Alternative Fuels

Annex A of the Handbook 'Navigating Transport NAMAs'

TRANSfer Project – Towards climate-friendly transport technologies and measures

The concept

A shift from conventional fuels (petrol and diesel) to alternative fuels, such as natural gas, liquefied petroleum gas (LPG), biofuels, hydrogen or electricity (see Factsheet '*Electric Vehicles*') is frequently discussed as a promising potential for emission reductions in the transport sector. The GHG mitigation potential of these fuels depends on the specific GHG emissions per energy unit of the whole fuel chain (well-to-tank) and on the drive train efficiency (tank-to-wheel) (Kahn Ribeiro *et al.,* 2007). The specific emissions of petrol are 89 g CO_2e/MJ and for diesel 84.9 g CO_2e/MJ (Fischedick *et al.,* 2004). The efficiency of a modern petrol engine is 25 to 30 %. Diesel engines operate more efficiently and therefore diesel cars produce less carbon emissions (16–24 %) than petrol cars. But on the other hand, diesel vehicles emit more atmospheric pollutants that reduce local air quality (Kahn Ribeiro *et al.,* 2007).

To ascertain that alternative fuels lead to improvements in terms of vehicle emissions, the whole lifecycle of these fuels has to be considered (see Chapter 1 and Chapter 3). Besides fuel processing, the fuel's feedstock can also produce GHG emissions. The potential for a widespread use and the side effects of alternative fuels vary considerably between the different options and often depend on local circumstances. Furthermore, the fuels and associated technologies are at different stages of development. For this reason, present and future availability and competitiveness have to be evaluated carefully. It is essential to thoroughly review the different fuel options. Each country has to consider its environmental challenges, financial resources, technical capabilities and natural resources to ensure that a specific alternative fuel not only provides mitigation potential, but that it is also cost-effective and sustainable. Governments should implement the necessary incentives or mandates for market penetration of alternative fuelled vehicles only if the mentioned requirements are fulfilled.

Available options for the substitution of conventional fuels:

- Natural Gas
- Liquefied Petroleum Gas (LPG)
- Biofuels
- Hydrogen

For more details on each option see below.

Therefore, the available options for the substitution of conventional fuels are outlined and the emission reduction potentials, barriers, side effects and conflicts are shown for each alternative fuel. Although the compiled information does not intend to provide a final conclusion on the various options, it still can provide a first insight into the factors that should be considered before introducing policy options for alternative fuels.

Delhi, India – Photo by Pongnarin Petchu, 2008

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Natural gas

Fuel characteristics

Natural gas is a fossil energy source that is used as vehicle fuel in a gaseous form as compressed natural gas (CNG), in a fluid form as liquefied natural gas (LNG) or as gas-to-liquid fuel (GTL). The primary component of natural gas is methane.

LNG and GTL are converted from natural gas by different processes.

Application

Today, CNG is more common than the liquefied fuels originating from natural gas. In many countries a refuelling infrastructure exists, at least partially. For instance, in Germany more than 400 CNG refuelling stations are in use (Fischedick *et al.,* 2004). However, extensions to the existing infrastructure might be necessary and can lead to considerable investment costs. To store the gas a larger and heavy tank is necessary. In passenger cars, these tanks can result in a reduction of useful space. Due to the low energy density of CNG and the storage requirements, CNG vehicles have a lower driving range than conventional vehicles. Depending on the vehicle type, current driving ranges vary between 180 and 450 km (Geitmann, 2008)

Today, several vehicle manufacturers produce CNG vehicles and existing petrol or diesel vehicles can be converted to run on CNG. Most converted cars have a combined drive system that accepts CNG and petrol. There are also CNG driven heavy-duty vehicles. CNG buses are in operation in Paris, New York, Los Angeles, Dehli, Jakarta and in several other cities. Here, the tank is usually installed on the roof or can be fitted under the floor so that the loss of space is minimal (Walsh and Kolke, 2005).

Due to the large and heavy tanks for CNG storage and the lack of dense refuelling infrastructure, CNG vehicle can be used most effectively in urban transport, where the fuelling infrastructure is denser and usually only short distances need to be covered (Walsh and Kolke, 2005).

The use of LNG in transport would require a new distribution infrastructure since it has to be stored at -163°C to sustain the liquid form. Furthermore, higher energy demand and costs compared to CNG makes a widespread application of LNG unlikely (Fischedick *et al.,* 2004).

GTL is compatible with existing diesel vehicles and distribution infrastructure. However, only few plants to produce GTL are in operation worldwide (Kejun, 2009; Fischedick *et al.,* 2004).

GHG reduction potential

The use of natural gas can contribute to lower GHG emissions, since it contains less carbon per unit of energy than petrol. The European natural gas mix has specific GHG emissions over the CNG fuel chain of 72.8 g CO_2e/MJ (Fischedick *et al.,* 2004). Due to its low carbon content, the total life cycle emissions of CNG engines are 15 to 25 % lower than of petrol engines (Kahn Ribeiro *et al.,* 2007). However, well-to-tank emissions vary depending on the gas supply structure. Transport energy and leakage of methane can reduce the GHG mitigation potential.

Natural gas consists mainly of methane, which is a stronger greenhouse gas than CO_2, but which has a shorter lifetime in the atmosphere. Since natural gas is often flared in refineries, the use of otherwise wasted natural gas can provide additional reduction potential.

The liquefied forms of natural gas vary in their life cycle emissions. LNG causes much lower CO_2 emissions during the production process compared to GTL. Furthermore, the CO_2 emissions from burning LNG in an engine are low compared to GTL and conventional diesel. However, the energy content of LNG is considerably lower than of conventional diesel and GTL.

GTL can even result in increased greenhouse gas emissions (fuel chain emissions of 99 g CO_2e/MJ) compared to conventional fuels, since the current processes are relatively inefficient (Fischedick *et al.,* 2004). Only if CO_2 sequestration is used during the production process GTL offers GHG mitigation potential.

Local air pollution and noise

In terms of local pollutants, natural gas provides advantages compared to petrol and diesel engines. Hydrocarbon emissions are reduced by 80 % and nitrogen oxide emissions by 20 % compared to petrol vehicles. Furthermore, compared to diesel vehicles, sulphur dioxide, particulate matter and black carbon are reduced by 99 % (Geitmann, 2008). Therefore, in polluted cities CNG is often used in public transport vehicles as a substitute for diesel. However, exhaust gas after-treatment devices for gasoline engines reduce the emission advantage of CNG in terms of air pollution (Kahn Ribeiro *et al.,* 2007).

Natural gas vehicles produce 50 % less noise emissions than conventional vehicles (Geitmann, 2008).

Conclusion

Today, CNG only constitute a small part of the transport fuel consumption (IEA, 2009). An increase in the share of CNG fuelled vehicles offers GHG mitigation effect. However, the development of a distribution and refuelling infrastructure is necessary and will be associated with huge investments. An additional barrier to widespread utilisation is the incompatibility with conventional internal combustion vehicles. Some of these barriers can be overcome with liquefied natural gas fuels (LNG and GTL). However, these fuels are disadvantageous compared to CNG in terms of GHG emissions and cost. Currently, the use of CNG is most promising for vehicle fleets that operate close to filling stations (*e.g.* urban buses, waste collection, urban taxis or minibuses).

As natural gas is a fossil fuel it will ultimately face depletion and rising costs as it is widely used for electricity generation or for domestic cooking and heating. Thus, in the long run, natural gas is not suitable to substitute oil based transport fuels.

Liquefied petroleum gas (LPG)

Fuel characteristics

Liquefied petroleum gas (LPG) is a mixture of several hydrocarbon gases. In contrast to natural gas, it consists mainly of propane and butane. LPG is derived from fossil fuels as a by-product in petroleum refining and natural gas extraction.

Application

LPG driven vehicles are often converted from conventional petrol based vehicles. Usually, converted vehicles are designed for bi-fuel operation, *i.e.* they can run on gas or petrol. Thereby, the vehicles are less dependent on a widely available LPG infrastructure.

GHG reduction potential

LPG has a lower carbon content than petrol, but drive train efficiency is less, so that these vehicles have higher fuel consumption (Vossenaar, 2010).

Bi-fuelled LPG cars can result in GHG emission savings of about 15 % compared to cars that run solely on petrol[1]. However, in the long run the GHG emission advantage of LPG can be diminished as much research is put into energy efficiency improvements of conventional vehicles. With higher efficiency tank-to-wheel emission of conventional vehicles will decline (Vossenaar, 2010).

Compared to CNG and LNG the life cycle of LPG is advantageous since less energy is necessary to liquefy the propane/butane mixture than to liquefy or compress natural gas (Vossenaar, 2010).

Local air pollution and noise

Compared to conventional petrol the use of LPR reduces nitrogen oxides by 80 %, hydrocarbons by 60 % and sulphur dioxide and black carbon by 100 % (Geitmann, 2008).

LPG vehicles reduce noise pollution by 50 % (Geitmann, 2008).

Conclusion

In addition to the limited GHG reduction achievements, the potential of LPG is restricted by supply constrains as it is bound to petroleum and natural gas extraction and refining. Thus, a large-scale switch to LPG is unlikely in many regions. The use of LPG is most suitable for limited fleets that operate in areas sensitive to air pollution. For instance, urban buses, taxis or delivery trucks can be switched to LPG (Vossenaar, 2010; Walsh and Kolke, 2005). Overall, LPG will not play a major role in CO_2 mitigation actions in the transport sector.

[1] LPG performs hardly any better than diesel fuel with regard to the GHG emissions.

Biofuels

Fuel characteristics

Biofuels are liquid or gaseous fuels that are produced from organic matter derived from plants or animals. The main biofuels used in the transport sector are ethanol, biodiesel and biogas. The predominant feedstocks for biofuels are oilseed crops, grains, sugar crops, agricultural residues, trees and grasses. Currently, research focuses on algae as next-generation biofuel feedstock, which offers the potential of a more sustainable biofuel production. Biofuels can be divided into first generation (or conventional) and second generation (or advanced biofuels). However, there is no uniform classification. Typically, either maturity of production technology, GHG emission balance or feedstock determines if the fuel is classified as a first or second generation biofuel (Howarth *et al.,* 2009; IEA, 2009; IEA, 2011a).

Application

Today, 3 % of the energy used globally in road transport comes from biofuels. Single countries achieve much higher shares in biofuels, such as Brazil, where biofuels constitutes 21 % of the total road transport consumption. The US and the European Union have biofuel shares in road transport of 4 % and 3 % respectively (IEA, 2011a).

The different fuels can substitute petroleum based fuels and are either used in pure form or blended with conventional fuels. To use pure biofuels, modifications of the engines are usually necessary, whereas blended fuels can be burned in most conventional internal combustion engines. Many vehicle manufacturers certify their cars to operate on a certain level of biofuel blend. Typically, conventional petrol cars can be blended with 10 to 15 % ethanol. For conventional diesel engines biodiesel blends up to 20 % are coming into use. Flex-fuel-vehicles allow the use of fuels with higher ethanol or biodiesel blends (IEA, 2011a). Brazil has the largest fleet of flex-fuel-vehicles and their share is rising, as more than 80 % of new car sales in Brazil are flex-fuel-vehicles (ANFAVEA, 2011).

The fuels are, to a great extent, compatible with the existing distribution and supply infrastructure (Howarth *et al.,* 2009).

GHG reduction potential

The GHG reduction potential of biofuels varies largely and depends on the feedstock, the farming practices, the refining operations and the potential induced land-use changes. For instance, the use of sugarcane for ethanol production can lead to higher GHG savings (about 80 to 100 %) than ethanol production form corn (about 30 to 50 %[2]) (Howarth *et al.,* 2009). On the other hand, conversion of rainforests to palm oil plantations can even increase the net emission of greenhouse gases. In general, biofuel generation from organic waste is favourable when compared to energy crops in terms

[2] Depending on the process-energy also a net increase of GHG emissions can be associated with the use of ethanol from corn.

of GHG emissions and environmental effects. Furthermore, new feedstock and conversion technologies are being developed to improve the environmental performance of biofuels (IEA 2011a; Howarth *et al.,* 2009).

Local air pollution and noise

Emissions of carbon monoxide and sulphur are reduced compared to conventional fuels by using biofuels, but they cause higher emissions of nitrogen gas, which causes acid rain. Several studies indicate a decrease in the overall amount of particulate matter emissions from biodiesel, but the amount of ultrafine and nano particles, which have a stronger toxic effect, can be higher from biodiesel exhaust than from conventional diesel (Chien *et al.,* 2009).

Adverse effects

Adverse social and environmental effects and conflicts can be associated with the use of biofuels. These environmental consequences depend on the feedstock that is used as well as on the cultivation and conversion processes that are applied (Howarth *et al.,* 2009)

Conflicts arise between land use for first generation biofuel production and the growing demand for land for food and feed production.

Deforestation, conversion of grassland, and monoculture cultivation of crops for biofuel production lead to a loss of biodiversity.

Competition for freshwater as irrigation of biofuel crops decreases the water availability for food production and other uses. Furthermore, adverse effects for freshwater ecosystems can be expected.

Water pollution (especially by nitrogen) originating from the runoff from agricultural fields and from the production process of biofuels.

Air pollution from the vehicle exhaust of biofuels and from harvesting sugarcane[3].

Conclusion

Biofuels are expected to play an important role in reducing CO_2 emissions in the transport sector and to decrease the dependency on oil (IEA, 2011a). However, it has to be ensured that life cycle emissions of biofuels are lower than conventional fuels and additional sustainability criteria need to be considered to evaluate the overall performance.

[3] Often sugarcane is burned before harvest leading to smoke, fine particles and nitrogen gases that endanger the environment and human health.

Hydrogen

Fuel characteristics

Hydrogen is a secondary energy carrier and can be generated from fossil fuels, biomass and electricity. Currently, research is being undertaken to use algae for hydrogen production.

Application

Today, 96 % of hydrogen is produced from fossil fuel feedstock including natural gas, petroleum and coal. Only 4 % is obtained from the electrolysis of water (Creutzig *et al.,* 2001).

Hydrogen can be either used in an internal combustion engine or in a fuel cell. A fuel cell generates electricity from hydrogen by a reaction of hydrogen and oxygen, so the vehicle is powered by an electric motor. Using hydrogen in an internal combustion engine is less favourable, since the efficiency is much lower than in a fuel cell.

On-board storage and thus the vehicle's driving range are limited for both hydrogen fuel cell vehicles (HFCVs) and hydrogen driven internal combustion engine vehicles.

A main barrier to the use of hydrogen as transport fuel for cars is the lack of distribution and refuelling infrastructure.

Currently, HFCV are too expensive and they are mainly used in demonstration projects. To realise cost reductions by technological improvements and mass production of hydrogen fuel cell vehicles, substantial governmental actions are necessary. Today no attractive market for HFCV exists. Only with governmental interventions and financial incentives will research institutions and the automotive industry invest in these vehicles.

The costs for hydrogen production from renewable energy sources are very high.

GHG reduction potential

The life cycle GHG emissions of hydrogen vary largely across the different production processes. The primary energy source that is used for hydrogen production determines the sustainability of the fuel. Thus, the whole life cycle of the fuel has to be considered to determine the mitigation potential.

With current fuel cell vehicle efficiency and efficiency of hydrogen production from natural gas, the well-to-wheel CO_2 emissions of HFCVs are 50 to 60 % lower, compared to conventional petrol vehicle (Kahn Ribeiro *et al.,* 2007).

Gasification of biomass is also an option for the production of hydrogen, which offers GHG reduction potential.

If hydrogen is produced from water using electricity provided by low-carbon energy sources such as solar, wind or hydropower, HFCV offer the potential of zero carbon emissions (Kahn Ribeiro *et al.,* 2007).

Local air pollution and noise

Fuel cell vehicles fuelled by hydrogen have zero tailpipe emission and have a very low noise level (Kahn Ribeiro *et al.,* 2007).

Conclusion

In general the use of hydrogen in transport is very cost-intensive due to the need for new vehicle technologies, infrastructure and the relative high cost of hydrogen production (IEA, 2009). However, if hydrogen is produced from low-carbon energy sources, the GHG reduction effect is immense. Additionally, HFCV are very quiet, non-hydrocarbon pollution is little and, since hydrogen is produced from a variety of sources, its use provides energy security (Kahn Ribeiro *et al.,* 2007). Although hydrogen buses are already used in public transport in several cities around the world (*e.g.* London, Berlin, Beijing, Perth), the widespread use of HFCV is only likely in the long-term time frame.

Table 1: Typical GHG emission level of different transport fuels (adopted from IEA, 2009)

High	Petrol
	Diesel
	GTL
High to moderate	LPG
	Hydrogen from fossil fuels
	Electricity from fossil fuels
	LNG
	CNG
	Ethanol from corn
Moderate	Oil seed biodiesel
Low	Ethanol from sugar cane
	Advanced biodiesel
Very low	Hydrogen from renewables
	Electricity from renewables

Policies and measures to create a favourable framework for alternative fuels

Decision-makers can increase the share of alternative fuels, but they need to ensure that these fuels offer a sustainable GHG reduction potential.

Instruments	Intended effects
Low-carbon fuel standards (see Factsheet '*Decreasing the Carbon Intensity of Fuels*').	Ensure that alternative fuels, which offer life cycle GHG emission reduction potential, are promoted.
Emission-based fuel taxation (see Factsheet '*Decreasing the Carbon Intensity of Fuels*').	Promote alternative fuels that offer GHG emission reductions. Yet, it is difficult to include all the alternative fuels and their upstream emission in the tax scheme.
Renewable fuel quotas (see Factsheet '*Decreasing the Carbon Intensity of Fuels*').	Foster market penetration of biofuels. It is highly important to bind this measure to life cycle emission assessments to avoid adverse effects. Many countries adopted blending mandates for biofuels. For instance, Colombia has a biofuel mandate of 10 % for biodiesel and ethanol (IEA, 2011a).
Financial incentives for vehicles that run on alternative fuels (*e.g.* vehicle tax rebates, tailor-made scrappage programmes with special subsidies) (see Factsheet '*Promotion of Energy Efficient Vehicles*').	Enable market penetration of alternative fuels and vehicles.
Certification scheme for biofuels.	Ensures a sustainable production of biofuels. Life cycle analysis and direct and indirect land-use changes have to be considered (biofuel production from organic waste should be favoured).
Land-use guidelines.	Preserve areas for agriculture, forestry and nature conservation by limiting biofuel production to marginal and degraded lands.[a] Reduce the adverse effects from biofuel production and prevent conflicts with other land uses.

[a] Some degraded lands may offer the possibility to produce energy crops. However, it is questionable whether energy-crops can be grown efficiently on these lands due to potentially large investments in fertilisers (Howarth *et al.,* 2009).

Further reading

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