the wet DGS is considered a low value by-product according to appraoch 3 as described in the methodology document (see §5.3, Vellinga et al, 2012), which means that all upstream emissions are allocated towards Ethanol. After this allocation step, the drying of DDGS is to be attributed to this by-product specifically.

3.4.7 References

CVB-table (2012): see appendix 1 in Vellinga et al. (2012)

Vellinga, T.V., Blonk, H., Marinussen, M., van Zeist, W.J., de Boer, I.J.M. (2012) Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization Wageningen UR Livestock Research and Blonk Consultants. Lelystad/Gouda, the Netherlands.

Anonymus 2006. An Assessment of the Potential for Energy Savings in Dry Mill Ethanol Plants from the Use of Combined Heat and Power (CHP). Energy and Environmental Analysis

EPure 2011. Information from the website http:\\ www.epure.org (data 9 may 20110)

Malça, J. & F. Freire 2006. Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation. In: Energy, Vol 31, pag 3362 – 3380.

Mortimer, N. D., M. A. Elsayed and R. E. Horne 2004. Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet:, Resources Research Unit, Sheffield Hallam University. Final Report for British Sugar, Report No 23/1, January 2004.

Punter, G., D. Rickeard, J.F. Larivé, R. Edwards, N. Mortimer, R. Horne, A. Bauen and J. Woods 2004. Well-to-Wheel Evaluation for Production of Ethanol from Wheat. Low CVP Fuels Working Group.

Schepens, R. 2009. Personal communication. Bonda,