Joint European Well-to-Wheels study

An analysis of future automotive fuels and powertrains in the European context

The Well-to-Wheels (WTW) study carried out jointly by EUCAR, JRC/IES and CONCAWE was completed at the end of 2003. A full report was prepared and is available on the JRC website at http://ies.jrc.cec.eu.int/Download/eh

The study considered a wide range of primary energy sources, automotive fuels and powertrains. The energy and GHG balance was estimated for close to 500 combinations, thus creating an extensive database for these key elements of the alternative fuels debate. Also included are considerations of the quantities of alternative fuels that could potentially be produced, as well as the associated costs considered from a macro-economic point of view and for Europe as a whole.

This is a field where a lot of development activities are taking place with new, more efficient and/or cheaper routes and processes bound to be developed in the years to come. In order to integrate such developments, the database will need updating at regular intervals and the partners to the study are committed to doing this through a yearly review process.

In this article we briefly revisit the main conclusions of the study in terms of energy and GHG balance, giving particular attention to the issues of potential volumes and optimum use of limited resources.

Energy efficiency and GHG emissions: an inevitable trade-off?

The wide range and diversity of options has been conveniently represented in Figure 1 by plotting the total WTW GHG emissions associated to a pathway (expressed in g CO_2 equivalent per km) against the total energy required (in MJ per 100 km).

Comparison of well-to-wheels GHG emissions and associated energy consumption
(box in lower left hand corner indicates current gasoline vehicle performance)

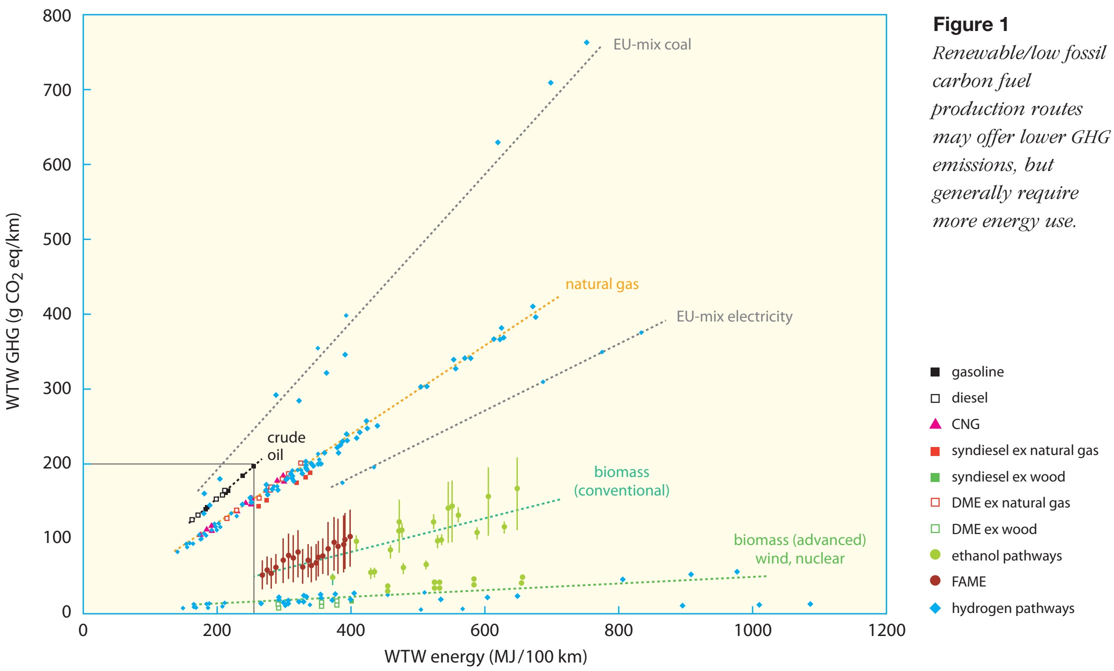

Figure 1
Renewable/low fossil carbon fuel production routes may offer lower GHG emissions, but generally require more energy use.

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The data points cluster on trend lines representing the different primary fuel sources, reflecting a constant GHG emission factor (in g CO_2eq/MJ). For the fossil-based fuels this illustrates the fact that coal, crude oil or natural gas are the primary energy sources used throughout the production pathway of the respective fuels. Thus fuels derived from coal give more GHG emissions for the same energy consumption than equivalent fuels derived from crude oil or natural gas, on account of the lower carbon content of the primary energy source.

Equally noteworthy is the large range of variation along the trend lines—how the fuel is produced and used is just as important as the resource used. The natural gas line illustrates the many ways of using this resource and how different the results can be in terms of energy and GHG emissions. For example, using hydrogen from natural gas reforming in a fuel cell vehicle can be three times more efficient than burning hydrogen in an internal combustion engine when the fuel is prepared by electrolysis and electricity generated from natural gas. The box in the lower left-hand corner of the chart highlights the performance of current gasoline vehicle technology while the points along the crude oil line represent different powertrain technologies, improving in efficiency from the 2002 gasoline conventional port injection engine to a 2010 diesel hybrid. Many of the possible pathways derived from natural gas or coal produce more GHG emissions and consume more energy than today's conventional fuels pathways.

There is more spread when it comes to biomass-based fuels as a range of energy sources is used at different stages of these pathways. Nevertheless, the 'conventional' biofuels (ethanol, FAME) broadly fall on an intermediate line illustrating the fact that their production still involves a significant amount of fossil energy. For these fuels we have shown the large range of variation related to the specific uncertainties over N_2O emissions from agriculture.

The more advanced conversion technologies (e.g. synthetic fuels based on biomass gasification or wind electricity) utilise virtually only renewable energy for the conversion process. As a result GHG emissions are low and the corresponding points lie on an almost horizontal line, very close to the horizontal axis.

Energy efficiency and GHG emissions reduction are both important goals in the quest for alternative energies and fuels. In this plot the 'desirable' area is therefore the bottom left-hand corner. Taking the crude-oil based fuels as a starting point, it is clear that a majority of the alternative fuel routes towards lower GHG emissions correspond to an increase in primary energy use. Only the combination of the most efficient converters (fuel cells) and the most favourable fuel production pathways result in improved energy efficiency. This 'trade-off' between GHG emissions and energy is important because most of the energy resources associated with low GHG emissions have a limited availability. Optimum global GHG emissions reduction therefore implies optimum and efficient use of limited energy resources.

What potential for alternative fuels?

The overarching reasons behind the success of fossil fuels are their high energy density, relatively low cost and, importantly, their very wide availability. Very few, if any, of the alternative candidates can offer a similar package. Energy density is an issue for all gaseous fuels and in particular for hydrogen. Complex production processes, logistics and the like make for generally high costs compared to conventional fuels. But arguably one of the most serious issues facing most alternative fuels, is how much could, or should, be made.

Alternative fuels are pursued for two main reasons, GHG avoidance and diversification of energy supply. Attractive energy sources to produce them are therefore those that are renewable, or at least low-carbon, and 'home-grown'. In the renewable arena, this leaves space only for biomass, wind or direct solar energy. Nuclear energy delivers virtually carbon-free electricity (or high temperature heat) and nuclear fuel is in plentiful supply. It does, however, raise societal and political issues, the discussion of which would go far beyond the scope of this article. Nuclear fusion is likely to be more acceptable but it is still a scientist's dream.

The planet is unlikely to run out of wind any time soon but the number of sites that are suitable for large scale wind farms and also acceptable to the public is clearly limited (in the same way as practically all suitable and acceptable sites for dams have now been exploited). Technology is playing its role, producing ever larger, more efficient, quieter and cheaper turbines. A very wide range of estimates has been proposed for wind energy. What will actually be achieved will depend on a large number of factors, both technological and political.

In spite of spectacular technological advances in, for example, photovoltaic cells, the capture and storage of direct solar energy is still in its infancy and is unlikely to receive serious consideration on a very large scale for several decades.

Wind and most versions of direct solar energy produce electricity which can of course be used directly to meet a portion of the fast-expanding demand. Turning this electricity into say, hydrogen, is an additional step that is unlikely to be justified from an energy efficiency point of view, inasmuch as renewable electricity remains limited.

The amount of biomass that can be produced from a certain area of land is also limited. In addition, energy crops must compete with food crops and other desirable uses of land. Food production is an essential demand and it is difficult to imagine that energy production would ever be given a higher priority. In our attempt to produce a fair estimate of the potential of biomass for energy production, we have therefore adopted a 'constant food' scenario for Europe. The land available for energy crops is then what is currently not in use (set-asides) and what will become available as a result of increasing yields.

We have then considered a number of alternative scenarios in each of which one particular type of fuel would be maximised. The results of these calculations are shown on Figure 2. The cumulative bars show the amount of fuel that could be produced in each scenario, expressed in energy content. This would be achieved by using the surplus land preferentially for e.g. wheat (maximum ethanol), oil seeds (maximum FAME) or wood (maximum synthetic fuels). As most pathways use some fossil fuels, only a portion of that energy is really renewable. Diesel fuel production is more favourable than ethanol, particularly in the form of synthetic diesel (produced from woody biomass). Note also that these figures are expressed on a 'Well-to-Tank' basis, i.e. do not take into account the differences in powertrain efficiency. Reality is likely to be a mixture of these extreme scenarios. In all cases the maximum potential remains modest, say in the order of 1500 PJ/a, compared to a total expected demand for transport fuels of around 14,000 PJ/a.

Potential of biomass for energy production (WTT basis, EU-25)

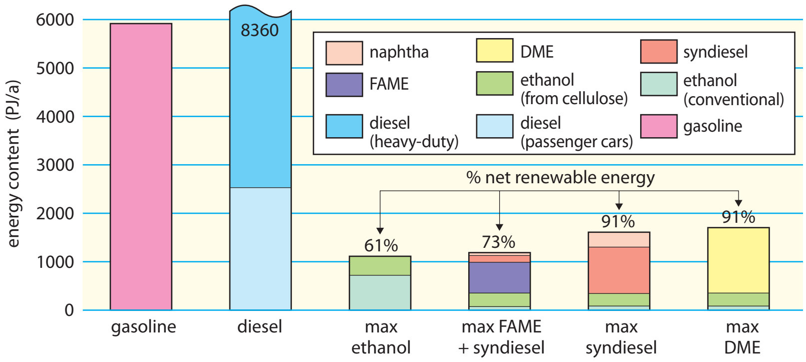
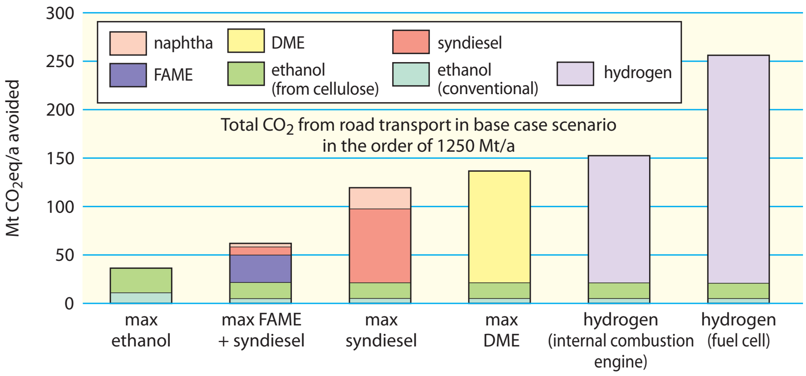


Figure 2
Maximum potential of biomass is around 10% of the European transport fuel demand.

From a 'Well-to-Wheels' point of view this would translate into CO_2 avoidance as shown in Figure 3, in which hydrogen options have been included. The higher biomass conversion efficiency of the synthesis pathways compared to the 'conventional' FAME and ethanol routes gives a clear advantage to the former. For hydrogen, the conversion efficiency is even higher and can be compounded by the high efficiency of the fuel cell. In the

Figure 3
The potential GHG savings depends on the fuel pathway chosen.

Potential CO_2 avoidance (WTW basis, EU-25)



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Potential for CO_2 avoidance through alternative uses of land

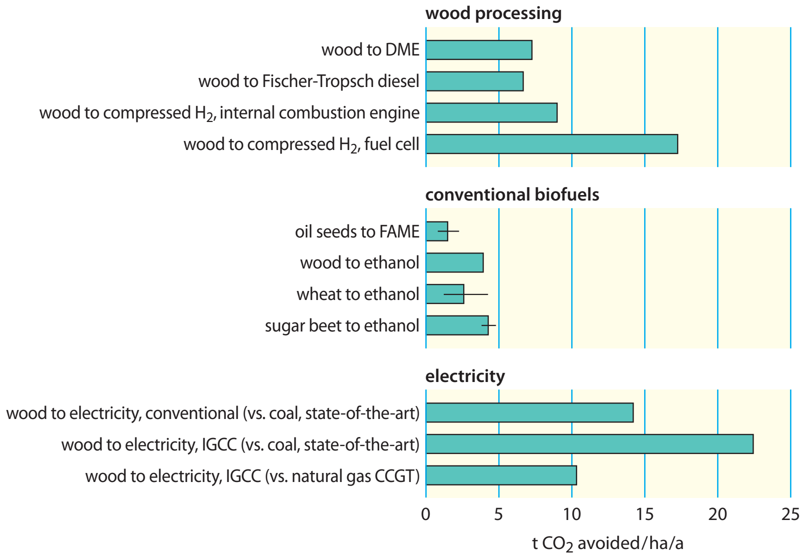

Figure 4

One hectare of land can be used in many different ways, resulting in very different GHG savings.

most favourable 'maximum hydrogen/fuel cell' scenario, the use of biomass could allow a CO_2 avoidance of about 20% of total transport emissions. It should be borne in mind however, that hydrogen involves a complex system of distribution infrastructure and new vehicles, whereas the liquid fuels can be virtually seamlessly integrated into the existing fuel systems. Again reality is likely to be more diverse resulting in a lower figure. The above figures also assume that all surplus biomass is available for road fuels production, which is unlikely to be the case.

Optimising limited renewable resources

It is clear from the foregoing that if renewable sources in general, and biomass in particular, have the potential to play a role in the future fuel mix, they will only be able to cover a fraction of the transport fuels demand. The same renewable energy sources are also eyed by other sectors, in particular electricity—the demand for which is growing at a steady pace. This opens the question of optimisation of their use and in particular of their potential for GHG avoidance.

Using the results of our study, Figure 4 illustrates, with a number of examples, the large range of net GHG that could be avoided through various alternative uses of a hectare of land. This net potential depends of course on the proposed crop and conversion process but also on what is being substituted. For example, displacing coal for electricity production is more effective than substituting gas, even more so when the efficient IGCC (Integrated Gasification and Combined Cycle) process is used. It is clear that the 'conventional' biofuels only have a modest potential in this respect compared to either electricity production or the more sophisticated wood conversion pathways into hydrogen or synthetic fuels. Hydrogen benefits from the expectation of very efficient fuel cells. It must be borne in mind, however, that this is but one aspect of the problem; biofuels and hydrogen are very different propositions in terms of investment, complexity, impact on fuelling infrastructure and vehicles, etc.

All the same, this illustrates the complexity of the issue and the necessity to treat energy questions globally rather than with a narrow focus on transport. Both GHG emissions and security of energy supply are global energy issues rather than specific to the transport sector, and what is favoured for the latter should not be detrimental to the former.