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CNG and LPG for Transport in Germany

Environmental Performance and Potentials
for GHG Emission Reductions until 2020

Patrick R. Schmidt
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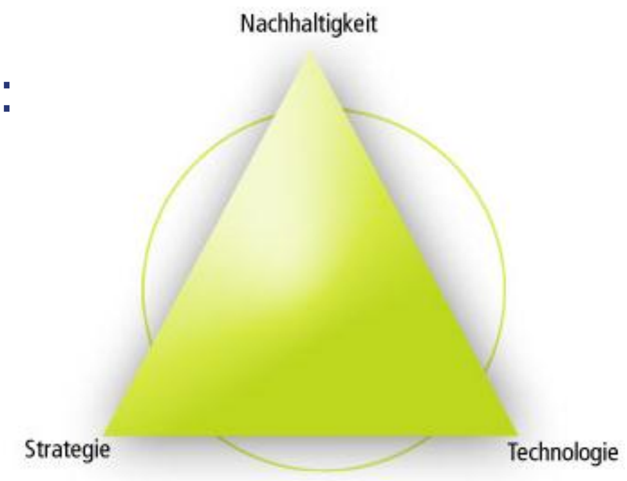
Content

LBST – Ludwig-Bölkow-Systemtechnik GmbH

- 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

- LBST
- **Status quo**
- Environmental performance
- Emission reduction potentials
- Conclusions and perspectives

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Status quo
Alternative vehicles

Alternative Vehicles in Germany

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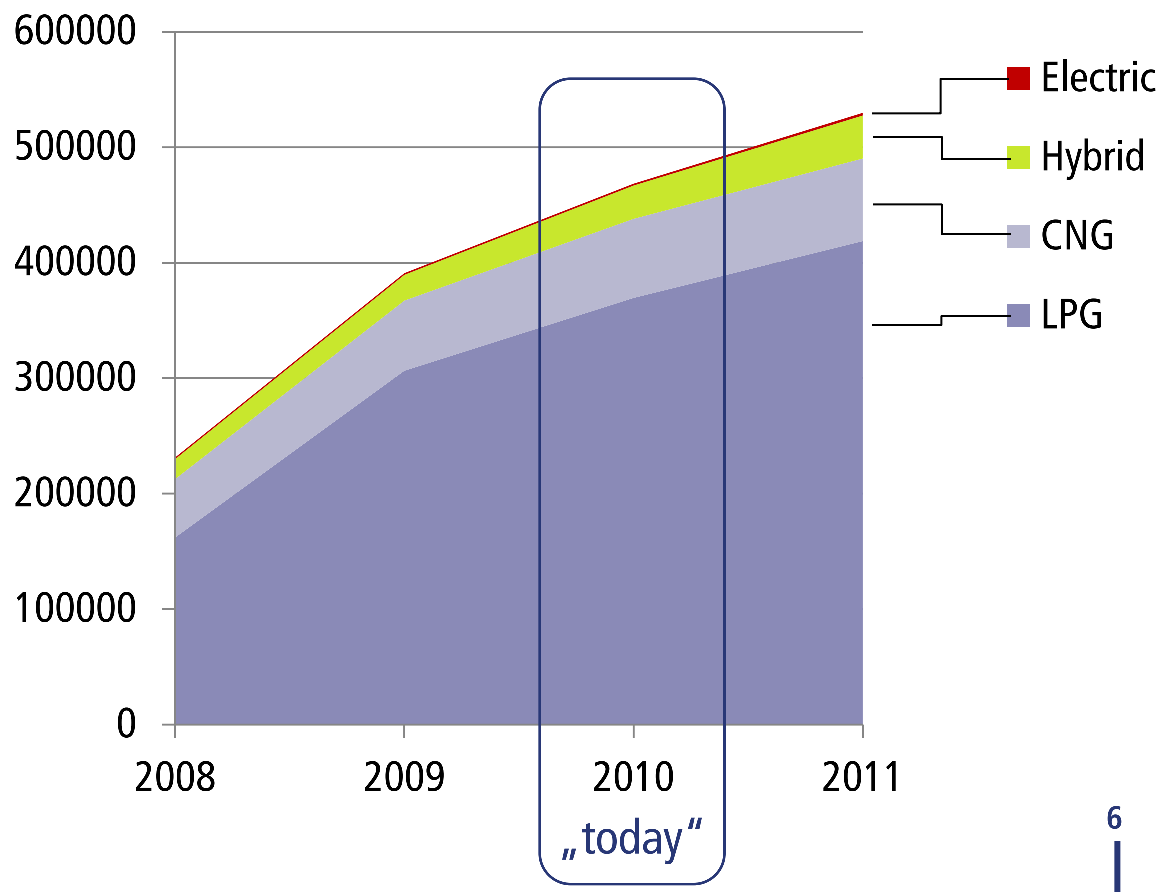
- Passenger vehicles registered in Germany on 1 January 2011: Total = 42,3 million
- Thereof:
  - LPG: 418,659
  - CNG: 71,519
  - Hybrid: 37.256
  - Electric: 2,307

→ LPG profited most from oil price rise



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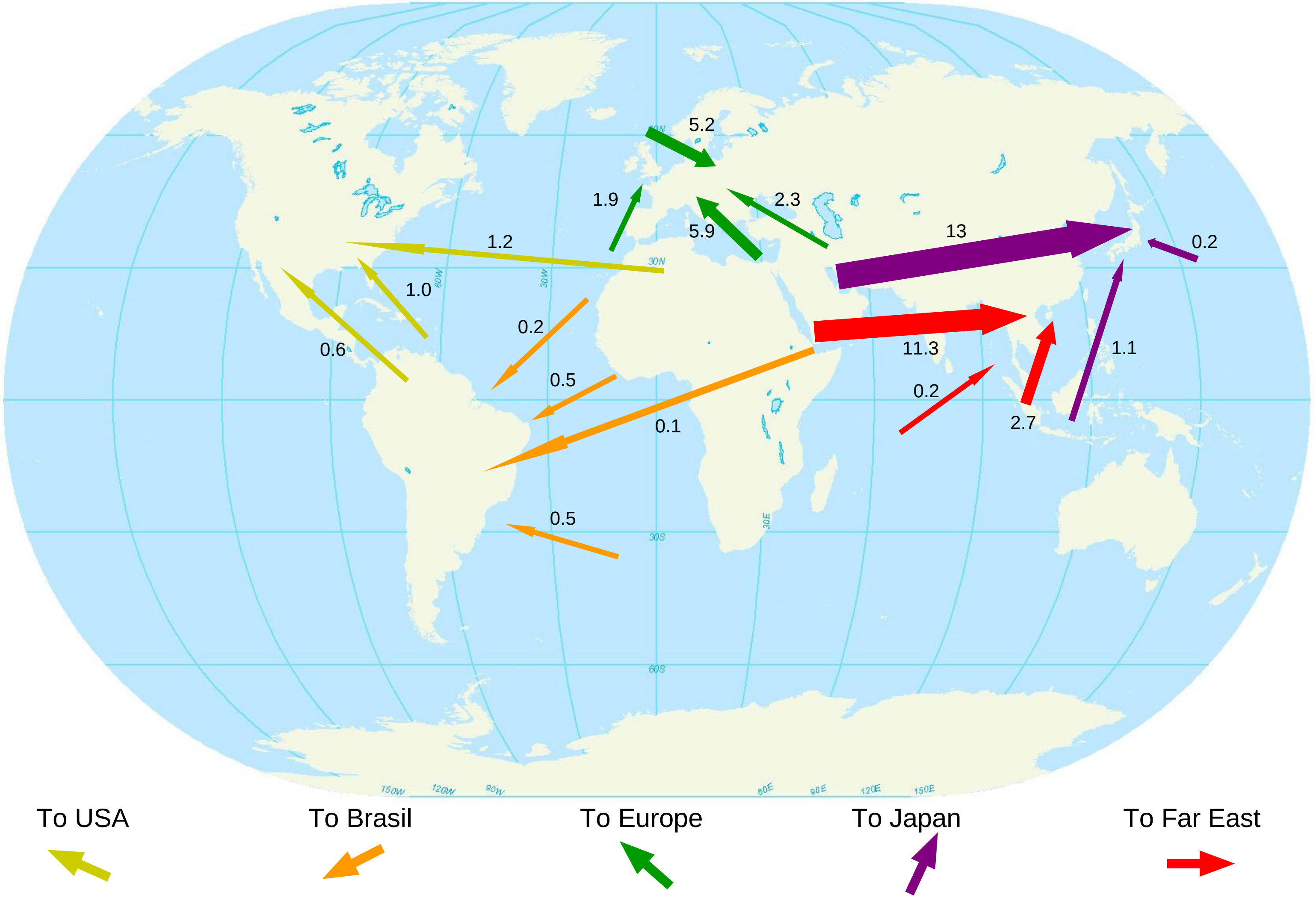
Status quo
LPG

International LPG Trade



Source: Statistical Review of Global LP Gas 2009

LPG Supply and Use

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

[1,000 t] 1 t = 46 GJ	Production: Gas Processing	Production: Refinery	Import	Export	Transport
Worldwide	126,194	115,512	73,500	73,933	20,879 (8.67%)
Europe/Eurasia	9,864	33,087	19,698	17,805	8,191 (18.79%)
Germany	0	2,512	889	557	247 (8.59%)

Source: WLPGA, Statistical Review of Global LP Gas, 2009

- 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

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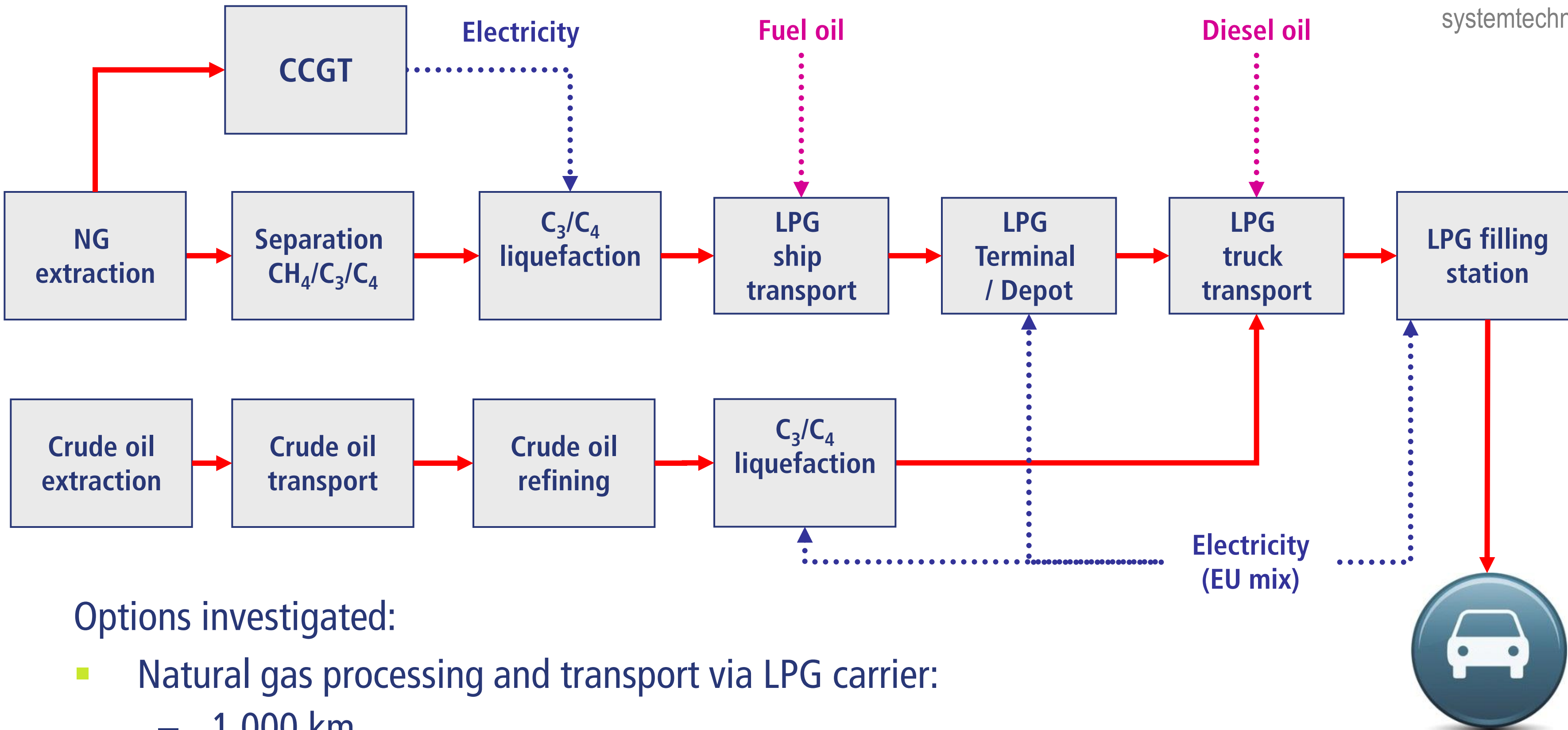

Options investigated:

- 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

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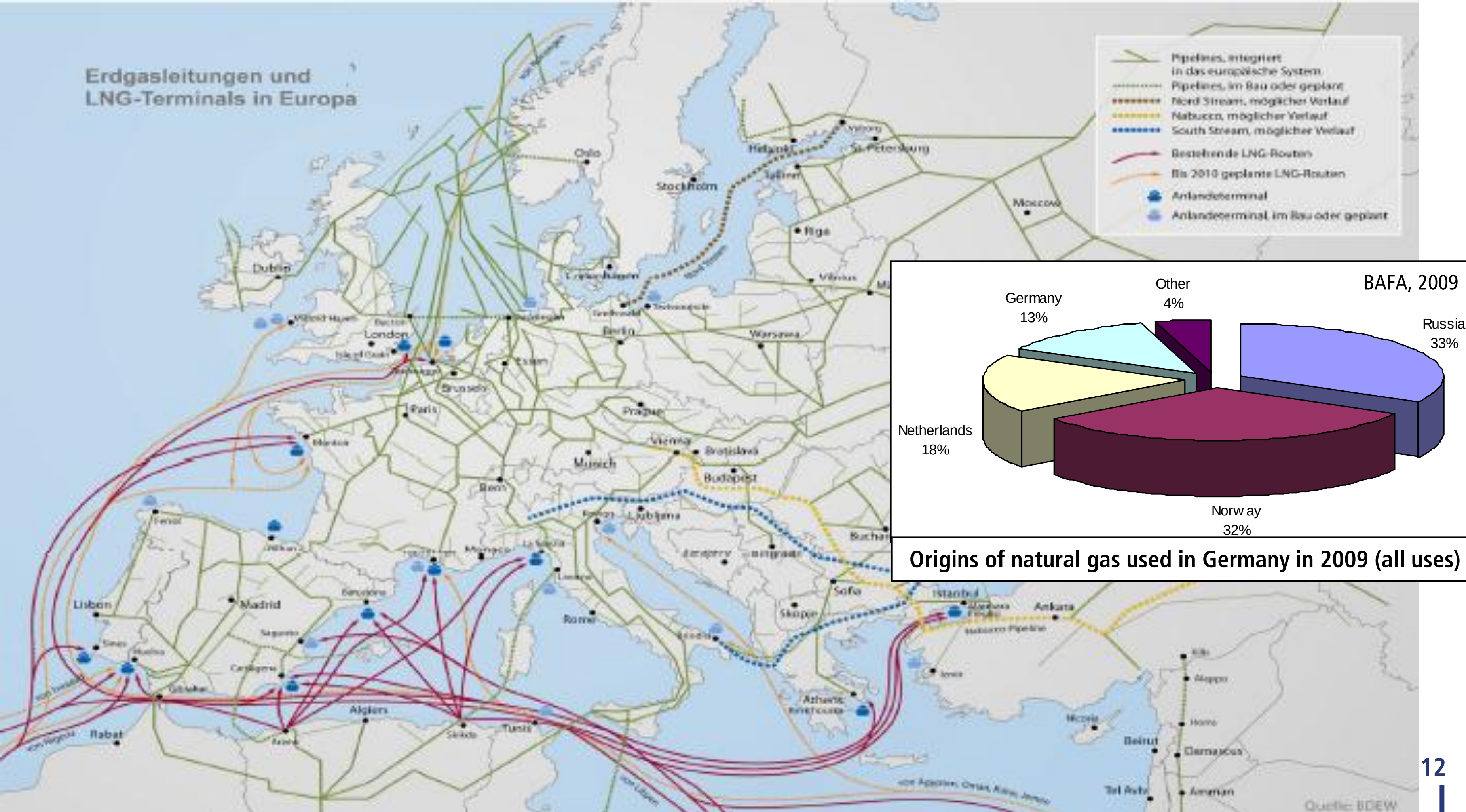


Origins of natural gas used in Germany in 2009 (all uses)

Natural Gas Supply and Use

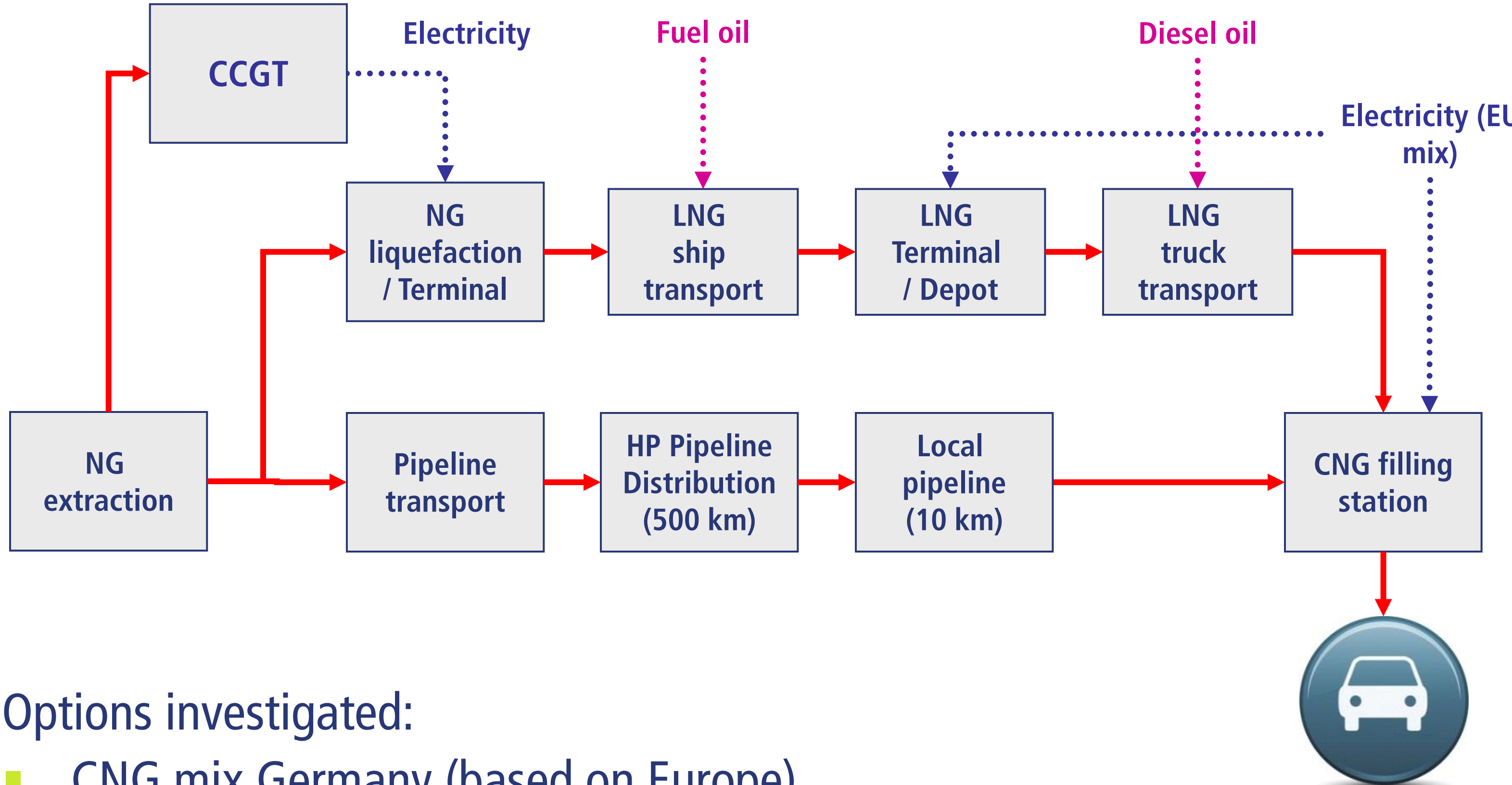
- Availability of natural gas in Germany, Europe and worldwide:

[PJ/yr]	Production	Import	Export	Thereof for transport	Share dedicated to transport
Worldwide (2007)	104,587.5	31,717.1	31,093.7	505.8	0.48%
OECD Europe (2007)	9,907.2	14,545.8	5,895.9	26.4	0.14%
Germany (2007)	598.8	3,323.7	450.9	4.1	0.12%
Germany (2008)	545.4	3,480.5	471.3	4.1	0.12%
Germany (2009)	509.9	3,551.3	421.0	6.1	0.17%

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

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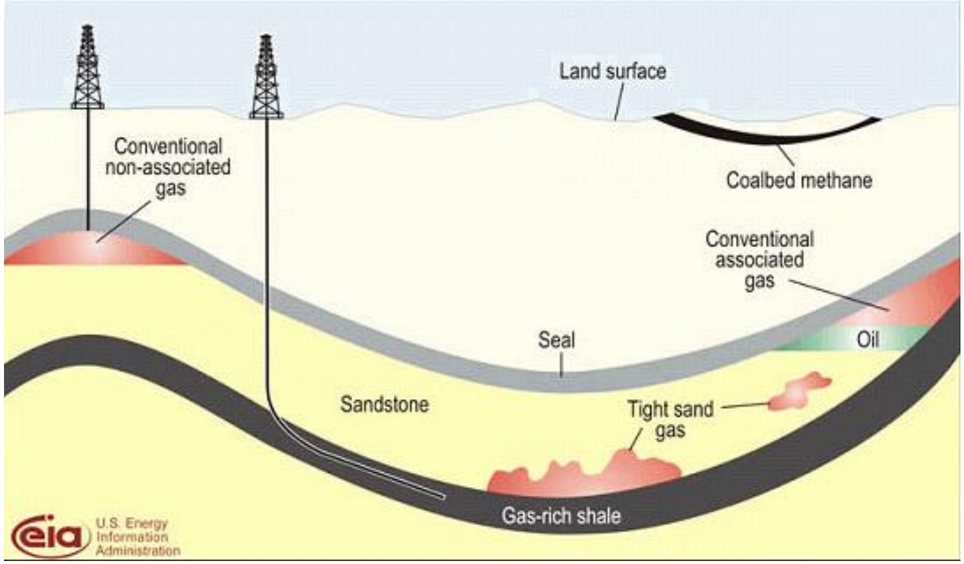
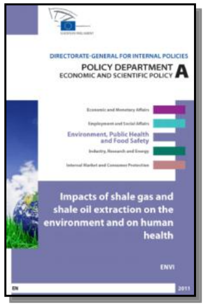
Shale Gas

- 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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Greenhouse Gas Emissions · Well-to-Tank

2010

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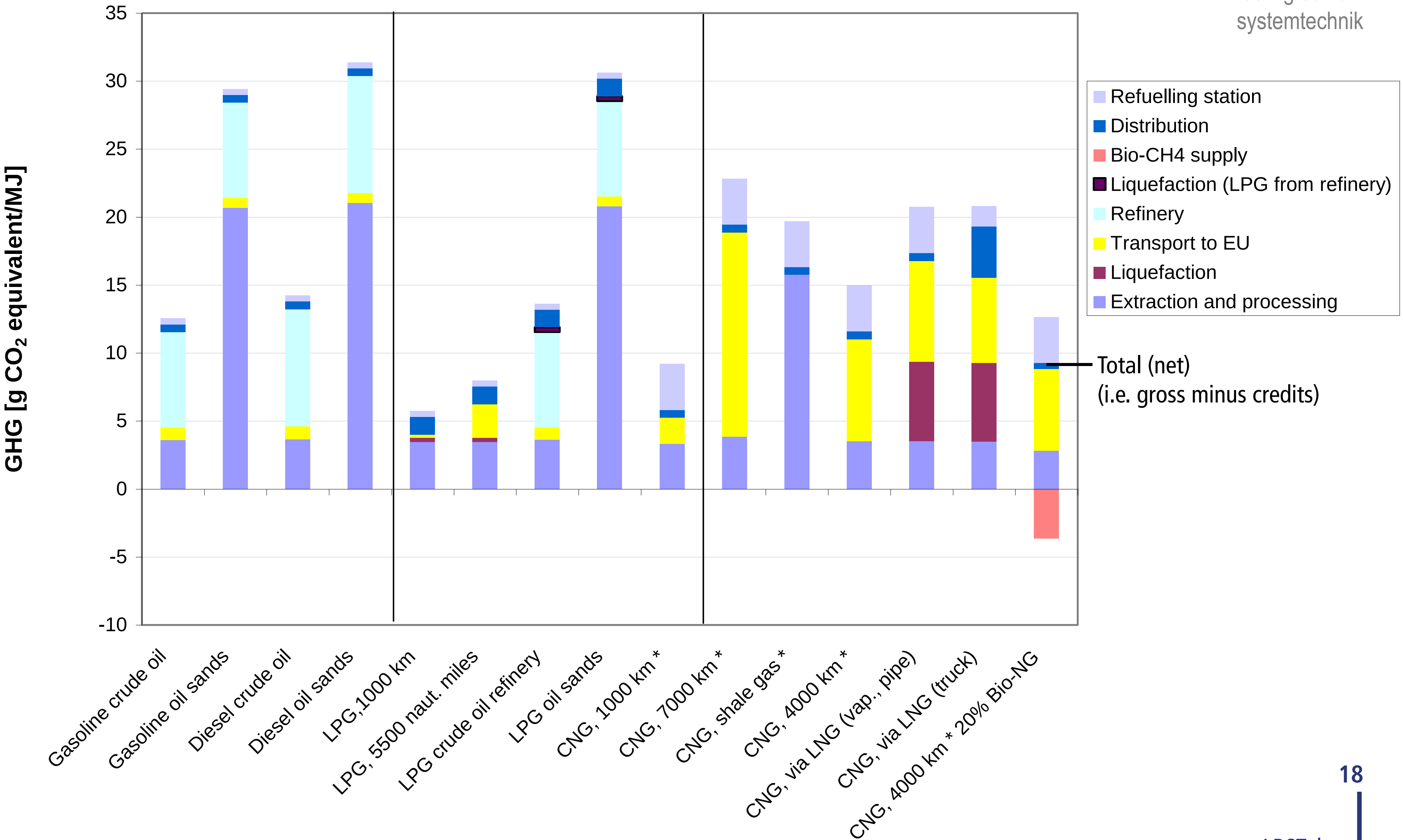

* plus distribution via the high pressure natural gas grid (500 km) and the local natural gas grid (10 km)

Environmental performance
Vehicle definition

„VW Golf"-Class Vehicle: Efficiencies

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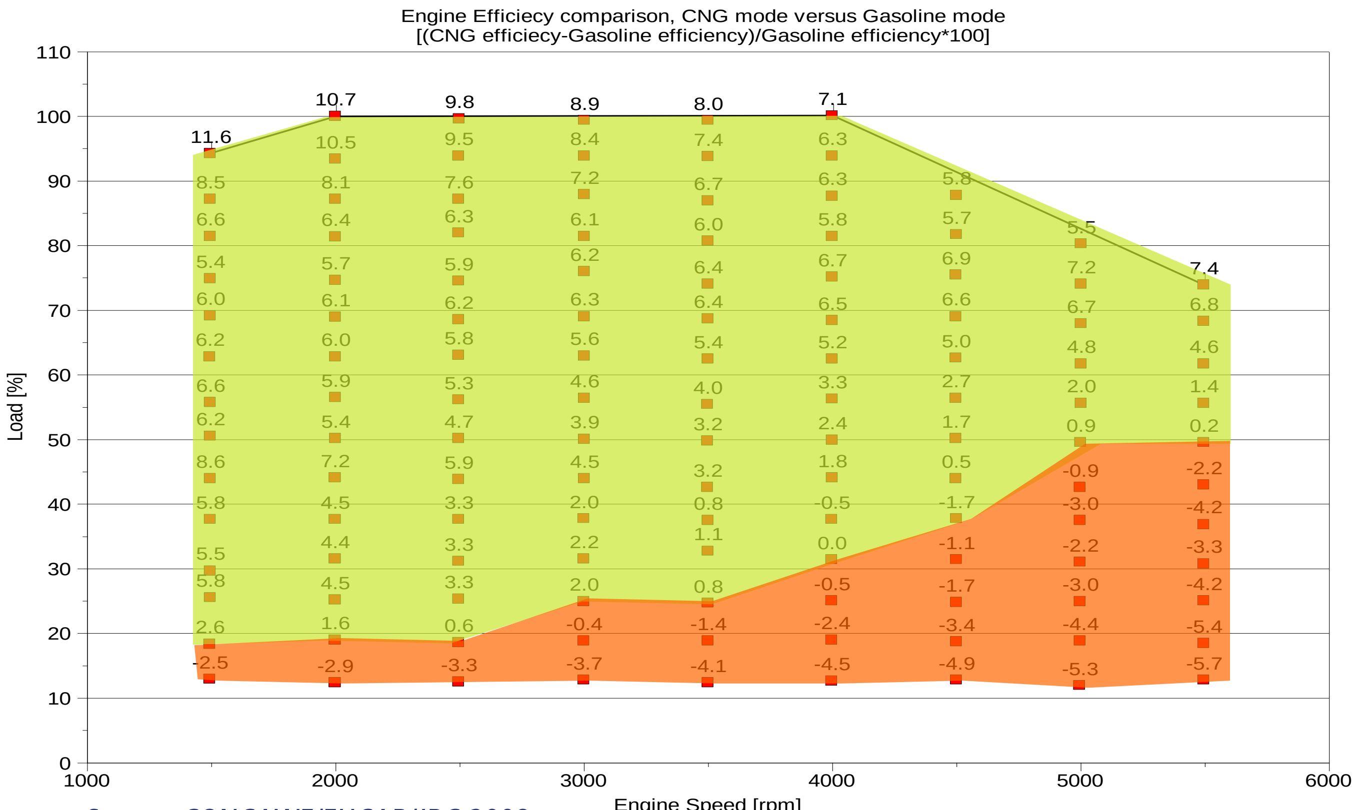
- Methane has a higher octane number → Higher compression ratio → Lower fuel consumption of dedicated CNG compared to gasoline ICE over a broad operating range (green)
- Hybridisation allows for exploiting this advantage



Source: CONCAWE/EUCAR/JRC 2008

„VW Golf"-Class Vehicle: Fuel consumption

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Power train	Time horizon	Used in WtW	Used in Scenario	Non-hybrid l_{GE}/(100 km)	Hybrid l_{GE}/(100 km)
Gasoline PISI 1.6 l	2002 / mix today		X	6.9	-
Gasoline DISI 1.6 l	2002 / mix today		X	6.5	-
LPG bi-fuel PISI 1.6 l	2002 / mix today		X	6.9	-
CNG bi-fuel PISI 1.6 l	2002 / mix today		X	7.1	-
Gasoline PISI	2010-2020	X		5.9	-
Gasoline PISI 1.6 l 14 kW	2010-2020	X	X	-	5.0
Gasoline DISI	2010-2020	X	X	5.8	-
Gasoline DISI 1.6 l	2010-2020			-	5.1
Diesel DICI DPF	2010-2020	X		5.1	-
Diesel DICI DPF 1.9 l	2010-2020	X		-	4.5
LPG bi-fuel PISI	2010-2020	X	X	5.9	5.0
CNG bi-fuel PISI	2010-2020	X		5.9	-
CNG bi-fuel DISI*	2010-2020	X		5.9	-
CNG dedicated PISI 1.6 l	2010-2020	X	X	5.8	4.3
CNG dedicated DISI*	2010-2020	X	X	5.8	4.3

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

	CO [g/km]	CH_4 [g/km]	NMVOC [g/km]	NO_x [g/km]	PM [g/km]
Spark Ignition (SI)	1.000	0.032	0.068	0.060	0.005
Compressed Ignition (CI)	0.500		0.090 (THC)	0.080	0.005

PI: Port Injection
CI: Compression Ignition

CO: Carbon monoxide
CH4: Methane
NMVOC: Non-Methane Volatile Organic Compound
NO_x: Nitrogen oxide
PM: Particular Matter

- 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

Environmental performance
Well-to-Wheel (WtW)

Bandwidth of Greenhouse Gas Emissions · Well-to-Wheel

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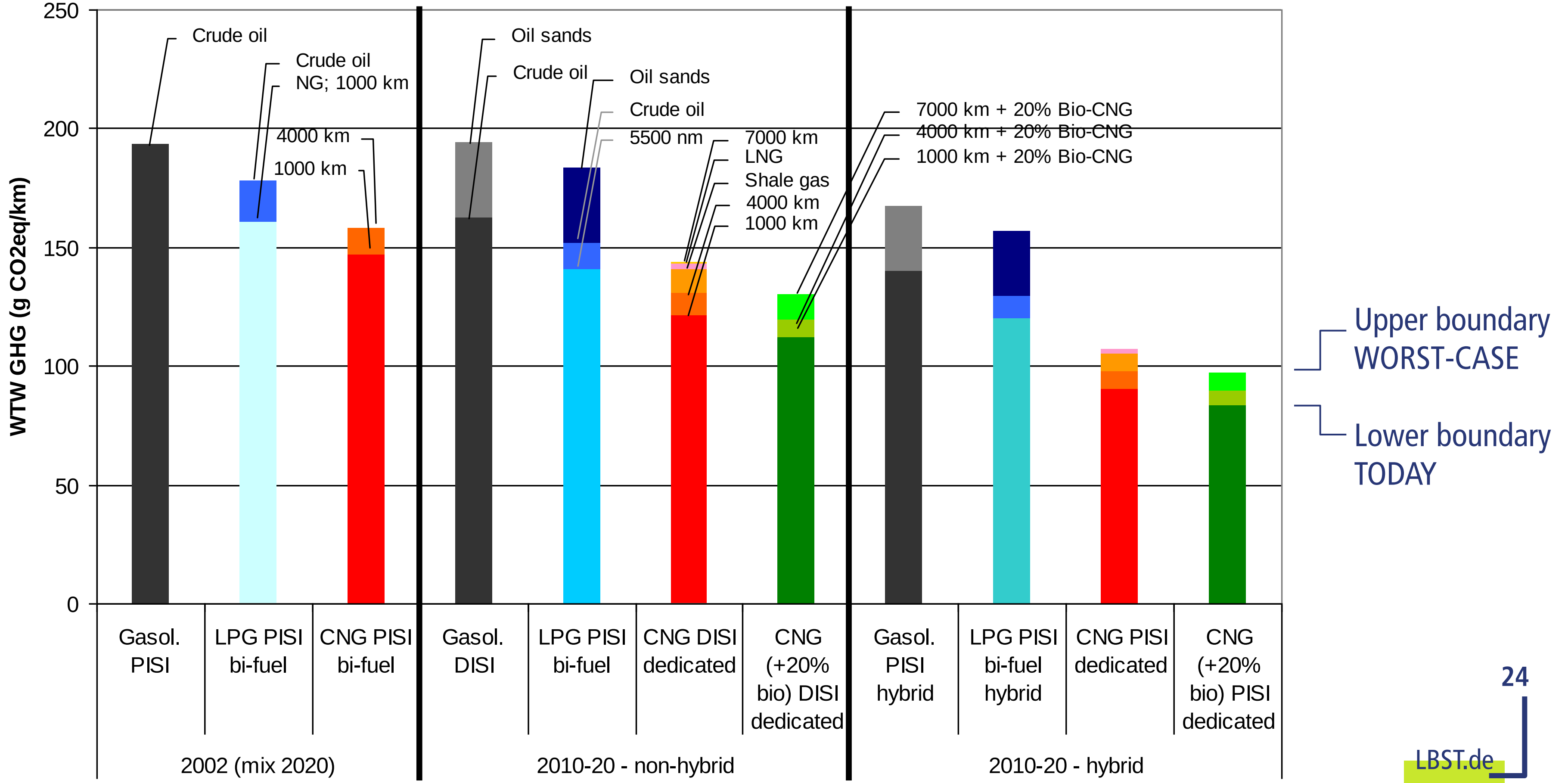
- CNG bandwidth lower than LPG bandwidth in all cases
- Difference in lower WtT emissions and carbon content of CNG
- Also, efficiency improvement through hybridisation higher for CNG



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Current GHG reductions (2010)

Greenhouse Gas Savings from CNG and LPG TODAY

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- 2008: 146 million tons CO_{2eq} (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 [RENEWBILITY study]

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

Technology	GHG savings per car (2010)	# of cars (2010)	Overall GHG savings (2010)
CNG (dedicated PISI; 1000 km transport distance)	0.592 t_{CO2eq} / a	68,500	40,527
CNG (dedicated PISI; 4000 km transport distance)	0.424 t_{CO2eq} / a	68,500	29,067
LPG (bi-fuel PISI; crude oil refining)	0.194 t_{CO2eq} / a	370,000	71,765
LPG (bi-fuel PISI; NG 1000 km)	0.420 t_{CO2eq} / a	370,000	155,048

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Additional GHG reductions (until 2020 and beyond)

Changes until 2020

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- 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 FUTURE

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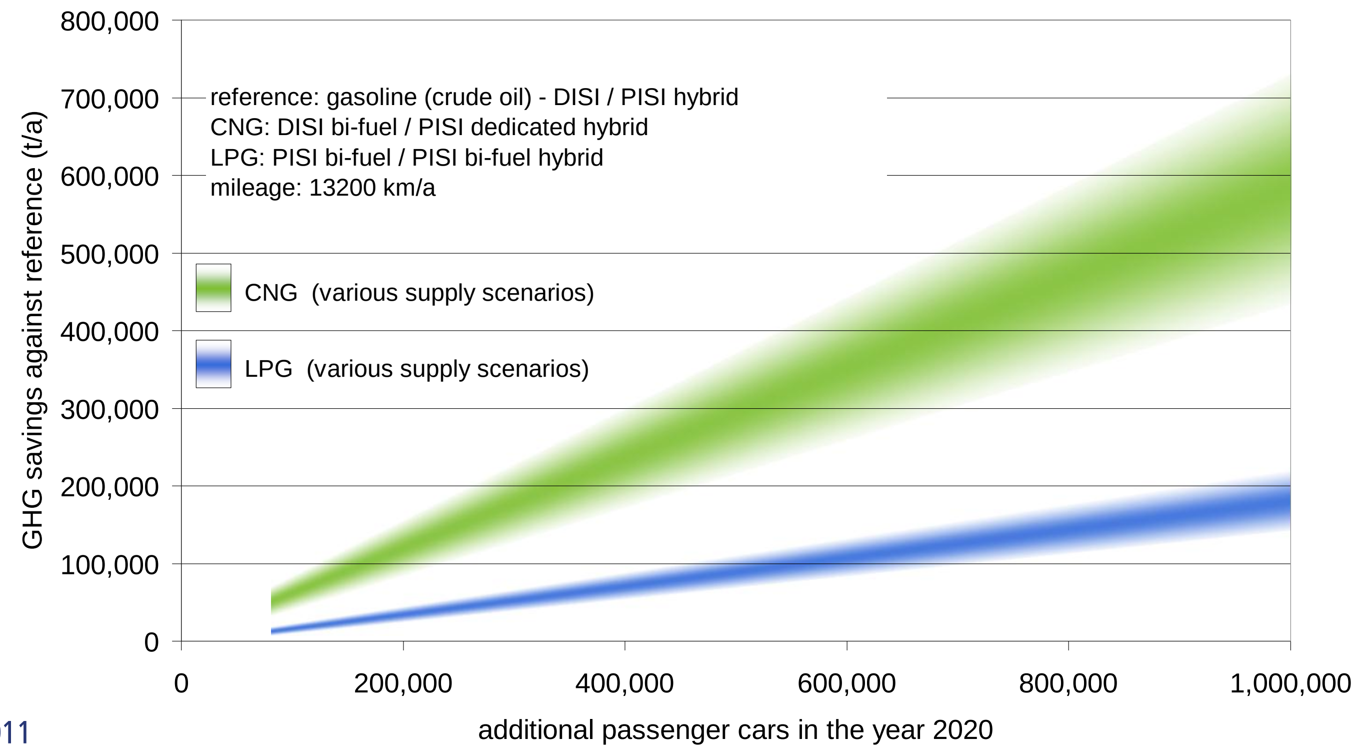
- One million LPG vehicles can save up to 260,000 t CO_{2eq} assuming hybrids (replacing hybrids), and up to 290,000 t CO_{2eq} assuming non-hybrids (replacing non-hybrids)
- One million CNG vehicles can save up to 670,000 t CO_{2eq} assuming hybrids (replacing hybrids), and up to 570,000 t CO_{2eq} assuming non-hybrids (replacing non-hybrids) (assuming 20% bio-methane*)

* No land use change



Achievable Quantities & GHG Reduction

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- 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

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Contribution to comply with EC regulations

EC Directives

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

Transportation fuel		EU Directives RED	EU Directives FQD	Annotation
Methane	CNG	–	✓	
	Bio-methane	✓	✓	
	SNG	✓*	✓	*If non-fossil CO_2 is used
LPG	Crude oil refining by-product	–	✓	
	NG extraction by-product	–	✓	

–	cannot contribute
✓	contribution possible
✓*	not defined / conditioned

Contribution of 1 million vehicles to FQD 6% target

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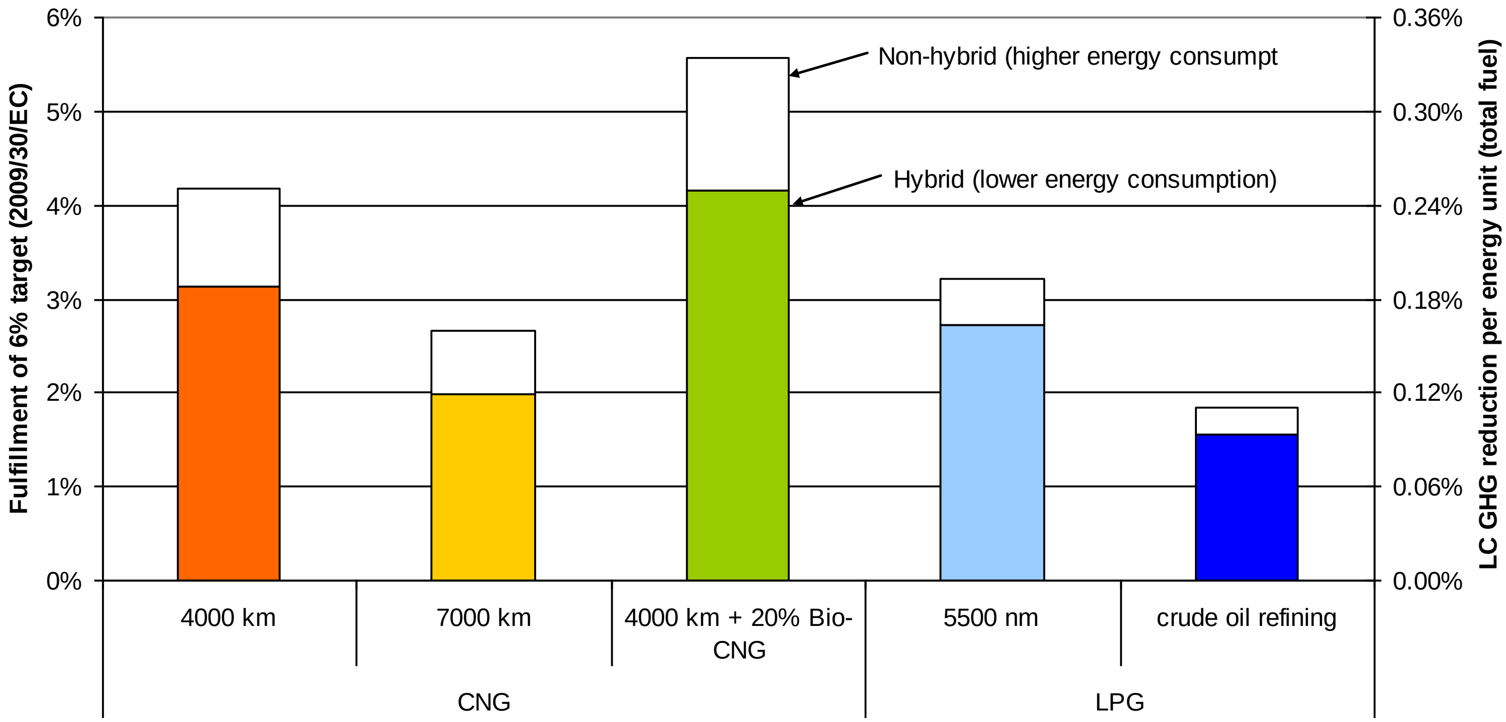
- Overall lifecycle per-energy GHG reduction of 1 million vehicles between 0.09 and 0.33%
- Representing 1.6 to 5.2% of the 6% target (CNG 2-5.6%; LPG 1.6-3.2%)

→ 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

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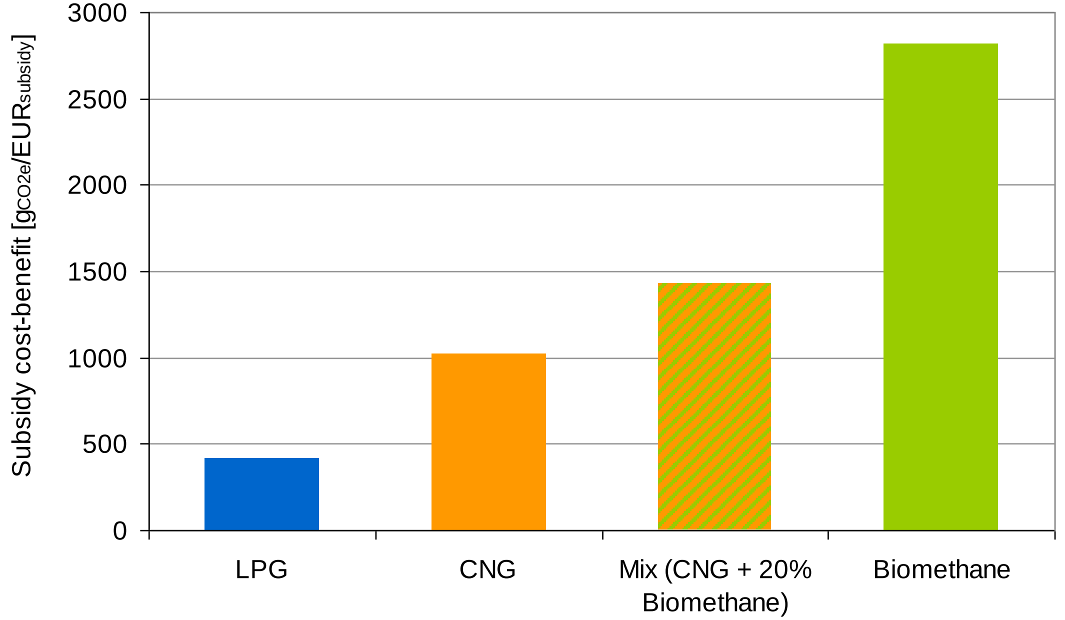
- Energy tax rate reduced for CNG, bio-methane and LPG until 2018
- Reduced energy tax ~ Subsidy
- Cost-benefit of energy tax reduction in terms of GHG emissions avoided:



- 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.

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- LBST
- Status quo
- Environmental performance
- Emission reduction potentials
- **Conclusions and perspectives**

Conclusions and Perspectives

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- 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.

Thank you!

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BACKUP
EU Regulations
RED & FQD

EU Renewable Energy Directive (RED)

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„Promotion of the use of energy from renewable sources"
(EU-RED – Directive 2009/28/EC – 23 April 2009)

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

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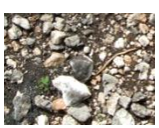
„Promotion of the use of energy from renewable sources"
(EU-RED – Directive 2009/28/EC – 23 April 2009)







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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.)

EU Fuel Quality Directive (FQD)

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„Promotion of the use of energy from renewable sources" (EU-FQD – Directive 2009/30/EC – 23 April 2009)

« 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. … »