# The potential of biofuels for energy and GHG savings in road transport

## *Updated data from the joint European Well-to-Wheels study*

In December 2003, a consortium of JRC, EUCAR and CONCAWE published the first version of a comprehensive Well-to-Wheels (WTW) analysis of fuels and powertrains in the European context, focusing on energy efficiency, GHG (greenhouse gas) emissions, costs and potential availability issues. The fields of alternative fuels as well as motor vehicles are in constant development. From the outset, the consortium agreed to update the study at regular intervals, taking into account comments and suggestions from interested third parties. The second version of the study is about to be released, and now includes both updated and new pathways as well as revised cost and availability estimates (see Table 1). While a full presentation of all results would be beyond the scope of this short article, we focus on the potential of biofuels with particular emphasis on ethanol and biodiesel, the two short-term alternatives currently being promoted in the EU, and look briefly at the prospects for more advanced biomass conversion options.

### Ethanol and biodiesel: the first generation of biofuels

In the short term, and for most of the next 5 to 10 years, there are only two serious contenders for biomass-derived road fuels in Europe, namely ethanol as a substitute for gasoline and biodiesel (esterified vegetable oil) as a substitute for diesel fuel. In Europe, these biofuels will be produced from traditional agricultural crops: sugar beet and wheat for ethanol; predominantly rapeseed for biodiesel.

In all these pathways, only a fraction of the plant biomass is used to produce the desired fuel. The fate of the remaining biomass has a large impact on the overall energy and GHG balance. Looking at the different routes to ethanol from wheat gives a good illustration of the wide range of energy and GHG benefits that can be obtained when producing the same biofuel from the same raw material.

**Table 1 Main additions and modifications to the joint WTW study**

| | |
|---|---|
| Conventional powertrains | • Fuel efficiency penalty associated with a diesel particulate filter reduced from 4 to 2.5% |
| Ethanol | • Additional wheat to ethanol pathways including four energy source options for the ethanol plant and two separate uses for DDGS<br>• New pathways for straw and sugar cane to ethanol |
| Ethers | • New pathways for MTBE and ETBE |
| Biodiesel | • Rape ethyl ester (based on wheat ethanol) in addition to methyl esters of rape and sunflower oil |
| Nitrous oxide emissions from agriculture | • Revised data based on updated land model |
| CNG | • Minor revision of methane losses for gas pipeline transport and discussion of the potential of higher pressure pipelines for reducing gas transport energy<br>• New CNG engine data yielding somewhat more favourable efficiency figures |
| Biogas | • Pathways for conversion of organic waste into biogas for road transport |
| LPG | • Pathway for remote LPG (associated to gas field) into bi-fuel PISI vehicle |
| Synthetic fuels | • Synthetic diesel and DME from coal in addition to natural gas and biomass<br>• Special option for diesel or DME from wood via 'black liquor' |
| Hydrogen | • No changes |
| $CO_2$ capture and storage (CCS) | • Preliminary comparative data produced (with/without CCS) for a number of pathways |
| Costs | • Revised fossil fuel costs with two crude price scenarios (25 and 50 €/bbl)<br>• Revised cost of crops and biomass in line with latest projections from DG-AGRI |
| Potential availability | • Revised estimates of crops and other biomass availability in Europe based on DG-AGRI data |

*Full report with detailed results and analysis at: http://ies.jrc.cec.eu.int/WTW*

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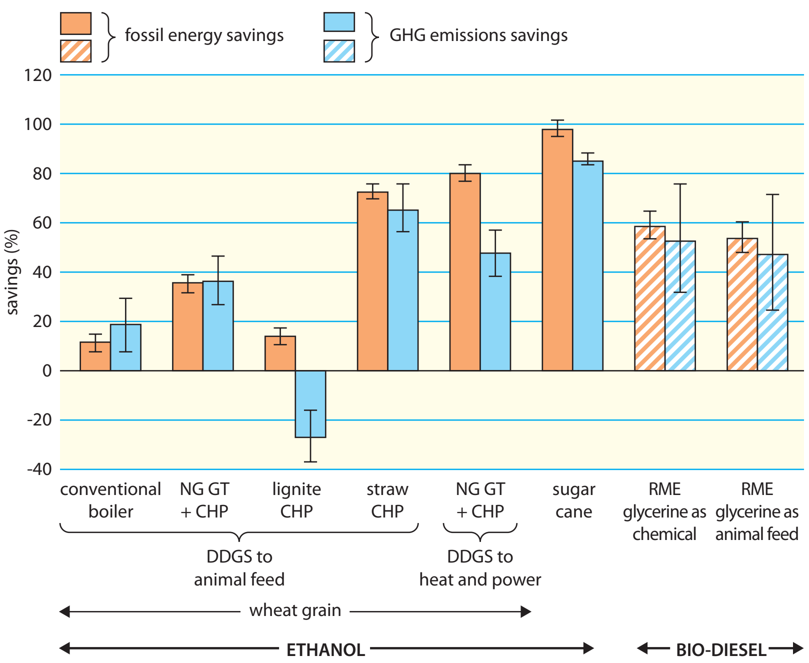
Ethanol from grain is obtained through hydrolysis of starch, followed by fermentation and distillation of the alcohol. The overall process requires a large amount of energy chiefly in the form of heat (mostly steam) and, to a lesser extent, electricity. There are several practical options for supplying that energy.

In the most basic (and low capital) scheme, representative of many existing facilities (in Europe and elsewhere), a simple, usually gas-fired, boiler provides the steam while electricity is taken from the grid. However, because the heat is required at low temperature, ethanol plants offer good opportunities for combined heat and power (CHP) schemes. Combining this with a natural gas (NG) fired gas turbine (GT) results in a very energy-efficient if capital-intensive process. In areas where coal or lignite is cheap and abundantly available, a simpler CHP scheme based on a coal-fired steam boiler combined with a backpressure steam turbine can also be envisaged. Finally surplus straw from the wheat itself can, in principle, be used as fuel through a similar CHP scheme. If this is likely to be a winner in terms of GHG emissions, this is also a very expensive and largely untested scheme to set up and to operate. Figure 1 shows the fossil energy and GHG savings for each pathway, compared to conventional gasoline.

**Figure 1**
*All schemes yield a saving of fossil energy, although potential savings vary widely between schemes. The wider uncertainty range for GHG emissions is due to the large variations in nitrous oxide emissions from agriculture.*

**WTW fossil energy and GHG savings of: a) various ethanol pathways; and b) biodiesel pathways, compared to conventional fuels**




All schemes yield a saving of fossil energy but the potentials are very different; from 11% in the simplest scheme to 72% when using straw. The variations are even greater in terms of GHG emissions, the lignite pathway actually producing a net increase! The wider uncertainty range for GHG emissions is due to nitrous oxide emissions from agriculture which are subject to large variations depending on soil type and agricultural practices.

It is important to keep in mind that the above schemes are not all equivalent from a cost point of view. For a 100 kt/a ethanol plant, the total capital investment would start at around 60 M€ for the basic scheme increasing to about 80 M€ for a NG turbine CHP and above 100 M€ for the solid fuel schemes. This is partly compensated by the different fuel costs and the potential revenues from surplus electricity sales. Our calculations suggest that the NG gas turbine CHP scheme is likely to be the most attractive from an overall cost point of view, even in a high fossil fuel price scenario. Although the straw pathway achieves the greatest reduction in GHG emissions, it is unlikely to be selected; besides the high costs, a straw burning scheme also involves issues of continued straw availability, transport logistics, complex and less reliable solid fuels handling and combustion systems, making it relatively unattractive.

In most of these pathways the fate of by-products is crucial to the final energy and GHG balance. DDGS (Distillers Dried Grain with Soluble), the biomass left over after fermentation of the grain, is a high-protein product suitable as an animal feed component. This is overwhelmingly the way it is used today, typically as a substitute for soy meal. After drying, it could also, in principle, be used as fuel e.g. co-fired with coal in a power plant, now replacing coal and generating a much increased fossil energy saving and, to a lesser extent, GHG saving. The economics are however unlikely to favour this application in the foreseeable future.

For reference, Figure 1 also shows that the typical savings achieved with sugar cane in Brazil are considerably higher than what can be hoped for in Europe. The main reason for this attractive balance is the use of 'bagasse', the leftover after extraction of the sugar, which is a convenient and abundant fuel for which there is no alternative use. In the best cases surplus electricity can be produced, further boosting the energy balance.

Figure 1 also shows the same data for RME, the methyl ester produced from rape seed oil and methanol. This process splits the tri-glyceride molecule, separating out glycerine as a by-product and producing a fuel which boils at around 350°C and can be blended into diesel fuel. Pure vegetable oil is very viscous and unstable, so unsuitable as a component in road diesel fuel.

RME can save up to around 55% of fossil energy and 50% GHG emissions compared to conventional diesel fuel. The fate of the glycerine by-product has a discernable but limited impact on the balance. Field nitrous oxide emissions have a particularly large effect on the GHG balance because rape requires a lot of nitrogen fertiliser.

## The future: advanced biofuels

There are two promising routes to turn more biomass into liquid road fuels. Cellulose can be broken down into fermentable sugars, serving as raw material for ethanol. This opens the possibility of large scale conversion of various cellulosic materials such as wheat straw, wood etc. Biomass can also be used as the raw material for production of synthetic diesel via gasification followed by Fischer-Tropsch synthesis (the so-called biomass-to-liquids or BTL process). Although these processes are energy-intensive, they use part of the biomass feed to generate the process energy, resulting in very low fossil energy usage (mostly for agriculture, transport and the like) and very favourable GHG balances.

Various processes are in the development stage but there are still many technological and economic issues to be resolved before commercial scale plants are a reality. BTL in particular requires complex and capital-intensive plants for which scale is likely to be a major economic argument, whereas the feasibility of providing the biomass feed to a large plant and the associated logistics are a challenge.

## Availability and cost

Because they rely on traditional food crops and are obtained from only a fraction of the available biomass, there is limited potential for first generation biofuels. Our estimates suggest that Europe will only be able to produce the net equivalent of about 5% of its road fuels demand (energy content basis). Production costs are high while GHG emissions avoidance is limited. As a result the cost per tonne of $CO_2$ avoided is substantial.

Second generation biofuels offer better prospects. A range of biomass feedstocks can be used including various waste products but also farmed biomass using crops specially selected for their capacity to efficiently metabolise biomass.

Figure 2 shows the relative costs of $CO_2$ avoidance versus the potential for $CO_2$ savings (100% represents the $CO_2$ emissions from fossil fuels meeting the same energy demand for transport). Even in this high crude oil price scenario, the cost of $CO_2$ avoidance remains high. The BTL option offers the highest savings albeit at a somewhat higher $CO_2$ cost than most other options, as these routes are penalised by the high capital required. Because they are in development, the investment figures are only estimates at this stage: it is clear that process improvements and economies of scale will be required to make these routes viable.

**Figure 2**
*Even in a high oil price scenario, the cost of $CO_2$ avoidance remains high.*

**Cost and potential for $CO_2$ avoidance of selected biofuels pathways (50€/bbl crude oil) compared to conventional fuel case**