CNG and LPG for Transport in Germany
Environmental Performance and Potentials for GHG Emission Reductions until 2020

Patrick R. Schmidt
Ludwig-Bölkow-Systemtechnik (LBST)
Content

- LBST
- Status quo
- Environmental performance
- Emission reduction potentials
- Conclusions and perspectives
Based in Munich, office in Dresden

Founded 1982

Expert consultants for energy and environment: strategy, technology, sustainability

Serving international clients in industry, finance, politics, and NGOs

Cutting edge competence, interdisciplinary, over two decades of continuous expertise

Rigorous system approach; global and long term perspective

Focus on
- Energy (renewables, energy storage, hydrogen and fuel cells)
- Mobility (fuels and drives, infrastructure, mobility concepts)
- Sustainability
Content

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Status quo
Alternative vehicles
Alternative Vehicles in Germany

- Passenger vehicles registered in Germany on 1 January 2011: Total = 42.3 million

- Thereof:
  - LPG: 418,659
  - CNG: 71,519
  - Hybrid: 37,256
  - Electric: 2,307

→ LPG profited most from oil price rise

Source: data from KBA 2011 as per January 1st
Status quo
LPG
# LPG Supply and Use

## Availability of LPG in Germany, Europe and worldwide in 2008

<table>
<thead>
<tr>
<th></th>
<th>Production</th>
<th></th>
<th>Import</th>
<th>Export</th>
<th>Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas Processing</td>
<td>Refinery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worldwide</td>
<td>126,194</td>
<td>115,512</td>
<td>73,500</td>
<td>73,933</td>
<td>20,879 (8.67%)</td>
</tr>
<tr>
<td>Europe/Eurasia</td>
<td>9,864</td>
<td>33,087</td>
<td>19,698</td>
<td>17,805</td>
<td>8,191 (18.79%)</td>
</tr>
<tr>
<td>Germany</td>
<td>0</td>
<td>2,512</td>
<td>889</td>
<td>557</td>
<td>247 (8.59%)</td>
</tr>
</tbody>
</table>


- In Germany, LPG is mainly
  - sourced from refineries
  - used for residential heat provision and chemical industry input
- Italy is the only EU Member State in the 2008 world top 10 list of countries using LPG in the transport sector
- Today, petroleum gas is used in Otto engines because of similar Octane number
Overview of LPG Pathways

Options investigated:

- Natural gas processing and transport via LPG carrier:
  - 1,000 km
  - 5,500 nautical miles (10,186 km) [CONCAWE/EUCAR/JRC]

- Co-product from refining of
  - Conventional crude oil
  - Unconventional crude oil (Canadian tar sands)
Status quo
CNG
Natural Gas Trade (CNG and LNG) with Europe

Origins of natural gas used in Germany in 2009 (all uses)

- Russia: 33%
- Norway: 32%
- Netherlands: 18%
- Germany: 13%
- Other: 4%

BAFA, 2009
Natural Gas Supply and Use

- Availability of natural gas in Germany, Europe and worldwide:

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Worldwide (2007)</td>
<td>104,587.5</td>
<td>31,717.1</td>
<td>31,093.7</td>
<td>505.8</td>
<td>0.48%</td>
</tr>
<tr>
<td>OECD Europe (2007)</td>
<td>9,907.2</td>
<td>14,545.8</td>
<td>5,895.9</td>
<td>26.4</td>
<td>0.14%</td>
</tr>
<tr>
<td>Germany (2007)</td>
<td>598.8</td>
<td>3,323.7</td>
<td>450.9</td>
<td>4.1</td>
<td>0.12%</td>
</tr>
<tr>
<td>Germany (2008)</td>
<td>545.4</td>
<td>3,480.5</td>
<td>471.3</td>
<td>4.1</td>
<td>0.12%</td>
</tr>
<tr>
<td>Germany (2009)</td>
<td>509.9</td>
<td>3,551.3</td>
<td>421.0</td>
<td>6.1</td>
<td>0.17%</td>
</tr>
</tbody>
</table>

Sources: IEA 2009a, IEA 2009b, AGEB 2009, BAFA 2009, BMWi 2010

- Long-distance transport of natural gas to Europe via pipelines (e.g. Norway, Russia) and LNG ships (e.g. North Africa)

- In Germany, natural gas is mainly
  - sourced from Russia, Norway, Netherlands, and own resources
  - used for power generation, heating, cooking, and by the chemical industry
Overview of CNG Pathways

Options investigated:
- CNG mix Germany (based on Europe)
- LNG ship (5,500 nautical miles) with/without NG for vaporisation
- Pipeline lengths: 1,000 km / 4,000 km / 7,000 km
- US (Barnett) shale gas with LNG transport to Germany as a boundary case
Outreach of Pipelines
Shale Gas

- Belongs to the group of non-conventional NG sources
- EU resources, e.g. in DE, PL, UK
- Production:
  - Fracturing of the rock via injection of a chemical fluid
  - Fluid stripping, intermediate pond storage, and disposal
- Associated risks:
  - Use of toxic and carcinogenic substances for fracturing
  - Mobilisation of radioactive substances
  - Pollution of drinking water
- Regulation in Germany: Federal law with State veto rights

Dr. Werner Zittel (LBST), et al.: Impacts of shale gas and shale oil extraction on the environment and on human health
Study commissioned by the European Parliament, ENVI Committee, Brussels, June 2011
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- Conclusions and perspectives
Greenhouse Gas Emissions • Well-to-Tank

GHG [g CO₂ equivalent/MJ]

Refuelling station
Distribution
Bio-CH4 supply
Liquefaction (LPG from refinery)
Refinery
Transport to EU
Liquefaction
Extraction and processing

Total (net)
(i.e. gross minus credits)

* plus distribution via the high pressure natural gas grid (500 km) and the local natural gas grid (10 km)
Environmental performance
Vehicle definition
Methane has a higher octane number → Higher compression ratio → Lower fuel consumption of dedicated CNG compared to gasoline ICE over a broad operating range (green)

Hybridisation allows for exploiting this advantage

Engine Efficiency comparison, CNG mode versus Gasoline mode
[(CNG efficiency-Gasoline efficiency)/Gasoline efficiency]*100
### „VW Golf“-Class Vehicle: Fuel consumption

<table>
<thead>
<tr>
<th>Power train</th>
<th>Time horizon</th>
<th>Used in</th>
<th>Non-hybrid</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline PISI 1.6 l</td>
<td>2002 / mix today</td>
<td>X</td>
<td>6.9</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline DISI 1.6 l</td>
<td>2002 / mix today</td>
<td>X</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td>LPG bi-fuel PISI 1.6 l</td>
<td>2002 / mix today</td>
<td>X</td>
<td>6.9</td>
<td>-</td>
</tr>
<tr>
<td>CNG bi-fuel PISI 1.6 l</td>
<td>2002 / mix today</td>
<td>X</td>
<td>7.1</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline PISI</td>
<td>2010-2020</td>
<td>X</td>
<td>5.9</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline PISI 1.6 l 14 kW</td>
<td>2010-2020</td>
<td>X X</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>Gasoline DISI</td>
<td>2010-2020</td>
<td>X X</td>
<td>5.8</td>
<td>-</td>
</tr>
<tr>
<td>Gasoline DISI 1.6 l</td>
<td>2010-2020</td>
<td></td>
<td>5.1</td>
<td>-</td>
</tr>
<tr>
<td>Diesel DICI DPF</td>
<td>2010-2020</td>
<td>X</td>
<td>5.1</td>
<td>-</td>
</tr>
<tr>
<td>Diesel DICI DPF 1.9 l</td>
<td>2010-2020</td>
<td>X</td>
<td>-</td>
<td>4.5</td>
</tr>
<tr>
<td>LPG bi-fuel PISI</td>
<td>2010-2020</td>
<td>X X</td>
<td>5.9</td>
<td>5.0</td>
</tr>
<tr>
<td>CNG bi-fuel PISI</td>
<td>2010-2020</td>
<td>X</td>
<td>5.9</td>
<td>-</td>
</tr>
<tr>
<td>CNG bi-fuel DISI*</td>
<td>2010-2020</td>
<td>X</td>
<td>5.9</td>
<td>-</td>
</tr>
<tr>
<td>CNG dedicated PISI 1.6 l</td>
<td>2010-2020</td>
<td>X X</td>
<td>5.8</td>
<td>4.3</td>
</tr>
<tr>
<td>CNG dedicated DISI*</td>
<td>2010-2020</td>
<td>X X</td>
<td>5.8</td>
<td>4.3</td>
</tr>
</tbody>
</table>

GE: Gasoline Equivalent  
PISI: Port Injection Spark Ignition  
DISI: Direct Injection Spark Ignition  
DICI: Direct Injection Compression Ignition  
DPF: Diesel Particulate Filter  
* Assumption: same fuel consumption as PISI because of no sufficient data available
„VW Golf”-Class Vehicle: Pollutant emissions

- Emissions limits “Euro 6” applicable for cars from 1 September 2015
- For diesel engines, no dedicated NMVOC emission limits are indicated
- For petrol engines, PM limits are introduced because of direct injection (DISI)
- Stoichiometric and homogeneous DISI operation can avoid PM formation

<table>
<thead>
<tr>
<th></th>
<th>CO [g/km]</th>
<th>CH₄ [g/km]</th>
<th>NMVOC [g/km]</th>
<th>NOₓ [g/km]</th>
<th>PM [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spark Ignition (SI)</td>
<td>1.000</td>
<td>0.032</td>
<td>0.068</td>
<td>0.060</td>
<td>0.005</td>
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<tr>
<td>Compressed Ignition (CI)</td>
<td>0.500</td>
<td>0.090 (THC)</td>
<td>0.080</td>
<td></td>
<td>0.005</td>
</tr>
</tbody>
</table>

PI: Port Injection  
CI: Compression Ignition  
CO: Carbon monoxide  
CH₄: Methane  
NMVOC: Non-Methane Volatile Organic Compound  
NOₓ: Nitrogen oxide  
PM: Particular Matter
Environmental performance
Well-to-Wheel (WtW)
Bandwidth of Greenhouse Gas Emissions · Well-to-Wheel

- CNG bandwidth lower than LPG bandwidth in all cases
- Difference in lower WtT emissions and carbon content of CNG
- Also, efficiency improvement through hybridisation higher for CNG

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>2002 (mix 2020)</th>
<th>2010-20 - non-hybrid</th>
<th>2010-20 - hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasol. PISI</td>
<td></td>
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<tr>
<td>LPG PISI bi-fuel</td>
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<tr>
<td>CNG PISI bi-fuel</td>
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<tr>
<td>CNG DISI dedicated</td>
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<td></td>
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<tr>
<td>CNG (+20% bio) DISI dedicated</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Gasol. PISI hybrid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG PISI bi-fuel hybrid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNG PISI dedicated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNG (+20% bio) PISI dedicated</td>
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</tr>
</tbody>
</table>

Upper boundary: WORST-CASE
Lower boundary: TODAY
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Current GHG reductions (2010)
Greenhouse Gas Savings from CNG and LPG

- 2008: 146 million tons CO$_{2}$eq (TTW) from transportation in Germany; thereof 2/3 from passenger cars
- 68,500 CNG and 370,000 LPG vehicles are on the road 2010
  - Applying predominantly bi-fuel PISI technology
  - Using predominantly CNG from 1000 km distance and LPG from oil refining
  - Substituting gasoline from crude oil used in PISI vehicles
  - Driving 12,800 km/year [RENEWIBILITY study]

→ Today, CNG cars save 0.592 tons and LPG cars save 0.194 tons CO$_{2}$eq/year each (absolute savings: CNG ~40,500 tons and LPG ~72,000 tons CO$_{2}$eq/year)

→ A CNG passenger car saves about 3 times more GHG emissions than an LPG car

→ 5 times more LPG vehicles save only 75% more GHG than CNG vehicles

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</tr>
</thead>
<tbody>
<tr>
<td>CNG (dedicated PISI; 1000 km transport distance)</td>
<td>0.592 t$_{CO2eq}$/a</td>
<td>68,500</td>
<td>40,527</td>
</tr>
<tr>
<td>CNG (dedicated PISI; 4000 km transport distance)</td>
<td>0.424 t$_{CO2eq}$/a</td>
<td>68,500</td>
<td>29,067</td>
</tr>
<tr>
<td>LPG (bi-fuel PISI; crude oil refining)</td>
<td>0.194 t$_{CO2eq}$/a</td>
<td>370,000</td>
<td>71,765</td>
</tr>
<tr>
<td>LPG (bi-fuel PISI; NG 1000 km)</td>
<td>0.420 t$_{CO2eq}$/a</td>
<td>370,000</td>
<td>155,048</td>
</tr>
</tbody>
</table>
Additional GHG reductions (until 2020 and beyond)
Changes until 2020

- **Vehicle technologies will change**
  - Substituted vehicles: DISI / hybrid PISI
  - CNG vehicles: dedicated DISI / hybrid PISI
  - LPG vehicles: bi-fuel hybrid PISI

- **Fuel supply pathways will change**
  - Gasoline from non-conventional oil (oil sands)
  - Longer transport distances for CNG (4000 km; 7000 km; LNG)
  - LPG also from NG processing with 5500 nm ship transport distance, or from oil sands
  - LPG from Canadian tar sands and CNG from US gas shales as boundary cases
Greenhouse Gas Savings from CNG and LPG

- One million LPG vehicles can save up to 260,000 t CO$_2$eq assuming hybrids (replacing hybrids), and up to 290,000 t CO$_2$eq assuming non-hybrids (replacing non-hybrids)

- One million CNG vehicles can save up to 670,000 t CO$_2$eq assuming hybrids (replacing hybrids), and up to 570,000 t CO$_2$eq assuming non-hybrids (replacing non-hybrids) (assuming 20% bio-methane*)

* No land use change
Achievable Quantities & GHG Reduction

- 1 million additional CNG cars by 2020: close to assumption of DENA study
  - NG consumption 18.4 to 24.7 PJ/a*, representing 0.5-0.68% of overall NG demand in Germany (2009).
  - Low share indicates no strict limitation of CNG vehicle deployment
  - Bio-methane** and e-methane can drop-in for fossil CNG

- 1 million additional LPG cars would increase LPG consumption in Germany by 16-20%
  - Production rather subject to decline (along with oil) than to further extension
  - Additional LPG for transport must be taken away from other regions/sectors; substitution possibly causing GHG increases there
  - Several million LPG vehicles in Germany do not appear realistic from this side

For high penetration numbers (e.g. 5-10 million), GHG reduction effect may not scale linearly due to higher share of non-conventional sources of supply
- GHG-wise, CNG from shale gas performs better than LPG from oil sands
- But: local impacts in the mining area might be severe in both cases
- For LNG supply, the GHG reduction of CNG vehicles remains significant.

- CNG fuel has a significantly higher GHG reduction potential than LPG fuel
  - due to higher energy efficiency increase by hybridisation
  - Due to the potential to use bio-methane**
  - And due to the limitations that exist for LPG supply.

* 13,200 km/year; lower bound: PISI dedicated hybrid; upper bound: DISI dedicated
** No land use change

27.10.2011
Contribution to comply with EC regulations
## EC Directives

- **Possible contributions of CNG and LPG to EU Directives RED & FQD**

<table>
<thead>
<tr>
<th>Transportation fuel</th>
<th>EU Directives</th>
<th>Annotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RED</td>
<td>FQD</td>
</tr>
<tr>
<td>Methane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNG</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>Bio-methane</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SNG</td>
<td>✓ *</td>
<td>✓</td>
</tr>
<tr>
<td>LPG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude oil refining by-product</td>
<td>—</td>
<td>✓</td>
</tr>
<tr>
<td>NG extraction by-product</td>
<td>—</td>
<td>✓</td>
</tr>
</tbody>
</table>

- **Legend:**
  - ❌ cannot contribute
  - ✔ contribution possible
  - ✔️ contribution possible
  - ✔️* not defined / conditioned

27.10.2011
Contribution of 1 million vehicles to FQD 6% target

- Overall lifecycle per-energy GHG reduction of 1 million vehicles between 0.09 and 0.33%
- Representing 1.6 to 5.2% of the 6% target (CNG 2-5.6%; LPG 1.6-3.2%)
- Considering quantitative limitations of LPG, it becomes clear that CNG can contribute much more
- Furthermore, through bio-methane, CNG has a potential to contribute to the 10% target for renewable fuel (note: no land use change; EC demands accounting direct land use change)
German Energy Tax Reduction: Cost-Benefit

- Energy tax rate reduced for CNG, bio-methane and LPG until 2018
- Reduced energy tax ~ Subsidy
- Cost-benefit of energy tax reduction in terms of GHG emissions avoided:

- With 1 tax Euro, CNG saves 2.5 times the amount of GHGs 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.

27.10.2011
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Conclusions and Perspectives

- EU FQD target of 6% reduced GHG intensity of fuels and EU RED target of 10% renewable transport fuel in each Member State by 2020 provide significant political momentum, especially for methane from renewable sources.

- 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 lends itself for substitution of diesel-powered light and heavy-duty delivery trucks, especially with fleets.

- 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 → Perspective?

- The fossil resource base of CNG is less constrained than for LPG. In addition, bio-methane and e-methane are drop-in options to become independent from fossil resources.

- CNG and LPG both prepare grounds for acceptance of gaseous transport fuels.
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BACKUP
EU Regulations
RED & FQD
Article 3, Paragraph 4:

« Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10 % of the final consumption of energy in transport in that Member State. ... all types of energy from renewable sources consumed in all forms of transport shall be taken into account; »

- Applicable from 1 January 2011
- All transport sectors may contribute (road, rail, maritime, aviation)
- Includes sustainability criteria for
  - all bioenergy feedstocks
  - all countries of origin (EU and imports)
  - all bioenergy uses (“biofuels” and “bioliquids”)
- Methodology for inclusion of methane, hydrogen and electricity from renewable sources due by end of 2011
- EU Fuels Quality Directive (FQD) contains the same sustainability criteria
- First sustainability certification schemes accredited in Germany early 2010 (ISCC, REDcert)
- 7 voluntary sustainability schemes EU accredited in June 2011
**EU Renewable Energy Directive: Sustainability Criteria**


**Mandatory thresholds** (exclusion criteria):

- Article 17 (2) – Greenhouse Gas Emissions
- Article 17 (3) – High Biodiversity Value Areas (primary forest, …)
- Article 17 (4) – Land with High Carbon Stock (forests, wetlands)
- Article 17 (5) – Drained peatland
- Article 17 (6) – Good Agricultural Practice (GAP)

**Reporting obligations** (Article 18 (3) – Measures taken for…)

- Soil, water, and air protection
- Restoration of degraded land
- Avoidance of excessive water consumption
- Social sustainability
- Availability of foodstuffs at affordable prices
- Development issues
- Land use rights
- International treaties (ILO, et al.)
« Suppliers should, ... 2020, ... reduce life cycle greenhouse gas emissions by up to 10 % per unit of energy from fuel and energy supplied. This reduction should amount to at least 6 % by 31 December 2020, compared to the EU-average level of life cycle greenhouse gas emissions per unit of energy from fossil fuels in 2010, obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites. ... »