CNG and LPG for Transport in Germany
– Environmental Performance and Potentials for Greenhouse Gas Emission Reductions until 2020 –

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Abstract: The supply of CNG and LPG is described. The greenhouse gas emissions (GHG) of various CNG and LPG pathways are analysed 'well-to-wheel'. Potential contributions of CNG and LPG to greenhouse gas reduction in transport as well as to two EU regulations are assessed.

1 Current status

1.1 CNG

In Germany, natural gas comes mainly through pipelines from Russia, The Netherlands, Norway, and own German sources, and to a lesser extent also from LNG shipping, see Figure 1.

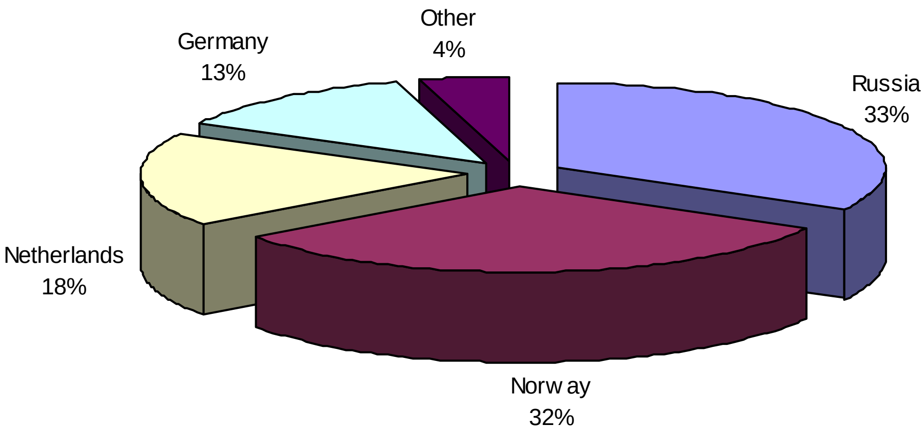

Figure 1: Origins of natural gas used in Germany in 2009 (all uses) [BAFA09]

In 2009, 0.17% of all natural gas in Germany was used as transportation fuel (world: 0.48%). 86,264 CNG vehicles were licensed end of 2009, thereof 80% passenger cars (68,587). Between 2002 and 2009, the number of CNG vehicles grew by an average of 31%/yr in Germany, see Figure 2.

1.2 LPG

There are two sources for petroleum gas, as a co-product from natural gas extraction and as a by-product from crude-oil refining. In Germany, LPG comes as a by-product from crude-oil refining and is mainly used as material input for the chemical industry as well as for residential heating purposes. 8.6% of the LPG is used as a fuel in the transport sector in Germany (world: 20.9%). 369,430 LPG passenger cars were licensed in Germany as of beginning of 2010, see Figure 2.

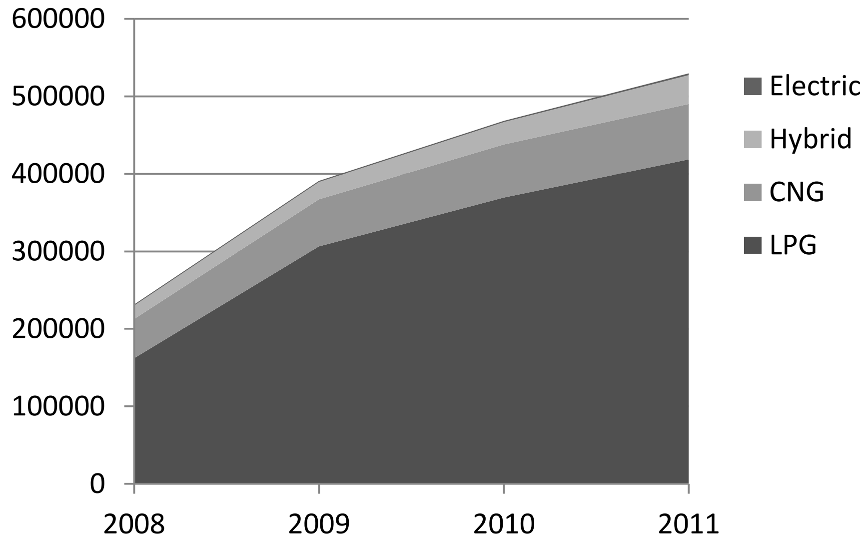

Figure 2: Number of alternative passenger cars licensed in Germany 2008 – 2010 [KBA11]

As can be seen from Figure 2, LPG followed by CNG are the most common alternative with passenger cars.

1.3 CO_2

To-date, the transport sector is relying on fossil crude-oil to almost 100%. Some 20% of German greenhouse gas emissions (GHG) stem from the transport sector. With 85% of German GHG emissions from transport or 146 million tons of CO_2 equivalents (t_{CO2eq}), road transport is the largest emitter in the transport sector.

As a fiscal measure to incentivise the use of alternative fuels in transport, the German Energy Tax rates have been partially reduced. In case of CNG, bio-methane and LPG the reduced tax rates will still apply until the end of 2018. In Figure 3, the economic costs from German Energy Tax reductions are put in relation with its benefits in terms of GHG emission reductions. The results thus show the cost-benefits in terms of emissions saved per € tax rebate.

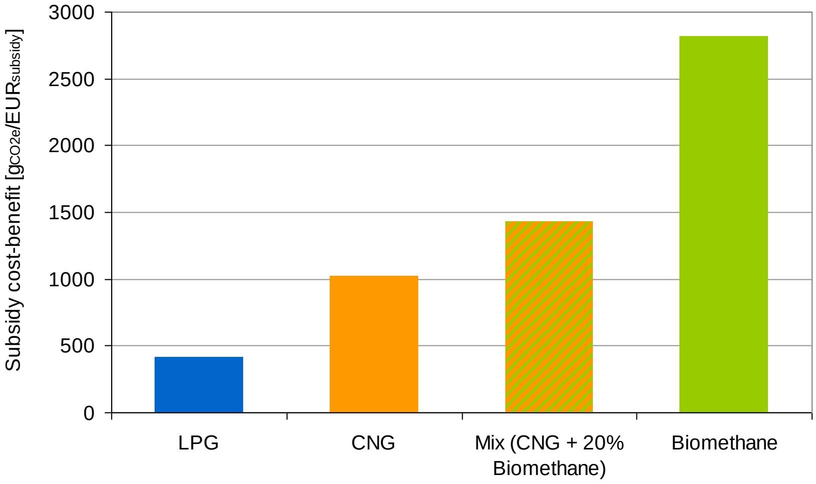

Figure 3: Greenhouse gas saving per energy tax subsidy (German energy tax, without VAT, car consumption considered) [LBST10a]

Based on specific emissions as described in the following chapter 2, CNG saves 2.5 times the amount of greenhouse gas emissions on a per-km basis compared to LPG. Assuming no land-use change, pure bio-methane provides the highest cost-benefit with 2.6 times that of CNG and 6.8 times that of LPG.

As a general remark, Figure 3 also shows that measures for reducing the greenhouse gas emissions in the transport sector generally require more efforts and are thus more costly compared to other sectors as, for example, building insulation.

2 Environmental performance

The greenhouse gas emissions along the supply ('well-to-tank') and use ('tank-to-wheel') of CNG and LPG have been calculated 'well-to-wheel'. The three emissions relevant to driving global warming in the transport sector have been taken into account, i.e. CO_2, CH_4 and N_2O with CO_2 equivalent factors of 1, 25 and 298 respectively [IPCC07].

2.1 Fuel supply ('well-to-tank')

CNG

Figure 4 depicts the detailed process steps for CNG 'well-to-wheel'.

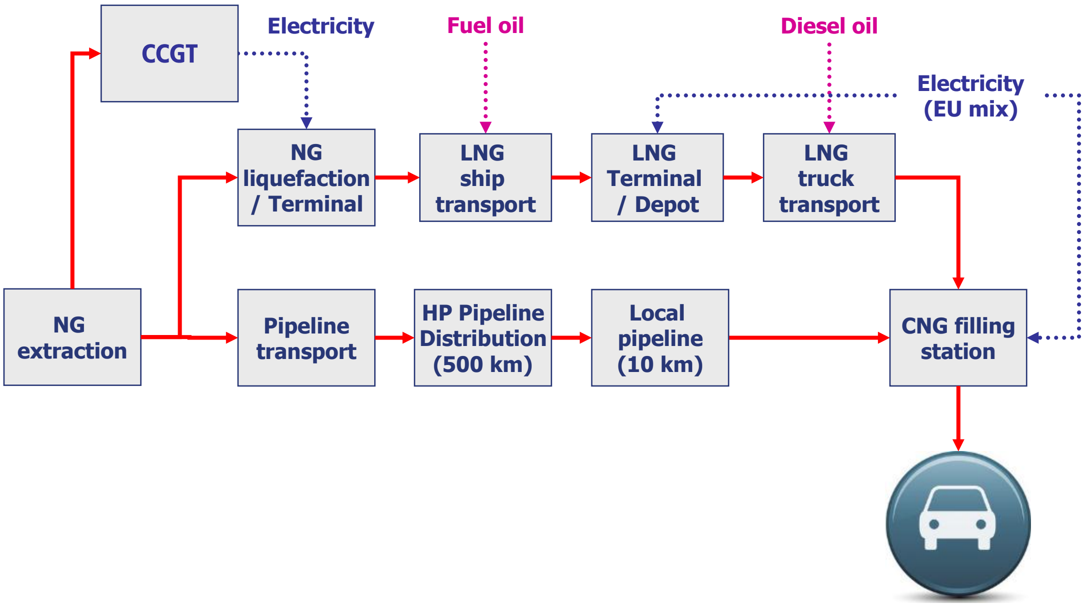

Figure 4: Detailed overview of CNG pathways well-to-wheel [LBST10a]

Three different pipeline transport distances of 1000 km, 4000 km and 7000 km have been assessed that reflect possibly increasing transport distances of CNG in the future.

Furthermore, feedstock 'shale gas' has been assessed as a currently heavily discussed, potential future source of CNG. However, so far there is only few experience and data published in Europe. Thus, shale gas was analysed based on data from the US shale gas field 'Barnett Shale', including transport of LNG to Europe, truck distribution and vaporisation at the CNG filling station.

A mixture of 80 energy-% of CNG and 20 energy-% bio-methane from upgraded biogas produced from energy crops has also been considered.

LPG

Figure 5 depicts the detailed process steps for LPG 'well-to-wheel'.

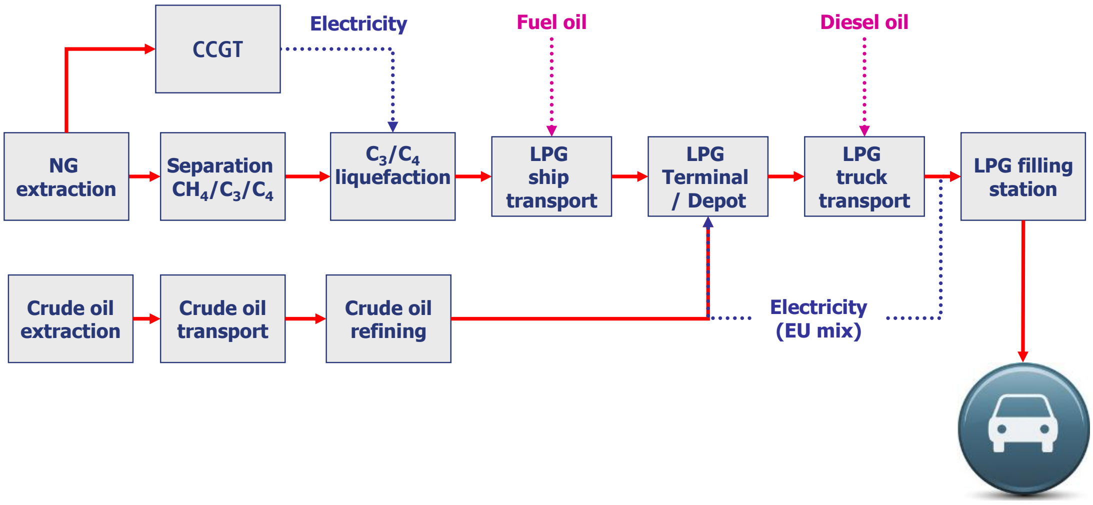

Figure 5: Detailed overview of LPG pathways well-to-wheel [LBST10a]

For LPG, two variants have been assessed, LPG co-production from natural gas extraction and LPG by-product from crude oil refining. As a boundary case for LPG, 'oil sands' from Canada have been calculated as LPG feedstock instead of conventional crude-oil.

2.2 Use in vehicle ('tank-to-wheel')

As vehicle, a typical 'Golf class' vehicle has been assumed, which is used in similar pathway analyses by JRC, EUCAR and CONCAWE [JEC08]. Variants of DISI, PISI (bi-fuel and dedicated) as well as hybridised power trains have been analysed to reflect current (2010) and future (2020) configurations. Hybridisation increases the energy efficiency of all power trains. However, a higher energy efficiency increase is achieved with the hybridisation of CNG engines compared to gasoline or LPG.

2.3 Pathway results ('well-to-wheel')

The fuel consumption of the vehicles adapted to the various fuels is different and thus has to be taken into account for a comprehensive assessment (well-to-tank + tank-to-wheel = well-to-wheel). Figure 6 and Figure 7 thus give the results for greenhouse gas emissions 'well-to-wheel' based on 2010 and possible 2020 situations on a per-km basis.

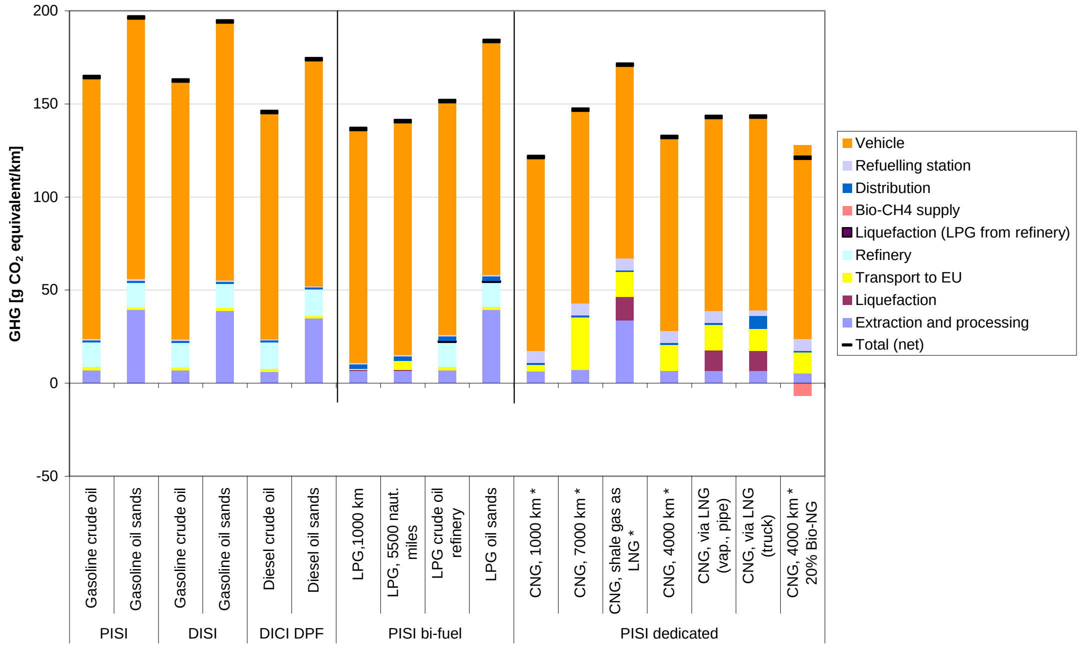

Figure 6: WTW GHG emissions for pathways involving LPG and CNG compared to gasoline and diesel fuel (2010) (non-hybrid vehicles only) [LBST10a]

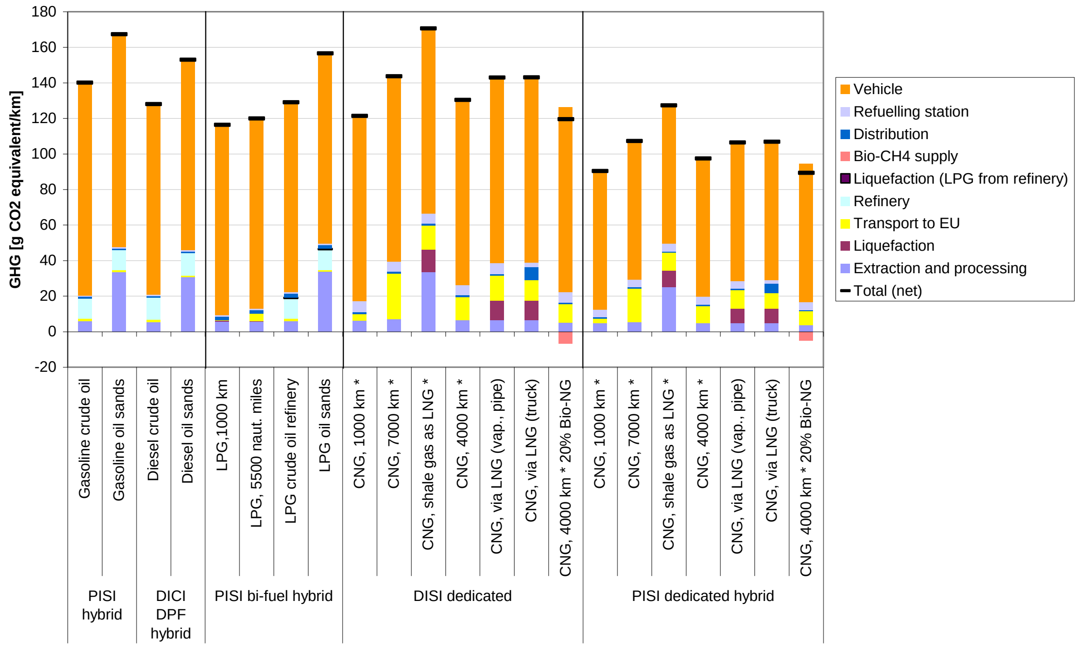

Figure 7: WTW GHG emissions for pathways involving LPG and CNG compared to gasoline and diesel fuel (2020) (hybrid and non-hybrid vehicles) [LBST10a]

CNG vehicles generally offer lower greenhouse gas (GHG) emissions than LPG and gasoline vehicles, mainly attributed to the lower carbon content of the fuel. Also in the case of LNG transport, the GHG reduction for CNG vehicles remains significant against all gasoline and LPG pathways with the exception of “LPG, 1000 km, 2010”.

Hybrid vehicles provide an opportunity for low fuel consumption, leading to low overall well-to-wheel GHG emissions. While for hybrid LPG vehicles, the relative savings through hybridisation are about similar to gasoline vehicles; savings are more significant for dedicated CNG engines due to different engine characteristics.

Future improvement of the efficiency of gas turbines used for natural gas compressors provides potential to decrease GHG emissions for natural gas transport. If these potentials are exploited, increasing transport distances will not necessarily increase the GHG emissions attributed to the gas supply logistics in the future.

With the progressing decline of conventional oil sources, LPG transport distances will increase and more LPG will be produced from non-conventional oil over time. As a boundary case, Canadian oil sands have been assessed as an additional source of crude-oil for LPG supply. Resulting GHG emissions as well as other environmental impacts are significantly higher compared to LPG from conventional crude-oil refining and natural gas processing.

As a boundary case, shale gases have been assessed as a supply option for CNG. While greenhouse gas emissions from shale gas production possibly increase only moderately compared to conventional natural gas supply, significant other environmental impacts are associated with its exploration and production [LBST11a].

From GHG emission point of view, CNG coming from shale gas performs possibly better than LPG from oil sands – however, local impacts in the mining area may be quite severe in both cases.

With a view to pollutant emissions, in spite of the EURO 6 vehicle emission limits to come, emissions of particulate matter (PM) will remain the most critical pollutant with both direct injection diesel and spark ignition engines. Using CNG in direct injection engines can significantly reduce PM emissions. CNG and LPG port injection engines both produce almost no PM emissions.

Greenhouse gas and pollutant emissions of CNG can be reduced further if methane derived from renewable sources is introduced, e.g. methane derived from biogas (provided that no land-use change occurs) or synthesised from renewable electricity and CO2 (so-called 'SNG').

3 Potential for greenhouse gas emission reduction

3.1 Current GHG emission savings

Most relevant parameters for a quantitative scenario with absolute figures for current greenhouse gas (GHG) emission reductions are the per-km well-to-wheel (WTW) GHG emissions, the average annual mileage of vehicles and the vehicles that are replaced by alternative drive trains.

The per-km WTW GHG emissions have been taken from own analyses as presented at an aggregated level in the preceding chapter 2 considering gasoline from conventional crude-oil; natural gas being transported over a distance of 1,000 km; and LPG from crude-oil refining.

The average annual mileage is taken from [Renewbility09] with 12,800 km by 2010, and 13,200 km by 2020.

Both CNG and LPG alternative fuel vehicles were assumed to substitute a gasoline vehicle of a similar engine technology, i.e. bi-fuel PISI, and assumed to be operated completely on CNG and LPG respectively.

As a result, today, a CNG passenger car saves about 3 times more greenhouse gas emissions than an LPG passenger car. 68,500 CNG passenger cars save about 0.592 t_{CO2eq} per car and year, i.e. 40,500 t_{CO2eq} a year in total. 370,000 LPG passenger cars save about 0.194 t_{CO2eq} per car and year, i.e. 72,000 t_{CO2eq} a year in total.

3.2 Future potential for GHG emission savings

Similarly to the calculation of current emission savings, a scenario for prospective GHG reductions until 2020 and beyond has been developed and calculated. Progressing towards 2020, both vehicle technologies as well as the typical fuel supply pathways will change.

Figure 8 gives the bandwidths of specific GHG emissions for 2020.

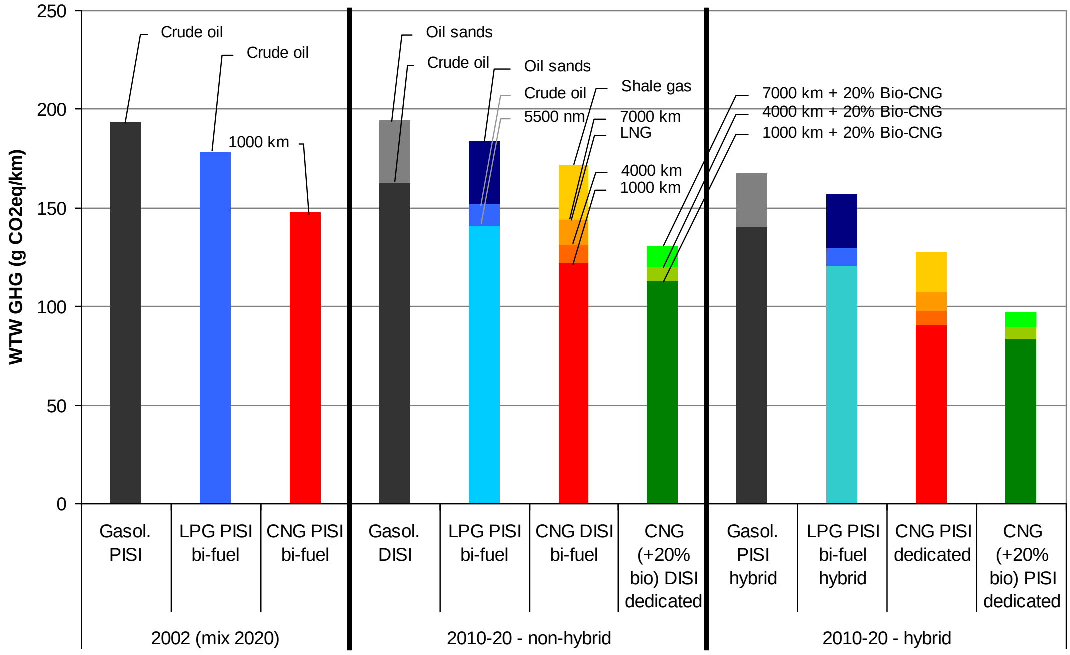

Figure 8: Specific GHG emissions against the reference vehicle [LBST10a]

To get an understanding on the possible absolute contributions of CNG and LPG to greenhouse gas emission reduction by 2020, the following assumption were made:

- For CNG supply, the bandwidths of average transport distances are assumed 1,000 km (as in 2010) including a 20% admixture of bio-methane and 7,000 km without bio-methane admixture respectively.
- For LPG supply, the GHG emission bandwidths are spanned by LPG produced from oil refining (as in 2010) and a share of 50% of LPG to come from natural gas processing with a ship transport distance of 5,500 nm (10,186 km) by 2020 respectively.
- For both CNG and LPG vehicles, instead of PISI technology, either DISI or hybridised PISI engines are assumed to become mainstream by 2020.

Considering the bandwidths defined above, a range between today's size and 1 million vehicles powered by CNG and LPG respectively has been calculated, see Figure 9.

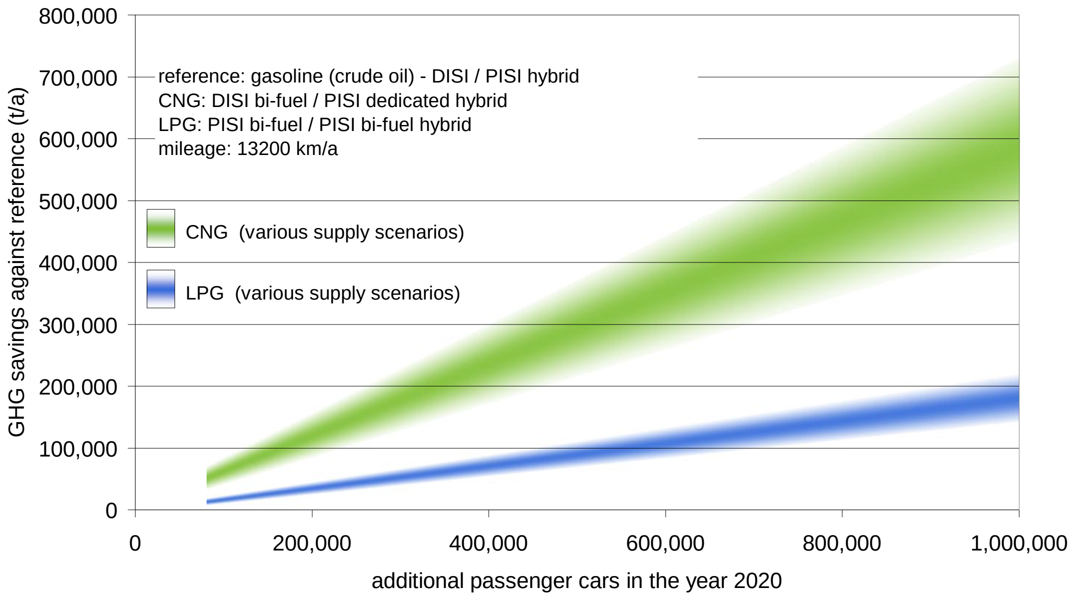

Figure 9: Greenhouse gas reduction potentials through additional CNG and LPG vehicles by 2020 [LBST10a]

One million additional CNG vehicles in 2020 provide a 3-5 times greater volume of greenhouse gas emission reductions compared to the introduction of the same amount of LPG vehicles (430-710,000 t_{CO2eq}/yr and 145-215,000 t_{CO2eq}/yr by 2020, respectively). CNG vehicles provide lower per-km well-to-tank GHG emissions compared to LPG vehicles. Secondary impacts from increasing demands of CNG and LPG have not been assessed.

Since LPG is a by-product of either crude oil refining or natural gas processing, it must be assumed that the production cannot be extended significantly both locally and globally. One million LPG vehicles would represent 16 to 20% of today's LPG consumption. A high number of LPG vehicles in Germany would cause strong repercussions to other LPG consumers (e.g. households and chemical industry) and a drastic increase of import shares.

On the CNG side, the situation is less limited, since the overall natural gas turnover is much higher (reducing the impact CNG vehicles have on overall consumption) and natural gas savings can be achieved at comparably low costs in other sectors, e.g. insolation to reduce demand from building heating. Furthermore, bio-methane CNG can fill in once the supplies face hard limits. Thus, CNG is able to supply a higher number of vehicles while reducing overall GHG emissions from transportation significantly.

For higher fleet penetrations (e.g. 5 to 10 million), the GHG reduction may not scale linearly, since a significant demand increase for CNG or LPG implies higher shares of the fuel coming from non-conventional sources such as oil sands or shale gas.

3.3 Possible contributions to EU targets

With regard to the use of alternative transport fuels, the European Union has voted two directives in 2009, i.e. the EU Fuel Quality Directive (EU FQD) and the EU Renewable Energy Directive (EU RED).

The leverage of one million additional CNG and LPG vehicles (2.1% of current car fleet in Germany) can contribute with 0.12–0.34 and 0.09–0.19 percentage points respectively to the EU Fuel Quality Directive target of reducing GHG intensity of conventional diesel and gasoline by 6% by 2020. This means that the leverage of CNG vehicles is up to 3 times higher than the potential of the LPG vehicles.

If bio-methane is used, CNG vehicles may in addition contribute to the EU Renewable Energy Directive (EU RED) target of 10% renewable transport fuel in 2020. In order to allow for the accounting of the bio-methane taken from the natural gas grid, the European Commission is currently reviewing calculation methodologies [LBST11b]. LPG, from today's perspective, is not able to make any contribution on the EU RED.

The following Table 1 gives an overview on the possible contributions of different CNG and LPG fuel pathways to EU regulation.

Transportation fuel		**EU policy contribution**		**Annotation**
		RED	**FQD**	
Methane	CNG	–	✓	
	Bio-methane	✓	✓	Including admixtures/grid
	SNG	✓*	✓	*If non-fossil CO_2 is used
LPG	from Crude oil refining	–	✓	
	from NG extraction	–	✓	

Table 1: Compliance of hydro-carbon based alternative transportation fuels with EU policies ([LBST10a] updated)

4 Main conclusions and perspectives

The EU targets of 6% lower life-cycle greenhouse gas emissions from transport fuels (EU FQD) and 10% renewable transport fuel in each Member State by 2020 including sustainability criteria for biomass-based fuels (EU RED) provide a significant political momentum for renewable methane in CNG vehicles.

CNG is a short term, readily available improvement of the environmental performance of the road transport sector. Concerning air pollutant emission reduction in urban areas, CNG's advantage is highest against diesel-powered light and heavy delivery trucks.

CNG vehicles have a higher potential for greenhouse gas reduction than LPG vehicles, both in relative as well as in absolute terms.

On a global level, as a by-product from either natural gas exploration or oil refining, the LPG potential is connected to the limited availability of fossil supplies. Global oil supplies may have peaked already in 2006 [LBST08], [IEA11]. Natural gas supplies may peak in the next decade [LBST11c]. The fossil resource basis of CNG is less constrained than for LPG. In addition, bio-methane from organic sources (upgraded biogas) and methane synthesised from renewable electricity and CO_2 (synthesised natural gas – SNG) are available as a drop-in substitute to stretch the eventually limited fossil resource base of natural gas.

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