European
Commission

ENVIRONMENTAL FACTSHEET: **Bioalcohols via FERMENTATION**

PROCESS INFORMATION

Fermentation is a **biochemical pathway** that permits the production of bioalcohols from a wide range of biomass materials. As shown in Fig. 1, the main steps in the process are:

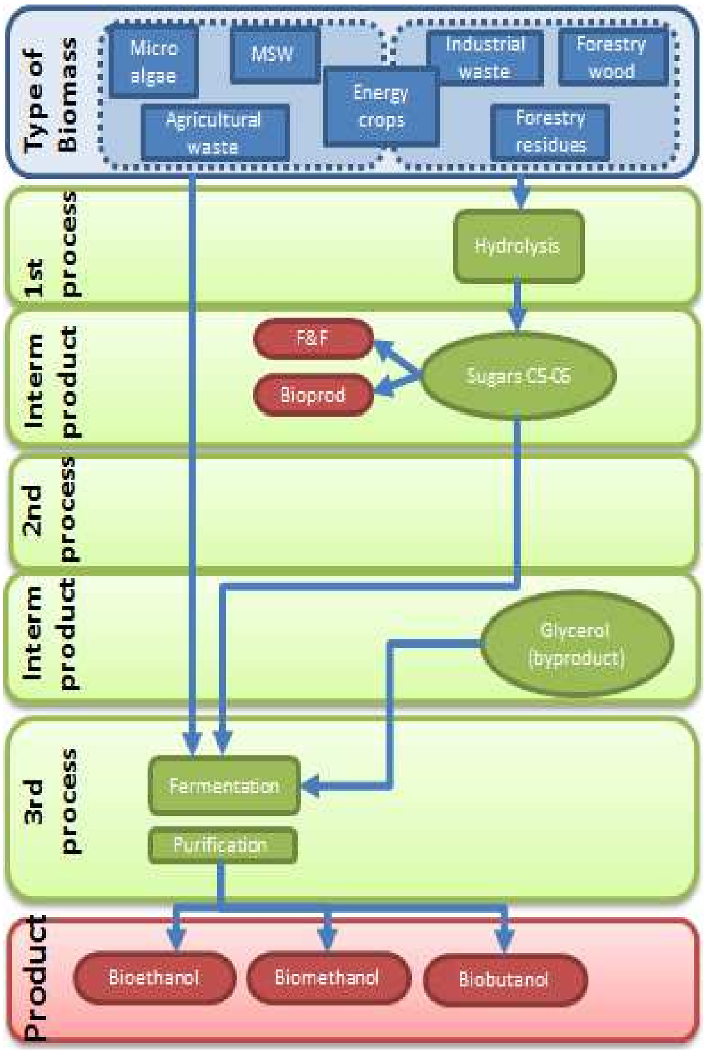


Figure 1. Flowsheet of the ***fermentation*** process

- During fermentation, sugars are converted (typically under anaerobic conditions) into cellular energy producing alcohol and carbon dioxide as metabolic waste products.
- A preprocessing and hydrolysis is necessary for some feedstock such as lignocellulosic biomass (e.g. wood, waste from the paper industry, some energy crops) in order to convert the starch and the cellulose/hemicellulose into sugars (mainly hexose C6 and pentose C5) that can then be converted to biofuel by most microorganisms. C6 and C5 can also be used to produce certain biochemicals (see sugars factsheet)
- To use this alcohol as fuel, water must be removed from the product (purification phase).
- Glycerol (by-product from the transesterification process – see biodiesel via transesterification factsheet) can also be fermented to produce bioalcohols.
- Other by-products of this path are biomass of the fermenting microorganisms used as fodder or fuel and lignin-rich material used for direct combustion, gasification or production of value added products.

Technological overview

Hydrolysis involves hemicellulose and lignin removal and **cellulose hydrolysis**. Three different processes are used: **acid hydrolysis (diluted or concentrated)** and **enzymatic hydrolysis**. After hydrolysis, the simpler resulting compounds are fermented to produce alcohol. There are four main technologies or configurations:

- **Separate Hydrolysis and Fermentation (SHF),** in which both processes take place in a two-stage sequential configuration,
- **Simultaneous Saccharification and Fermentation (SSF),** which consolidates hydrolysis and fermentation mainly to overcome the high concentration of glucose that inhibits the hydrolysis process and hence enhancing the yield of ethanol [1].
- **Simultaneous Saccharification and Co-Fermentation (SSCF),** where the microorganisms are compatible in terms of operational pH and temperature to perform both processes [2].
- Another promising alternative is the **Consolidated BioProcessing (CBP)**, where ethanol and the enzymes are produced in a single reactor by a single microorganism.

Finally, the product must be purified to produce fuel-grade ethanol. This is mainly done by azeotropic **distillation**, but other options are **pervaporation**, filtration and **membranes**.
For butanol production the ABE (acetone-butanol-ethanol) fermentation with *Clostridium* is the common practice.
Fig. 2 provides an overview of the readiness level of all this technologies. Considering the feedstock used, technologies can be divided in first generation (1G) that uses “food crops” such as sugar cane, corn or wheat and second generation (2G) that uses lignocellulosic biomass, agricultural residues or wastes. Both

are more advanced for the production of bioethanol than in the case of butanol production. Bioalcohol production from microalgae is still in an early stage of development.

Technology Readiness Levels

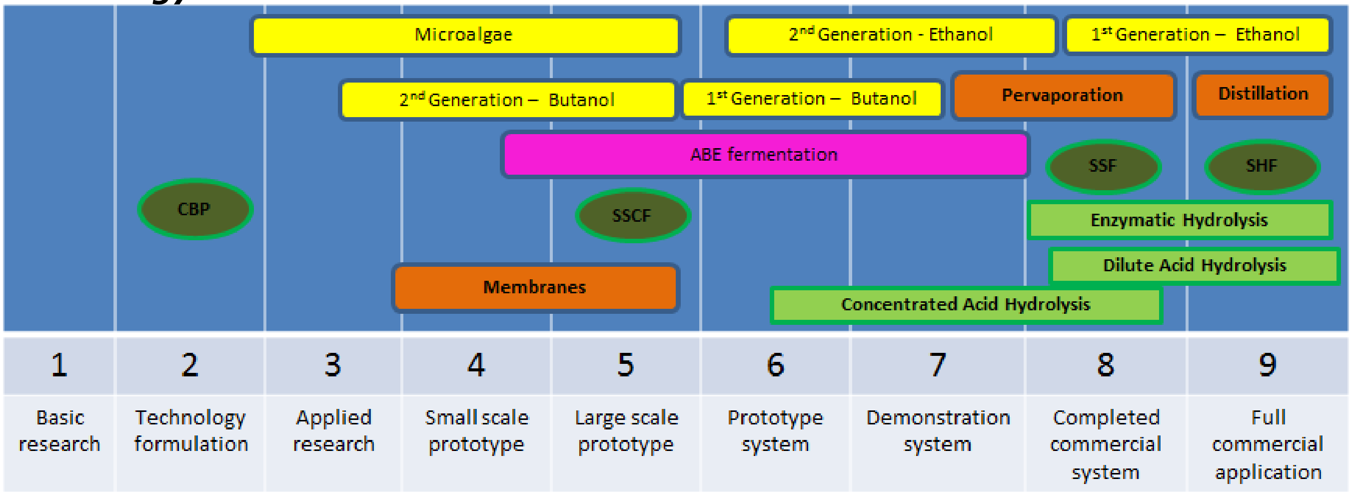


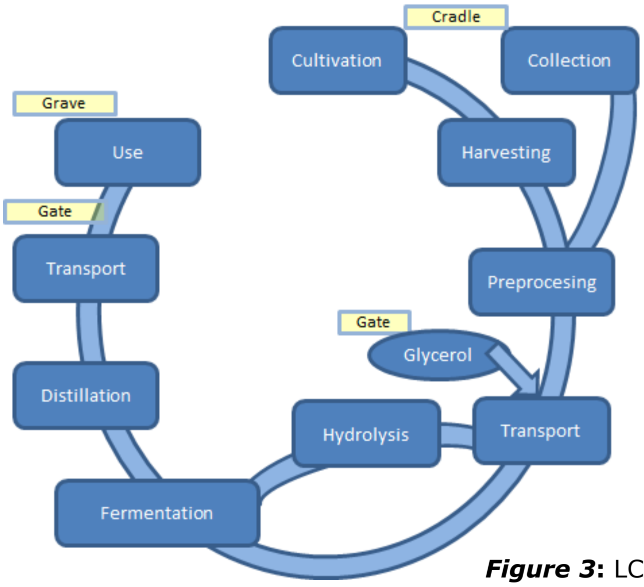
Figure 2. Technology readiness levels for fermentation of biomass

SWOT analysis (Strengths-Weaknesses-Opportunities-Threats)

S1. Well known and mature process **S2**. Abundant and different raw material as feedstock **S3**. Bioalcohols can be blended with petrol at any ratio	**W1**. High production costs due to the low energy efficiency and the quantity of enzymes required. **W2**. Blends with petrol increase emissions of volatile organic compounds.
O1. Improve ethanol fermentation from Xylose (a major fermentable from cellulose/hemicellulose) **O2**. A fuel tax reduction or exemption on ethanol could make it competitive with petrol from a cost perspective.	**T1**. Competition with food crops in land use and products. **T2**. Limited availability of infrastructure for bioalcohols distribution

ENVIRONMENTAL DATA AND INFORMATION

System boundaries of the environmental assessment:



1. **Cradle to grave (WELL TO WHEEL)**: includes cultivation (with production of ancillary products), harvesting or collection, pre-processing, transport, with or without hydrolysis, fermentation, distillation, transport to fuel tank and use in vehicles.
2. **Cradle to gate (WELL TO TANK)**: same boundaries as Well to Wheel excluding the use of the fuel in the vehicle (i.e. Tank to Wheel).
3. **Gate to gate**: special case for Glycerol - includes transport of raw material, fermentation and distillation.

***Figure 3*:** LCA system boundaries and stages for fermentation of biomass

Environmental assessment: settings & impacts

Table 1. LCA results for Functional Unit (F.U.) 1 kilometre driven

Raw material input (feedstock)	Wheat		Sugar cane		Willow		Glycerol	Corn	
LCA boundaries	1	2	1	2	1	2	3	1	2
Allocation/substitution	A($-E), S	A($)	A($)	A($-m-E)	A(E), S	A($)	S	A($-m-E), SE	A($)
Geographical coverage	Switzerland	France	Brazil	Brazil,Argent,Thai	USA	Sweden	EU	USA	USA
Product	Ethanol								
References	[9]	[3]	[7]	[3,5,6]	[4]	[10]	[11]	[8]	[3]
Impact categories from Environmental Sustainability Assessment methodology									
Climate change (kgCO$_2$eq)	(-0.016 – 1.15)	0.15	(0.05-0.25)	(0.06-1.59)	(-0.032-0.072)	-9.75E-7	0.22	(-1.23-0.39)	0.11
Ozone depletion (kg CFC-11 eq)	N.A.		(1.5E-8-3.1E-8)	(1.94E-4-2.71E-4)	N.A.	2.98E-6	1.05E-6	(2.9E-2-2.75E-1)	
Photochemical Ozone Formation (kg NMVOC eq)	N.A.	2.83E-4	N.A.	2.1 E-3	N.A.	N.A.	N.A.	N.A.	2.14E-4
Fresh water eutrophication (kg P eq)	N.A.	1.49E-5	N.A.	(9.57E-6 – 1.35E-3)	N.A.	3.75E-5	2E-5	N.A.	3.19E-5
Marine water eutrophication (kg N eq)	N.A.	1.2E-3	N.A.	8.86E-4	N.A.	N.A.	N.A.	N.A.	4.25E-4
Resource depletion – water (kg)	N.A.	N.A.	N.A.	N.A.	0.931	N.A.	N.A.	N.A.	N.A.
Resource depletion – mineral (kg Sb eq)	N.A.	N.A.	(3E-4-1.6E-3)	(2.10-1-2.93E-1)	N.A.	1.62E-4	N.A.	(5E-4-3.05E-2)	N.A.
Additional impact categories									
Acidification (kg SO$_2$ eq)	N.A.	1.06E-3	(8.5E-4-1.1E-3)	(8.15E-4 – 1.13E-3)	N.A.	2.73E-4	4.36E-4	N.A.	6.38E-4
Photochemical Ozone Formation (kg C$_2$H$_4$ eq)	N.A.	N.A.	(1.5E-4-1.6E-4)	(5.18E-4-9.85E-4)	N.A.	6.29E-5	2.18E-5	(1.6E-4-2.9E-4)	N.A.
Fresh water ecotoxicity (1,4-DB eq)	N.A.	N.A.	N.A.	(13.3 – 18.4)	N.A.	N.A.	N.A.	N.A.	N.A.
Terrestrial ecotoxicity (1,4-DB eq)	N.A.	N.A.	N.A.	(4.13 – 5.75)	N.A.	N.A.	N.A.	N.A.	N.A.
Human toxicity (1,4-DB eq)	N.A.	N.A.	(2E-2-7.7E-2)	1.7E-3	N.A.	N.A.	N.A.	(1.58E-4-3E-4)	N.A.
Non-renewable primary energy use (MJ)	(-1.48 – 1.81)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Cumulative Energy Demand (MJ)-non ren	N.A.	N.A.	N.A.	N.A.	N.A.	0.36	3	N.A.	N.A.
Fossil fuel use (MJ)	N.A.	N.A.	N.A.	N.A.	-0.95	N.A.	N.A.	N.A.	N.A.
Agricultural land occupation (m^2 year)	N.A.	0.2	N.A.	0.18	N.A.	N.A.	N.A.	N.A.	0.09
Land competition (m^2 year)	N.A.	N.A.	N.A.	N.A.	N.A.	6.26E-4	N.A.	N.A.	N.A.

Note. All values were transformed to the Functional Unit "power to wheels for 1 km driving a midsize car" assuming LHV of ethanol = 26.81 MJ/kg, density = 0.794 kg/l and efficiency in car = 190 MJ/100 km [12]. For glycerol: efficiency = 260 kg ethanol/t glycerol [GLY].

A=Allocation ($-economic; E-energy; m-mass). S=Substitution. SE=System expansion. N.A.= Not Available.

The normalisation presented in Figure 4 is performed using the normalization factors provided in the JRC methodology [13] and ReCiPe normalization values (see explanatory document).

Comments and interpretation of the environmental performance:

1 The highest normalised impact values are reported for Ozone depletion and Resource depletion impact categories mainly due to the use of fossil fuels in agriculture. That is also the main contributor to the impact values for Climate Change reported in ref [5].

2 Negative values for Climate Change (i.e. environmental benefit) are reported in studies that use substitution (i.e in ref [4] electricity produced during the process replaces the use of national grid electricity from fossil and in ref [9] DDGS and wheat straw replace animal feed production) and studies that consider biogenic CO_2 emissions are not contributing to Climate Change (ref [10]). Ref [8] also reports negative values but in this case system expansion is used and so the system boundary and the functional unit changes (including not only 1 km driven but also additional products).

3 Higher impact values reported for Fresh water eutrophication impact category (ref [6] and [8]) are mainly caused by the use of agrochemicals and fertilizers in the feedstock production and the wastewater discharge from the ethanol conversion process.

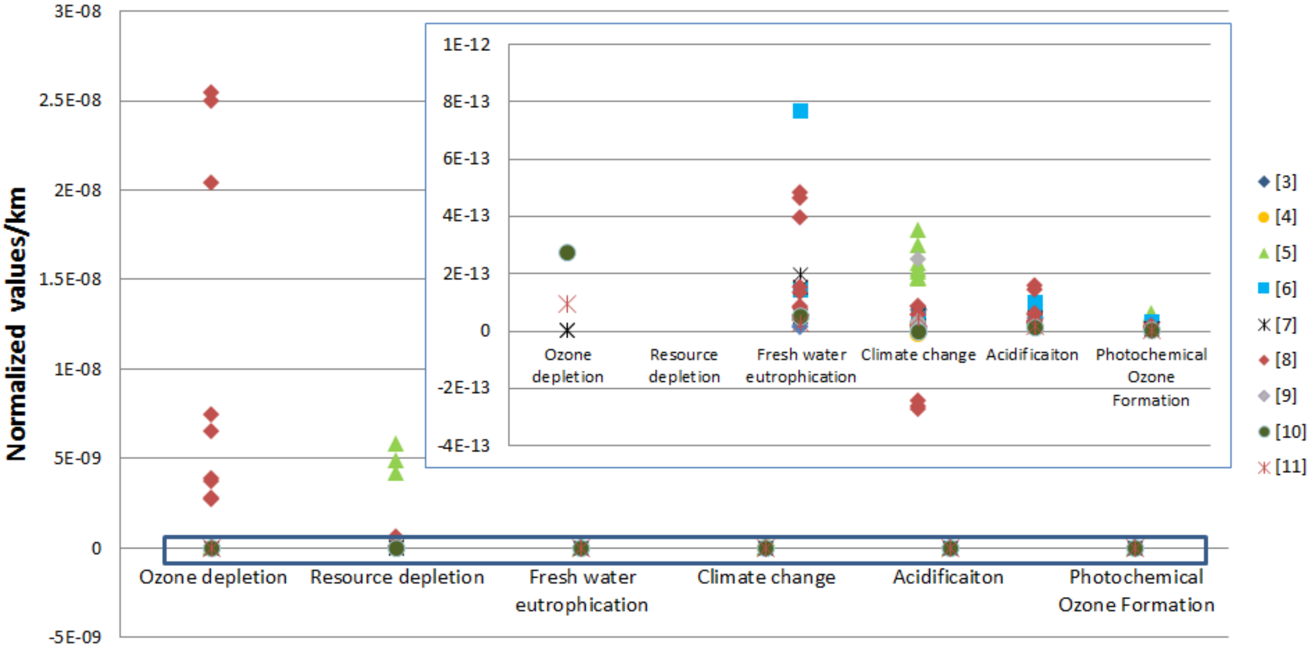


Figure 4: Environmental performance expressed as normalized impact categories

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FP7 Project REFERENCES in CORDIS (www.cordis.europa.eu)
4FCROPS
SWEETFUEL
GLOBAL-BIO-PACT
BIOLYFE
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