Energy balance of bioethanol
Why opinions differ ?

What is the energy balance of bioethanol? This question masks a legitimate concern: making sure that we do not consume more fossil fuel energy to produce bioethanol than the amount of energy contained in that bioethanol. Here is an overview of this thorny issue.

The amount of energy consumed by a bioethanol plant accounts for around 80% of the energy consumption of that sector.
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What is the energy balance of bioethanol?

The question is simple. As for the answer, contradictory figures have been circulating for over 30 years. They give a full array of conclusions, ranging from a "negative energy balance" to a "clearly positive energy balance".

Those differences are due to several factors: available data, evolution of yields, choice of calculation methods.

Actually, three main factors explain most of the differences.

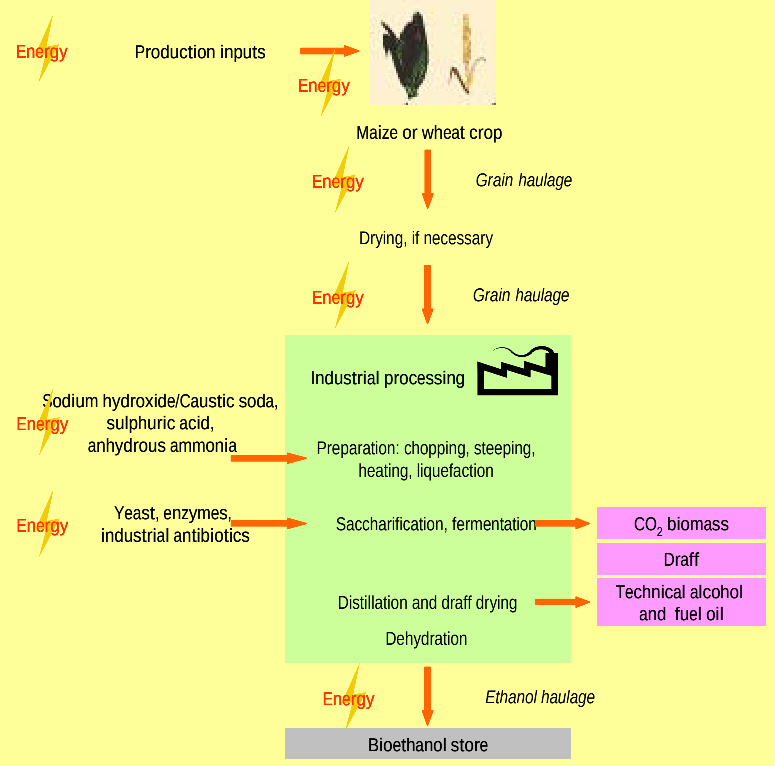
Identifying energy consumption

Establishing the energy balance of various biofuel sectors consists in listing all the fossil fuel energy used to make the biofuel. The sum total of this fossil fuel energy consumption is then compared with the amount of energy released by the biofuel.

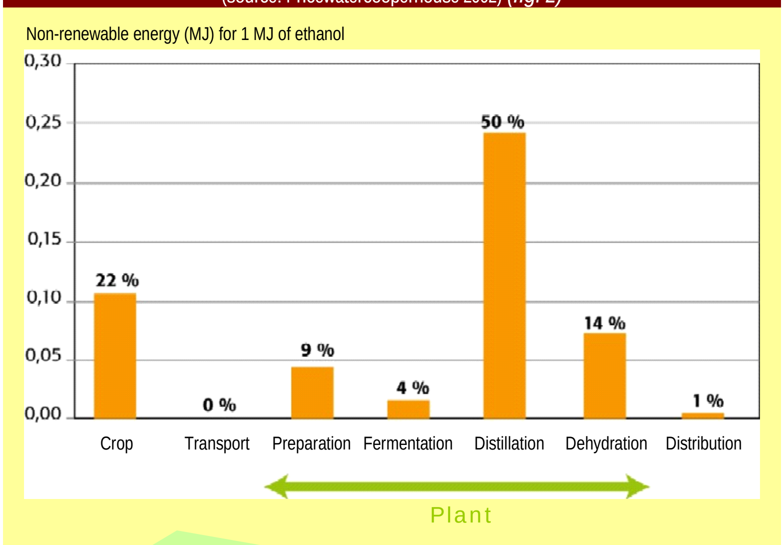
The indicator then used is called "energy efficiency" ratio, which is equal to the energy released - the total fossil fuel energy consumed by the biofuel sector in question.
For the wheat or maize bioethanol sector, this exercise consists in totalling up all of the following non-renewable energy consumptions *(figure 1)*:

- Energy consumed to manufacture crop inputs. This is the energy used to manufacture nitrogen fertilisers as well as other fertilisers, or the energy needed to manufacture pesticide molecules.
- Energy consumed to make resources and products available, for their transport, and to spread inputs. This covers for instance the energy used to make irrigation water available, to make and package pesticides, to transport fertilisers from the manufacturing plant to the supplier, then to the farm and finally to the cropped field, and the energy consumed by the tractors.
- Energy used to transport and store raw agricultural materials and other inputs needed by the bioethanol plant.
- Energy consumed by the bioethanol plant.
- Energy consumed to transport bioethanol to where it is going to be used.

Stages of bioethanol production (source: Pricewatercooperhouse 2002) *(fig. 1)*



Non-renewable energy mobilised at each stage in the wheat bioethanol sector (source: Pricewatercooperhouse 2002) *(fig. 2)*



Overall, the majority of the sector's energy consumption takes place in the plant (77%) and in the field (22%).

Those first calculations can cause part of the differences noted between energy balances. Two items are determining factors here: the amount of energy consumed by the bioethanol plant (it accounts for around 80% of the sector's energy consumption - *figure 2)* and, to a lesser extent, the evaluation of the energy consumption linked to the manufacturing and the use of fertilisers. As for the amount of energy consumed by the processing plant, this gets lower with each decade (and study results). Plants have reduced their energy consumption, even though there certainly is still room for significant improvement, either through further energy savings during the process, or by increasing the proportion of renewable energy used by the plant. Therefore, any facility replacing some of the gas currently used in the plants with biomass, would considerably improve final ratios.

Allocating a part of the consumption to each of the products manufactured

Once the overall energy consumption has been assessed, it must be broken down and parts of it allocated to the different products resulting from the manufacturing process. This is another cause of variation between energy balances.

For instance, the wheat bioethanol sector not only produces bioethanol, but plants also produce draff (leftover from the grain fermentation process) and CO_2 (gas emitted during the fermentation phase). The energy consumption is therefore spread out and an allocation formula must be considered for the energy consumption of by-products. Three solutions are possible:

- Allocation based on the weight of products and by-products, called "mass allocation". This is the allocation formula used between maize or wheat bioethanol and draff in the Ademe (French Environment and Energy Management Agency) 2002 study. This method attributes half the energy consumption to bioethanol. It is based on the fact that each tonne of bioethanol produced results in the production of the same tonnage of draff. The mass allocation is currently used to calculate the energy ratios of petroleum products coming out of a refinery. It has the advantage of being simple to apply and of allowing, thanks to the similarity of the methods, the comparison between a biofuel and the fossil fuel it replaces.
- Allocation based on the energy content, called "energy allocation". It is commonly used in the US, as part of the environmental assessment of maize bioethanol. It considers that the intrinsic value of the product, and its by-products, is entirely linked to their energy content.
- Allocation by substitution, or "system boundary expansion" method, also known as "reduced impact" method. This means removing from the sector's energy consumption, the equivalent of the energy used to produce products that the by-products of that sector replace. For the wheat bioethanol sector for instance, it supposes that draff is used as animal feed and partially replaces soyabean meal normally present in rations. In this case, the equivalent of the energy used to produce soyabean meal (from the soya crop to the manufacture of soyabean meal) can be deducted from the energy consumption of the bioethanol production. This substitution method requires a choice of scenarios which will have a considerable impact on the results.

The energy consumption of the bioethanol sector must be shared between ethanol and draff production (in this case, maize draff). © Passion Céréales

Calculation of the energy balance (energy released/non-renewable energy consumed) of bioethanol in different studies.

The energy balance of bioethanol is positive in every case, but varies perceptibly depending on the methods used.

Energy balance of reference scenarios

Source	Calculation method	Product	Energy released / non-renewable energy mobilised
ARVALIS - Institut du végétal based on ADEME 2002	2002 fictitious scenario – calculation up to storage of fuel – mass allocation of by-products	Petrol	0.873
		Wheat ethanol	2.05
		Sugarbeet ethanol	2.05
ARVALIS - Institut du végétal based on PWC 2004	2009 scenario – calculation up to storage of fuel – mass allocation of by-products	Maize ethanol	1.82
		Petrol	0.88
Based on Levington 2000	Calculation up to storage of fuel – energy allocation of by-products	Wheat bioethanol 1999 scenario (gas powered distillery)	1.1
		Wheat bioethanol 1999 scenario (distillery powered by renewable energy)	2.5
IEA 2004	Various European and American studies mentioned	Maize	1.02 to 2
		Wheat	1 to 1.2
EUCAR CONCAWE 2006	2006 scenario – reduced impact allocation	Sugarbeet ethanol / pulp for animal feed	1.2
		Wheat ethanol / natural gas powered plant / draff for animal feed	1.1
		Wheat ethanol / natural gas plant - cogeneration, draff used as fuel	5.0
		Wheat ethanol / plant using straw/draff as animal feed	3.3

In any case, the energy released by the bioethanol is greater than the fossil fuel energy used to produce it.

The choice of allocation method depends on what is to be compared!

As a determining factor of the way the final energy ratio is arrived at, the choice of allocation method must be based on the precise objective of the study: comparison between fossil fuel and biofuel sectors, comparison between biofuels, comparison of several processes within a given biofuel sector… Each method is more or less appropriate depending on the aim of the calculation. In any case, comparison is only possible between energy balances established using the same method. Ideally, this type of energy efficiency ratio must be calculated based on an existing sector rather than on a scenario. This cannot currently be the case in France since the sectors are "under construction".

The positive energy balance is constituted in the field…

From an energy point of view, one hectare of wheat or maize contains more energy than the amount of non-renewable energy used to produce the crop.

Energy consumed	Energy contained in the biomass
Manufacture of inputs (fertilisers, pesticides) + manufacture of agricultural equipment + fossil fuel (oil, fuel) = 16 to 20 GJ/ha	9t/ha of wheat grain and 4 t of straw = 129 GJ/ha

Out of all the energy used to produce the crop, two items account for most of the consumption: nitrogen fertilisation (40 to 60%) and fuel (20 to 30%). Let's remember that the non-renewable energy used for nitrogen fertilisation is the energy consumed to manufacture this artificial fertiliser.

The energy balance (energy contained in the biomass - non-renewable energy consumed) of the whole plant when it leaves the field is therefore clearly positive. But this positive balance exiting the field, does not necessarily prejudge the final energy balance of the energy product (heat, electricity or biofuel) manufactured from this biomass. Other factors come into play, such as whether all or only part of the plant is used, the energy consumption of the process (boiler, turbine, or biofuel plant) or the conversion yield of the energy contained in the biomass, depending on the process.

Which yield figure should be used?

The yield at different stages of the sector's activities is the last important, and determining, factor entering into the calculation of energy efficiency ratios. The crop yield per hectare actually reveals the level of energy fixation efficiency. The crop yield, as well as the bioethanol extraction yield from the grain, are two key elements. From an energy point of view, plant biomass production presents one particularity: it fixes solar energy through photosynthesis, as a different form of energy, i.e. the energy binding the carbon chains which make up plant matter. It is this binding energy which is released during the combustion of the matter and of the bioethanol.

In any case, the energy released by the bioethanol produced is greater than the fossil fuel energy consumed to produce it.

This means that beyond the crop stage, bioethanol manufacturing only incurs fossil fuel energy consumption. This is why we can say that the positive energy balance of the bioethanol sector is constructed in the field *(insert 1).*

In the plant, the better the extraction yield is, the higher the amount of energy recovered in the form of bioethanol will be, for a given energy consumption.

In the end, if the range of variation is great, but biofuels and the bioethanol sector do present positive energy efficiency ratios. In any case, the energy released by the bioethanol produced is greater than the fossil fuel energy consumed to produce it.

Let's note that the way agricultural practices and yields have evolved over the last few years improves energy efficiency in the field.
Likewise, bioethanol plants are improving the energy efficiency of their process. Those ratios can only progress in the right direction.

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For more information

- ADEME DIREM 2002.
- EUCAR CONCAWE 2006

Well to tank analysis of future automotive fuels and powertrains in the European context.