Biofuels

What are the real savings?

Biofuels can, in principle, provide a renewable source of energy and, by displacing fossil fuels, reduce greenhouse gas (GHG) emissions to the atmosphere. However, the biofuels production process itself consumes energy and emits greenhouse gases. To identify what the real savings are in terms of energy and GHG emissions, a careful evaluation of the entire 'field-to-tank' process is needed. In 1995, CONCAWE published a report (02/95) on alternative fuels, based on an extensive literature review. A new report to be published in due course updates the earlier report, including results from recent studies on the two main biofuels under consideration in Europe—ethanol from either wheat or sugar beet and rapeseed methyl ester (RME).

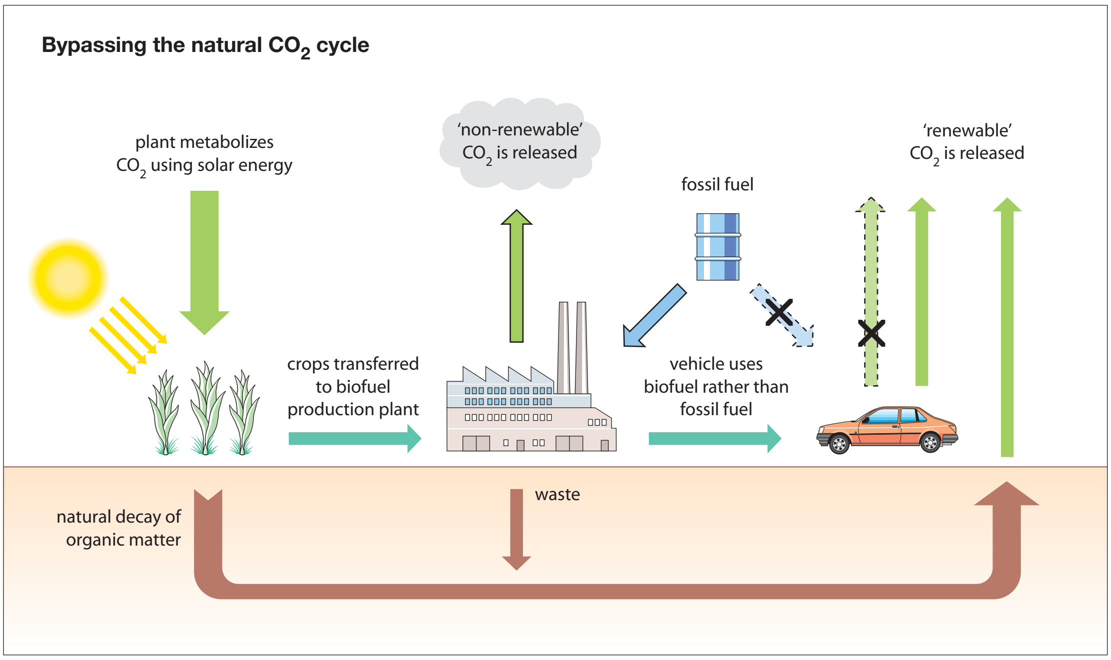
The biofuel production process is generally energy-intensive and the energy balance as well as the CO_2 balance can only become attractive with optimum use of by-products. Although technologies to that effect are being developed it remains to be seen whether practical and economic considerations would allow this to happen on a large scale. The real impact of field emissions of nitrous oxide and carbon sequestration in soil on the GHG balance is still largely unresolved, but both issues have the potential to negate most of the CO_2 gains.

The plant carbon cycle

Plants use solar energy to turn atmospheric CO_2 and water into organic carbon and hydrogen, thereby storing energy. In the natural cycle, the organic molecules are broken down as the plant decays and the carbon is returned to the atmosphere as CO_2. In this case and in food-based agriculture the energy is used to support other forms of life.

When growing a crop for fuel, part of the biomass produced by the plant is used directly to produce energy.

Figure 1
Biofuels potentially save fossil CO_2



The CO_2 originally metabolized by the plant is returned to the atmosphere during the combustion process. This CO_2 is therefore 'renewable' as it is simply a portion of the total amount involved in the natural cycle. In order to produce the biofuel, however, a certain amount of energy is required. In the case of biofuels for vehicle use, the production process is sophisticated and significant energy is required for growing, harvesting and processing of the biomass. Typically, most, if not all, of this production energy is of fossil origin. Its use generates CO_2 that is additional to the natural cycle and is not 'renewable'.

The energy balance

A certain amount of energy is embodied in a biofuel as measured by its heating value. From this must be subtracted the energy used during all stages of the production process, including such things as the production (and transport) of fertilizer, drying, fermenting, distillation etc. On the other hand, the biofuel will be used in place of an amount of conventional fuel which will no longer need to be produced. The energy required for producing this amount of conventional fuel is considered to be an additional 'saved energy' and is therefore a credit to the biofuel. The general consensus is that biofuels (at least those considered in this work) will be used mainly in blends with conventional fuels and will not affect positively or negatively the efficiency of the vehicles. The substitution can therefore be considered to occur on a pure energy content basis.

The production of biofuels leaves a large amount of unused biomass in the form of a number of by-products that can be broadly put into two groups. The first group concerns the protein-rich products such as the 'cake' left after pressing rapeseeds, or the residue of ethanol fermentation. Generally these products have the potential to be used as animal feed. As such they would substitute an equivalent amount of, for example, soy-meal that would not need to be produced and transported. The energy involved in such activities can then be saved and represents an additional potential credit for the biofuel. The second group is made up of waste material such as straw, leaves etc. This biomass has a certain energy content, although it is 'low density' energy because of the large volume and high water content. Nevertheless, some such products (such as wheat straw) could potentially be used as fuel in certain installations that may be either integrated with the biofuel production process or separate from it. The energy potentially generated represents a third source of credit for the biofuel.

If the credit for substituted fuel production is not in doubt, whether and to what extent the by-products will be used in real life is a matter of debate. The animal feed products are relatively low-volume materials, present in the fuel processing plant and which have to be disposed of in some way. The steps to use them as animal feed are simple and inexpensive and, at the right price, they are likely to find a ready market, possibly even in the immediate neighbourhood of a plant. For these reasons, we believe that it is realistic to associate an energy credit to such products.

Turning waste biomass products into fuel requires technologies that do exist and have been implemented in a small number of demonstration plants. They tend, however, to be complicated and costly. Because of the logistics involved in transporting the crops, biofuel production plants are likely to remain small to medium in size, so economies of scale will be limited. Biofuel plants will be built with a view to minimizing cost rather than saving energy or minimizing CO_2 emissions. Consequently, the maximum use of waste is unlikely to be a top priority in all but a fraction of the cases.

In the context of a complete 'life cycle analysis', other aspects would also need to be considered, such as the energy embodied in the additional farm machinery or process plants required. These are not systematically taken into account in all studies. Although it is useful to keep them in mind for a 'health check' of the conclusions, we believe that, generally, they are of a second order of magnitude compared to the main factors described above.

The overall energy balance figures reported in the studies considered in the survey are summarized in Figure 2. The columns represent the arithmetic average while the 'error bars' show the spread of the data. The

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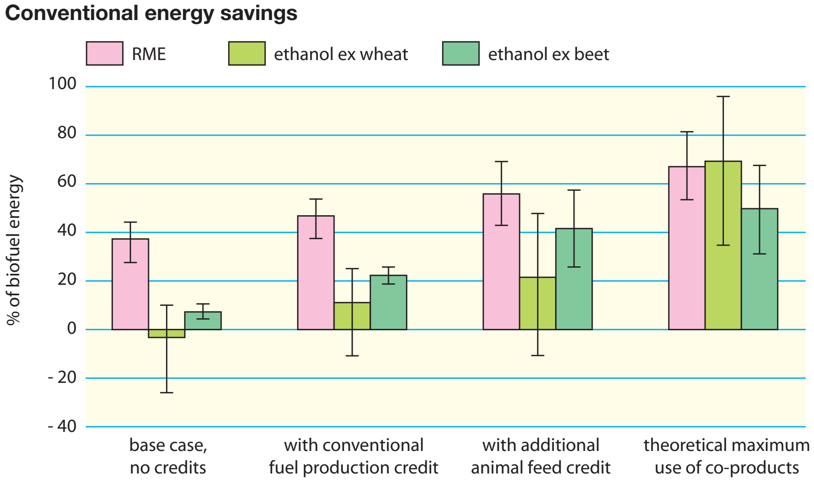
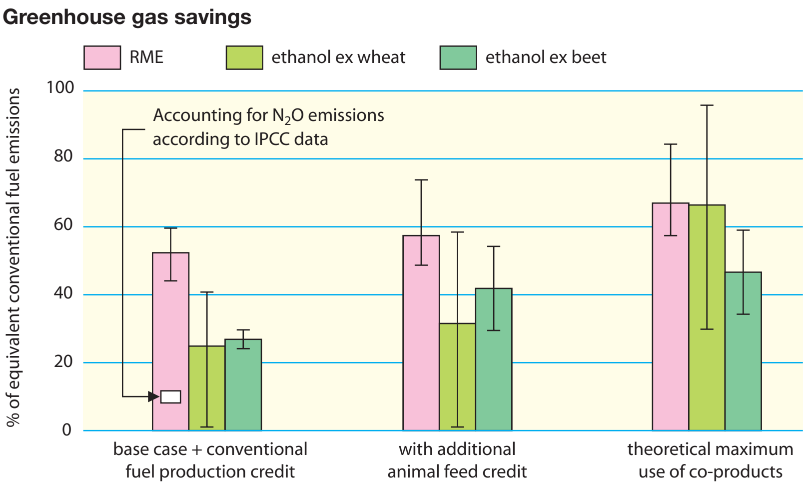


Figure 2
Ethanol shows a relatively poor energy balance compared to RME which gives the most favourable results overall.

first group represents the base case in which the energy balance is calculated without credits. In the next groups the credits are added stepwise, starting from production of the substituted conventional fuel and finishing with the waste biomass.

RME generally gives more favourable results than ethanol, reaching some 56% 'renewability' when the animal feed credit is included. Ethanol from wheat shows a particularly poor energy balance, only matching the other options when a waste biomass credit is included, which, as discussed above, we consider an unrealistic scenario on a large scale.

Figure 3
The CO_2 balance closely matches the energy balance; but N_2O emissions can affect the GHG balance.



The CO_2 and greenhouse gases balance

The CO_2 balance follows the same logic as the energy, with the additional complication of assessing from which fuel the energy required for each step is likely to come. This requires a number of assumptions and is a source of divergence between studies. Figure 3 summarizes the findings based on figures published in the reviewed studies. It must be noted that not all studies included GHG calculations and, in some cases, we made our own calculations based on the reported energy consumptions.

Predictably the general trend closely follows the energy balance, RME still coming out better than ethanol.

Although CO_2 is the main greenhouse gas in terms of volumes, others have to be considered. In the field of agriculture, the main culprit is nitrous oxide (N_2O), significant quantities of which are released from cultivated fields, particularly with intensive use of fertilizers. N_2O is more than 300 times more potent than CO_2 as a greenhouse gas, so that even modest volumes can turn out to have a non-negligible impact on the overall balance. One study by IFEU (Germany) takes into account N_2O emissions according to the IPCC[1] data, and suggests a dramatic effect on the GHG balance; from an average of more than 50% in the other studies, the CO_2-equivalent saving falls to about 10%. The exact effect of N_2O field emissions is still a matter of debate but this goes to show that more study is required to clarify an issue with such potentially dramatic impact.

Land use and potential biofuel production

Growing crops for biofuels requires agricultural land. In the context of large-scale production, set-aside land could be used rather than displacing existing food crops. The entire EU-15 set-aside area is estimated by the EU Commission at 5.6 Mha. On this basis and with the yields indicated in the literature, we have estimated the

[1] *Intergovernmental Panel on Climate Change*

maximum potential for biofuels in terms of production, net substitution on an energy basis and absolute GHG emissions reduction. Figure 4 summarizes the results assuming a 50/25/25 split between rape, wheat and sugar beet.

The first observation is that, even on a gross basis, set-aside land is not likely to be enough to meet the Commission's expressed target of 5.75% biofuels by 2010. The total biofuel energy that can be produced from the set-aside land is 8.9 Mtoe/a, or 3.3% of road transport needs. However once the energy input is factored in, this figure falls to 3.8 Mtoe/a, only 1.4% of road fuel consumption. The net CO_2 avoided is similarly around 1.5% of road transport emissions. It must also be realized that a large part of the set-aside land may not be suitable for growing such crops, or only with lower yields, so that this estimate may be optimistic. Also the more pessimistic estimates for N_2O emissions have not been included, and these would further reduce the GHG benefits.

With regard to CO_2 avoidance, another contentious issue is carbon sequestration in soil. Changing land use results in slow changes in the carbon content of the soil. Whereas soil bearing natural vegetation tends to have a high carbon content, regularly cultivated and ploughed land retains very little. The figures quoted by some sources are so large that using currently fallow land for biofuels could release enough carbon to negate the whole benefit of such endeavours for a number of decades.

Conclusions: biofuels versus bio-energy

Production of RME and bio-ethanol gives modest net gains in terms of overall energy balance. The entire EU-15 set aside area would account for about 1.5% of road fuels on an energy basis. The GHG balance is more uncertain in view of largely unresolved debates regarding N_2O emissions and carbon sequestration in soil. Judicious use of by-products such as protein-rich residues for animal feed and wheat straw as an energy source can improve the efficiency of the process. However, the real energy and GHG savings from animal feed are unclear, and it remains to be seen whether practicality and economics will support the use of straw or other biomass energy.

The current focus is very much on the use of available land for the production of motor fuels. An alternative might be to use that land to produce biomass as a fuel for generating electricity (the demand for which is in constant increase). The process to produce biofuels is energy intensive and the crops are selected to produce suitable compounds rather than for their potential to metabolize CO_2 and produce maximum biomass. Limited data on experimental schemes for short rotation coppicing or growing of selected grass varieties suggest that net CO_2 avoidance figures could be 4 to 8 times more favourable than for traditional biofuels.

Potential of biofuels based on entire EU-15 set-aside area

'renewability' of biofuels (42% average) ↓ — average yield 2.3 t/h ↓ — EU-15 set-aside land area (5.6 Mha) ↓

	biofuels production	oil equivalent		net CO_2 avoidance
		gross	net	
Mt/a	12.8			12.6
Mtoe/a		8.9	3.8	
% of road fuels		3.3	1.4	
% of crude energy			0.6	
% of total EU-15 emissions				0.3
% of road fuels emissions				1.5

Figure 4
Even on a gross basis, set-aside land is not likely to be enough to meet the Commission's expressed target of 5.75% biofuels by 2010.