EUCAR/JRC/CONCAWE well-to-wheels study

Interim results contribute to the Commission's work on alternative fuels

DG TREN's initiatives on alternative fuels for road transport

Following the publication of the Green Paper on the Security of Energy Supply in the autumn of 2001, the EU Commission and in particular DG TREN[1] focused on a number of actions to support the Green Paper's main objectives. These mainly concern the development of alternative fuels for transport, in particular the delivery of reductions in greenhouse gas (GHG) emissions and the enhancement of energy supply security. Three major routes were singled out as the most promising, namely biofuels, natural gas and hydrogen.

Biofuels were addressed through the Directive on the promotion of biofuels which has recently been adopted.

In June 2002, DG TREN established the 'Alternative Fuels Contact Group', the remit of which was to 'give advice to the Commission concerning the technical and economical developments in the field of alternative fuels for road transport, with priority on natural gas and hydrogen, and on the measures by which the Community can promote their use with the purpose to attain a 20% market share by 2020'. Such measures could include legislative actions as well as research and technical development.

The Contact Group brought together all relevant stakeholders including representatives of the automotive and oil industries.

A cooperative approach to well-to-wheels analysis

At the end of 2001, EUCAR[2], JRC[3] and CONCAWE started work on a joint analysis of various alternative road fuels and associated powertrains on a well-to-wheels basis with the following objectives:

- Establish the energy and GHG (greenhouse gas) balance for a number of different fuel/powertrain options in the context of plausible European scenarios;
- Estimate the scale at which such schemes could be developed and the associated investments and operating costs;
- Take into account data from all relevant reliable and authoritative sources;
- Report results in a fully transparent way, including the publication of the database and methodology.

The energy resources considered are crude oil, coal, natural gas, biomass and wind. From these, a variety of fuels can be produced, including conventional road fuels, compressed natural gas (CNG), hydrogen, methanol, dimethyl ester, fuels from Fischer-Tropsch synthesis, ethanol and biodiesel. The powertrains include port-injected gasoline, direct injection gasoline and diesel, dedicated natural gas and fuel cells (with and without reformer), with hybridisation as an option. The study focuses notionally on the 2010 horizon in terms of technologies.

The study gathered pace during 2002 with the assistance of LBST[4] for the well-to-tank part and IFP[5] for the tank-to-wheels part. It soon became clear that the well-to-wheels analysis, already under way in the EUCAR/JRC/CONCAWE collaboration, could be an essential building block in the work of the Contact Group. Close contacts were established between the study team and DG TREN, resulting in a prioritisation of the study work to focus first on natural gas and then on hydrogen.

The well-to-wheels analysis on the conventional fuels and CNG pathways has now been completed and the results presented to the Contact Group. The interim

[1] *Directorate General for Transport and Energy*
[2] *European Council for Automotive Research*
[3] *The EU Commission's Joint Research Centre in Ispra*
[4] *Ludwig Bolkow System Technik, a German consultancy specialising in alternative fuels and notably hydrogen*
[5] *Institut Français du Pétrole*

report from the Contact Group incorporating the results from the well-to-wheels study was published in April. An overview of the main findings is given below.

Conventional road fuels: marginal analysis is the key

Today, gasoline and diesel fuel account for nearly all of the road fuel market in Europe, as well as in the rest of the world. There is a general consensus that conventional oil-based fuels will continue to supply most of our transport fuel needs for the foreseeable future, alternatives taking a limited share of the market. It is therefore important to assess any shifts in the base gasoline and diesel pool on a marginal basis.

As a result of the pre-eminence of road freight transport and of the high proportion of diesel cars, Europe is structurally long in gasoline and short in diesel fuel. The European refining system struggles to meet the European diesel fuel demand while it over-produces gasoline. The marginal diesel fuel production is therefore more energy intensive than the marginal gasoline production (0.10 and 0.08 MJ/MJ respectively). The complete GHG balance for the marginal conventional fuels, including crude oil production and transportation as well as final fuel distribution, is shown in Figure 1.

Greenhouse gas emissions associated with the provision of marginal gasoline and diesel in Europe

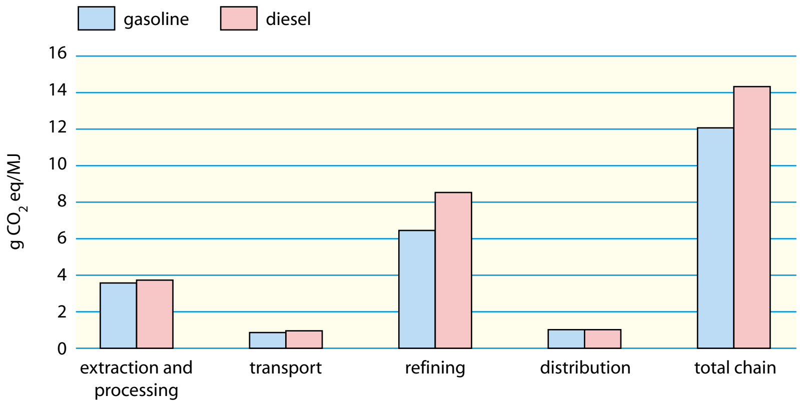


Figure 1
The marginal diesel fuel production in Europe is more energy intensive than the marginal gasoline production (0.10 and 0.08 MJ/MJ respectively).

Note: the GHG emissions include all identifiable sources of CO_2, methane and nitrous oxide (N_2O), converted into CO_2 equivalent using the Intergovernmental Panel on Climate Change (IPCC) factors of 21 for methane and 310 for N_2O.

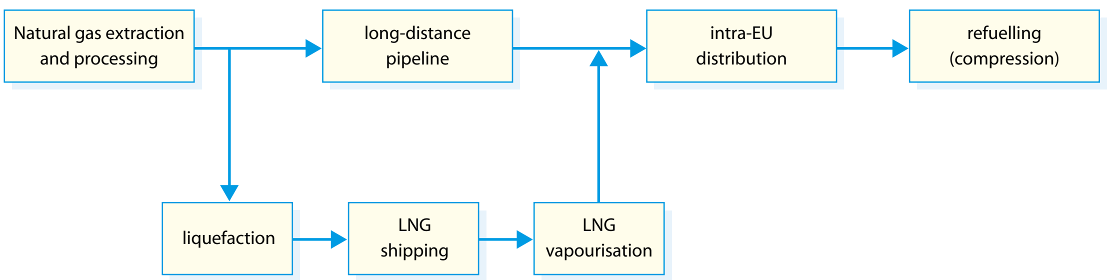
The routes to compressed natural gas

Natural gas is widely available in Europe, distributed through a dense network of pipelines to industrial commercial and domestic consumers. The indigenous European production (mainly from the UK, The Netherlands and Norway) is complemented by sizeable imports mainly from Algeria and Russia. Demand is expected to grow very strongly, mainly to feed the increasing demand for electricity, particularly in view of the nuclear phase out in many countries. World natural gas reserves are very large but European production is set to decline from around the end of this decade so that the share of imports in the European supply will increase steadily. Russia, other countries of the Former Soviet Union and the Middle East are the most credible long-term major supply sources for Europe.

The development of a natural gas market for road transport, in the form of CNG, would require further imports of marginal gas which we have taken as the basis to describe the potential supply chains.

Natural gas can reach Europe either overland via long-distance pipelines or by sea in liquefied form (LNG). We have considered three sourcing scenarios:

- 7000-km pipeline (typically from western Siberia);
- 4000-km pipeline (typically from south-west Asia);
- LNG shipping over a distance of about 10,000 km (typically the Middle East).



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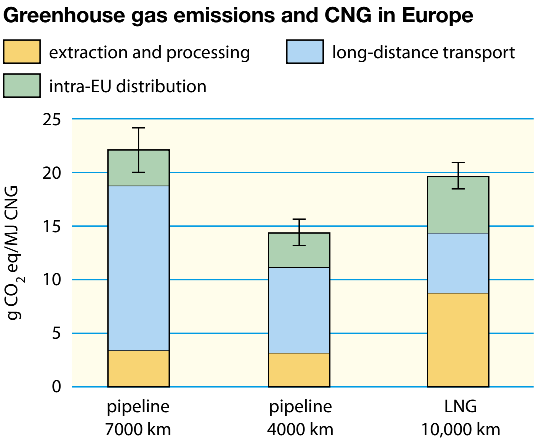


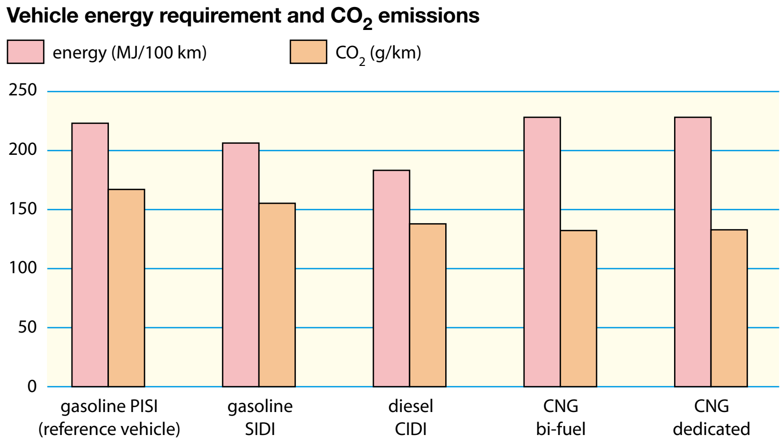


Figure 2 (above left)
The origin of the gas is a major factor determining the energy balance.

Note: The 'uncertainty bars' pertain to the total energy or GHG and represent the plausible range of variation to account for the variety of actual situations and the variability of some of the data from different sources.

Figure 3 (above right)
In terms of CO_2 emissions the CNG engine fares better because of the lower carbon content of natural gas. Fuel economy, however, is no better than the reference gasoline engine.

The well-to-tank GHG emissions for these routes are summarised in Figure 2.

The need to transport the gas over long distances accounts for a large part of the total energy. The origin of the gas is therefore the major factor determining the energy balance. Transport in liquid form is more efficient but this advantage is negated by the energy required for liquefaction so that LNG comes out worse than piped gas (for the 4000-km pipeline case).

The final compression (to 25 MPa in order to refuel the vehicles) also requires a large amount of energy which is highly dependent upon the pressure available in the network. In this study we have assumed the gas is available at 0.4 MPa (gauge), being the pressure of the modern EU networks with a plausible range of 0.1 to 2.0 MPa.

From tank to wheels

In order to evaluate the potential of various alternative fuels it is crucial to consider how and in what vehicle they are likely to be used, complementing the well-to-tank by a tank-to-wheels analysis.

So far in this study we have considered a 'virtual' vehicle based on the VW Golf, a typical European mid-class vehicle. With the help of the ADVISOR[6] software, the vehicle has been 'equipped' with a powertrain and relevant equipment (e.g. fuel tank) pertinent to each fuel. The basic premise is that all vehicle/fuel combinations must equal or exceed a fixed set of customer performance criteria.

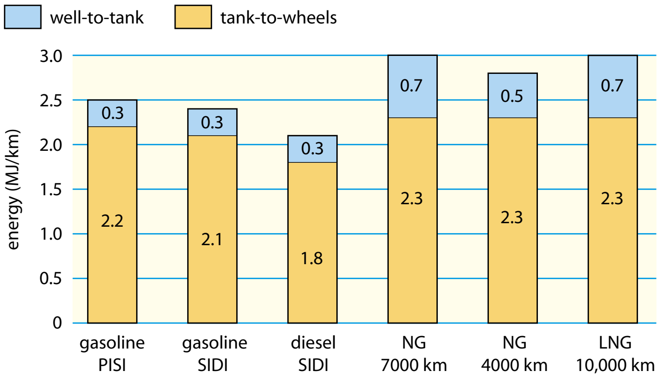
The engine technologies considered so far are those available in 2002, meeting Euro-3 emission standards. In the next phase of the study the assumptions will be revised to represent the best estimates of the performance of the 2010 technologies (and Euro-4 standard). The emissions and fuel consumption are judged on the basis of the New European Driving Cycle (NEDC).

The reference vehicle has a port-injection spark-ignition (PISI) 1.6 l gasoline engine. For gasoline the lean-burn direct injection (SIDI) technology offers a somewhat more efficient alternative (7%) although the real benefit over the driving cycle is far less than was hoped for a few years ago. The direct injection diesel engine needs to have a larger displacement in order to meet the performance criteria (1.9 l) but delivers the expected robust efficiency improvement (about 18% compared to gasoline).

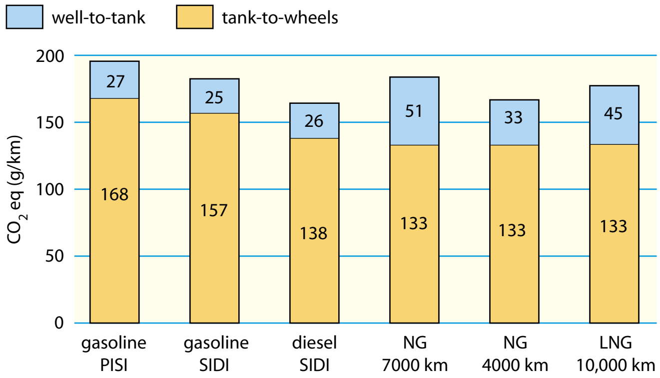
For CNG, two cases have been considered, either a bi-fuel (gasoline) vehicle based on the 1.6 l gasoline PISI, or a dedicated CNG vehicle. Direct injection is not considered feasible for CNG so the dedicated engine is also a PISI.

[6] *ADVISOR: a publicly available engine and vehicle simulation software*

Well-to-wheels energy requirement of conventional and CNG vehicles



Greenhouse gas emissions associated with conventional and CNG vehicles



The bi-fuel engine suffers a loss of torque when operated on CNG, due to the lower specific energy offered by this fuel. Although the resulting acceleration performance of the bi-fuel vehicle is affected, this has been accepted, as the minimum top speed is reached and as it is representative of a real commercial case. Because the engine is not optimised for natural gas, there is no energy efficiency benefit compared to gasoline. On the total cycle the fuel consumption turns out slightly higher than for gasoline. The dedicated engine can take advantage of the high octane rating of natural gas through an increased compression ratio leading to better efficiency. This advantage is, however, fully counterbalanced by low load inefficiency as a larger displacement (2.0 l) is needed to fulfil the performance criteria. Overall, the dedicated engine comes out as no better than the reference gasoline engine in terms of fuel economy (Figure 3). In terms of CO_2 emissions the CNG engine fares better because of the lower carbon content of natural gas.

Further technical developments such as downsizing and turbo-charging are expected to bring further efficiency improvements to CNG and gasoline engines alike. For diesel, performance gains are also achievable, although the room for such enhancements is more limited, present diesel engines being already direct-injected and turbo-charged.

The overall well-to-wheels picture

The total well-to-wheels picture is shown in Figures 4a and 4b.

CNG chains are generally more energy-intensive than those for conventional fuels. In terms of GHG emissions, this is partly compensated by the lower carbon content of natural gas so that the present CNG chains offer some benefit compared to gasoline but not compared to diesel.

The geographic origin of the gas is the single most important parameter. Future marginal gas supplies to Europe are far away and the associated transport energy penalises the CNG option.

Figure 4a (above left)
CNG chains are generally more energy-intensive than those for conventional fuels.

Figure 4b (above right)
CNG chains offer some benefit compared to gasoline because of the lower carbon content of natural gas. There is no benefit when compared to diesel.