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LNG in Germany: Liquefied Natural Gas and Renewable Methane in Heavy-Duty Road Transport.

What it can deliver and how the policy framework should be geared towards market entry.

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Berlin, September 2014

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"LNG with high energy density offers a cost-efficient alternative to diesel [...]. LNG is particularly suited for long-distance road freight transport for which alternatives to diesel are extremely limited." (EC, 2014)

German Mobility and Fuel Strategy: LNG should be systematically developed.

"The extension of the fuel base for trucks from diesel to a gas drive should be systematically addressed as a new pillar of the programme." (BMVBS, 2013)

1 Summary and recommendations.

Hype or opportunity: What can LNG really contribute to clean road transport?

Road-freight transport is a vital pillar of the German economy. Unfortunately, regardless of governmental objectives it has not been possible to decouple this sector's greenhouse gas emissions (GHG) from economic activity: Emissions increased 40 % compared to 1990 and 12 % compared to 2007. In the search for the "silver bullet" for improved energy security and climate-change mitigation, Liquefied Natural Gas (LNG) is now the top of discussion. However, despite encouragement from the EU's "Clean Power for Transport" strategy, German industry hesitates to make the necessary investments in new refueling infrastructure and trucks. Because it is too risky to bet on the wrong fuel in the low-margin logistics sector, two key questions must be answered:

- Can LNG compete with the long-established diesel fuel?
- If so, what are the key actions and policy instruments for successful market entry?

LNG is abundant and environmentally friendly.

LNG offers increased energy security for road transport, easing the transport sector's dependency on crude-oil imports and diversifying energy-supply countries. LNG-terminals in the Netherlands, Poland and Belgium provide access to secure LNG supplies. Natural gas resources are expected to last much longer than oil resources. Natural gas is the cleanest fossil fuel, and it allows for an admixture of up to 100 % renewable methane. Dedicated LNG Otto-cycle engines fulfil the tight Euro-VI emission standard, and due to their low noise levels they facilitate inner-city and nighttime delivery services.

The GHG performance of LNG can be increased by renewable methane from biomass, wind or solar power.

Natural gas offers the best carbon-hydrogen and carbon-energy ratio of all fossil fuels. However, for a cost-effective contribution to climate change mitigation, the energy efficiency of engines and fuel provision must be improved. New LNG trucks are being announced for availability in 2015 with 10 % GHG savings well-to-wheel compared to diesel trucks. Liquefied renewable methane from biomass, wind or solar power already offers up to 93 % GHG savings today. LNG, at a 4 % market share, could reduce the GHG emissions of road-freight transport in Germany by 240.000 t CO_2 per year, if 20 % biomethane is admixed.

LNG technology is mature and widely available.

Most truck manufacturers offer LNG trucks for various duties. Additionally, next-generation engine technologies with improved torque and fuel efficiency are being announced for 2015. LNG refueling technology is mature and provides safe handling.

Germany can learn from the best-practice market introductions in other countries.

LNG is successfully used as road fuel in North America, parts of Europe and China. Currently, more than 50,000 trucks and 1,300 filling stations are in operation. LNG forms a strategic pillar for tomorrow's clean, cost-competitive logistics as well as for the creation of future-proof jobs in these countries.

In the race for clean truck fuels, LNG is the only financially feasible option. It will not rely on permanent subsidies.

LNG is the only financially feasible option in the short-to-intermediate term that can reduce oil-dependency and the GHG emissions of heavy-duty road-freight transport. It probably has the lowest GHG mitigation cost of any alternative truck fuel. LNG's price advantage, as compared to diesel fuel, is expected to be sustained in the future, allowing for clean logistics at competitive costs once a critical market share is reached.

Industry and politics need to team up for successful market entry and growth.

A critical market share must be reached by 2024 in order to reap the financial benefits of economies of scale. Such a market share would be at least 10 % in the truck market and 4 % in the truck-fuel market. Industry and government must team up in a coordinated approach whereby industry invests in pilot fleets and infrastructure while government provides investment security and rewards first-movers. By means of a "national strategy platform for LNG in road transport," these actors should resolve the chicken-egg dilemma between trucks and filling stations and offer cross-industry advice to policy makers.

The authors suggest an effective policy framework that incentivises the demand and supply sides of the market.

The following policy instruments are recommended for successful market entry and growth in Germany.

Instruments to increase the willingness to demand LNG:

- Exemption from road tolls for pilot fleets
- Extension of road-fuel tax differentiation for natural gas
- Green purchasing of LNG trucks and buses for public fleets

Instruments to increase the willingness to supply LNG:

- A national strategy for LNG market entry and growth in road-freight transport
- Clear, quantitative, scheduled targets for LNG market share within national and EU clean-fuel strategies
- Standardisation of certification procedures for vehicles and filling stations

2 Challenges and political targets in road freight transport.

EU and German policy makers have clear directives to "break the over-dependence of European transport on oil . . . 84 % [of which is] imported". While EU member states pay energy import bills "of up to EUR 1 billion per day" to satisfy their transport needs, the environmental and social costs also increase (EC, 2014).

Despite these challenges, the "Energiewende" in transport in Germany is currently discussed mainly in the context of passenger vehicles. However, alternatives to established diesel fuel vehicles can make a difference in road-freight transport as well. However, any alternative fuel must match fleet customers' high expectations in regard to everyday usability, price and environmental performance.

While LNG market development in other countries has already entered the phase of early markets, the German market has not even entered the demonstration phase. There is little public information or awareness regarding the actual potential, limitations, and expected costs of LNG in the German context. Is it a viable option for road-freight transport or merely hype? Consequently, this gap must be filled in order to facilitate informed policy-making and investment decisions.

The main questions are shown below:

- Can LNG successfully compete against diesel fuel for relevant transport applications?
- Apart from being non-oil-based, can LNG help to decouple rising energy consumption in road-freight transport and GHG emissions?
- How has LNG market development been successfully launched in other countries' transport sectors (the lessons learned)?
- What are the barriers to market development?
- Which actions by politics and industry are necessary to overcome the barriers?

The authors aim at answering these questions with the following audience in mind:

- Politics at the EU, federal, state and regional levels
- Heavy-duty truck operators and fleets
- Private and municipal energy utilities
- Vehicle and engine manufacturers

2.1 Energy and climate challenges in German road transport.

Secure and affordable energy supply is of vital concern to industrialised economies, yet the environmental costs are high. GHG-emissions from transport accounted for 20 % of the total energy-based GHG emissions in Germany in 2012 – households 20 % and industry 15 %, energy provision 47 % (UBA, 2014). While all other sectors achieved reductions of 14.3 % from 1990 to 2012 on average, GHG emissions in transport today are as high as in 1990 (UBA, 2014).

Road-freight transport is of particular concern: GHG emissions in this sector remain coupled to economic activity. They increased more than 40 percent compared to 1990 (UBA, 2014) – practically ignoring political targets. Improvements in energy efficiency or GHG emission performance have not been able to compensate for the increased transport intensity. Furthermore, freight transport intensity is forecast to further increase by 39 % compared to 2010 (BMVI, 2014).

Heavy-duty trucks or articulated trucks are indeed a potential leader for successful alternative fuel policy: They consume 36 % of the diesel fuel in road transport (see Figure 1). Nevertheless, they represent less than 4 % of Germany's total vehicle fleet (KBA, 2010). Hence, even relatively minor action in this segment can be leveraged to great effect.

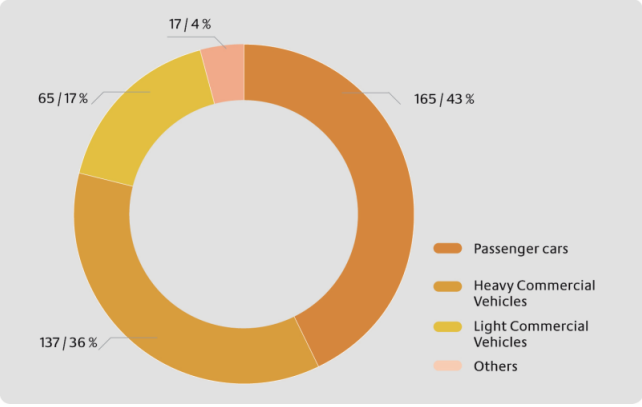

Figure 1: Diesel fuel consumption 2011 in TWh (DESTATIS, 2013)

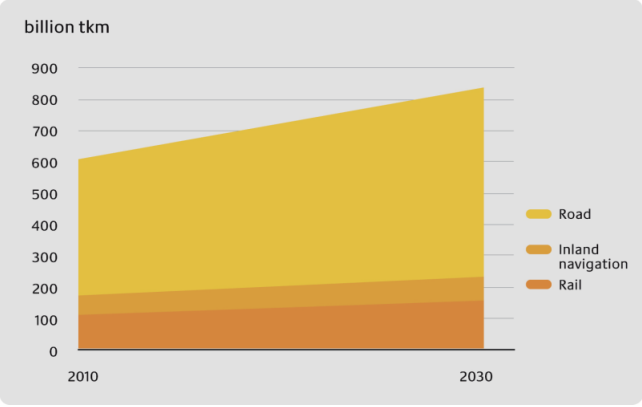

Figure 2: Future freight transport intenstiy in Germany (BMVI, 2014)

2.2 Policy targets and legislation on national and EU-level relevant for LNG market introduction.

Strong government objectives and legislation are needed to overcome above climate and energy challenges in road transport. Currently, however, road-freight transport plays a disproportionately small role in the German "Energiewende". Contrastingly, several EU policies directly target road-freight transport and LNG introduction.

European Clean Power for Transport (CPT) package

In April 2014 the European Parliament gave its final approval to the Clean Power for Transport (CPT) package. CPT highlights LNG as one of four alternative fuel options for the future and calls for minimum infrastructure coverage for LNG filling stations along major motorways of the Trans-European Transport network (TEN-T) by 2025. Supporting national policy frameworks must be developed by 2016, and member states will set their own paths for further infrastructural development.

European Fuel Quality Directive (FQD)

The 2009 Fuel Quality Directive mandates member states to reduce lifecycle GHG emissions of road fuels by 6 % until 2020. LNG, in combination with biomethane, could achieve both goals.

European Renewable Energy Directive (RED)

The Renewable Energy Directive (RED) mandates a 10 % renewable energy target for the transport sector. As part of a comprehensive renewable and alternative energy strategy, LNG admixtures with up to 100 % biomethane or synthetic methane have the potential to satisfy this policy.

The Euro VI emission standard

The 2014 Euro VI emissions standard substantially tightens heavy-duty vehicle (HDV) emission limits for nitrogen oxide (NO_x) and particulate matter (PM), among others. The new standard leads to substantially increased complexity and costs of diesel power trains over Euro V, enhancing the economic competitiveness of LNG trucks. Dedicated LNG Otto-cycle truck emissions stay below the Euro VI limits without costly after-treatment (Scania 2014; Iveco 2014).

EU innovation policy and funding

The European Commission has demonstrated its commitment to LNG as a truck fuel by co-funding the LNG Blue Corridors project, an international research-and-demonstration project. LNG Blue Corridors is intended to improve the knowledge and awareness of LNG for medium and long-distance transport. The project involves the construction of 14 LNG filling stations and the implementation of at least 100 LNG trucks, which will operate along trans-European routes covering twelve EU member states.

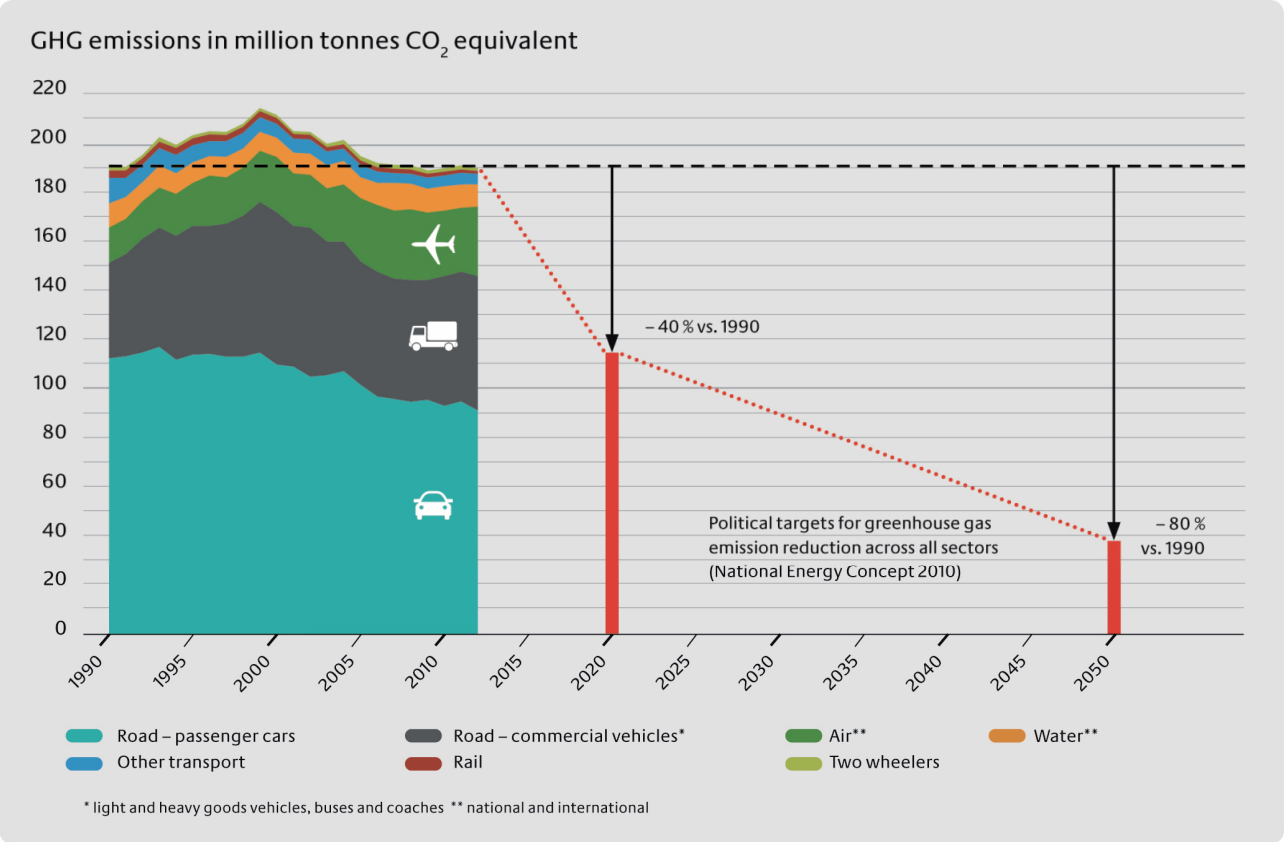

Figure 3: Annual GHG emissions in transport in Germany; data from UBA (2014)

EU strategy for reducing heavy-duty vehicles' fuel consumption and CO_2 emissions

The 2014 strategy targets certification, monitoring and the reporting of HDV emissions. It is addressed to the European Parliament and the Council, which are invited to endorse it and help deliver the actions thus outlined. The Commission plans to introduce legislative proposals in 2015.

National Energy Concept 2010

The German government intends to reduce GHG emissions in all sectors by at least 40 % by 2020 compared to the 1990 levels. If the transport sector is to contribute toward this target, dramatic action must be taken as illustrated in Figure 3. Furthermore, the "Energiewende" promotes a shift to renewable energy supply, e.g. renewable methane.

National Mobility and Fuel Strategy (MFS)

The German fuel strategy highlights LNG as a pillar of the future transport-fuel mix (see the fact box on the right).

However, the government currently favours a staggered LNG market introduction: first in the marine sector and then in road transport. Opposite to this two-step approach and in line with CPT, the authors pledge for sector-independent market introduction, i.e. to develop LNG for road transport concurrently with LNG for shipping.

LNG in the German National Mobility and Fuel Strategy:

"However, there is reason to fear that gains in truck efficiency will be cancelled out by a further increase in truck traffic. [...] The extension of the fuel base for trucks from diesel to a gas drive should be systematically addressed as a new pillar of the programme. 'Dual-fuel' vehicles [...] could contribute to a diversification of energy supply and lead to a reduction of CO_2 emissions in view of the option of including biomethane" (BMVBS, 2013).

3 Performance of LNG and renewable methane as a truck fuel.

This section compares the basic fuel characteristics, required vehicle technology and environmental performance of LNG with those of conventional diesel fuel.

3.1 Fuel characteristics.

The physical and chemical properties of LNG are very different from established transportation fuels such as diesel. It is stored in liquid form at temperatures ranging from -110°C to -164°C, which significantly reduces its volume and thereby increases the driving range: The energy content of 1 m³ of LNG corresponds to approximately 3 m³ of CNG and 0.6 m³ of diesel.

LNG typically contains between 81 and 99 % methane, 0 to 13 % ethane, 0 to 4 % propane, 0 to 1 % heavier hydrocarbon gas and 0 to 1 % nitrogen. It is colourless, odourless, non-corrosive and non-toxic. LNG can be used in both Otto- and Diesel-cycle engines. Its combustion produces the cleanest exhaust emissions of all fossil hydro-carbon fuels.

Parameter	Unit	Diesel	Liquefied methane (LNG, LBM, LSM)
Lower heating value (energy density)	MJ/kg	43.13	50
	MJ/l	35.88	21.00
Density	kg/l	0.832	0.36–0.42
CO_2 emission factor (TTW)	g/MJ	73.25	55.0
Sulphur content	ppm (mass)	10	0
Storage pressure	MPa	0.1	0.1 (cryogenic)
Auto-ignition temperature	°C	210	537
Environmental and health threats		 *  **	High gas concentrations will displace available oxygen from the air; cryogenic burns

Table 1: Chemical and physical characteristics, safety and environmental risks of selected fuels (LBST, 2014)

* WGK2, GHS09 (harms water quality, is toxic to aquatic organisms and may cause long-term adverse effects in the aquatic environment)

** GHS08 (irritates the skin and is harmful by inhalation)

LNG has fewer environmental and health risks compared to diesel (see Table 1). When spilled, diesel harms water quality, is toxic to aquatic organisms and may cause long-term adverse effects in an aquatic environment. There is no such indication for LNG or CNG. However, in direct contact with human body parts LNG will cause severe *cold-burns* and inhalation of its vapours may cause suffocation due to oxygen displacement.

The spillage of LNG into a body of water may lead to rapid phase transition, which is an important consideration for LNG transporters and first responders (SIGTTO 2010; DOE 2012). It is critical to realise that LNG's volume expands by a factor of 600 when fully evaporated from cryogenic liquid to gas.

3.2 Resource availability and distribution.

A functioning LNG market depends on LNG supply from sufficient reserves that can be delivered in a timely manner and at a competitive price level with respect to established fuels.

Fossil natural gas resources and reserves

The International Energy Agency confirms the abundance of gas for the next decades, and estimates world gas **resources** of 810 trillion cubic meters (tcm) and proven **reserves** of 187 tcm in 2012 (IEA, 2013). More than 50 % of reserves are concentrated in Russia, Iran and Qatar. In Europe, the largest conventional gas reserves are in Norway and the Netherlands. The USA holds approximately 3.6 % of the global reserve. Approximately one-third of it consists of coal-bed methane and shale gas.

Supply of fossil LNG

LNG is produced mainly in Qatar, Algeria, Nigeria and Norway. Until 2017, the already significant liquefaction capacity in the Pacific Basin will increase by nearly 50 %, mainly in Australia, while additions in the Atlantic Basin will grow at 18 % [IFPEN 2012]. Should LNG demand dramatically exceed these production capacities, Germany could obtain additional supplies through the liquefaction of piped natural gas and/or other renewable methane sources.

Nearly 19 % of total LNG exports were delivered to the EU in 2012, while less than 2 % went to the USA, where shale-gas production has saturated the market. Moreover, 69 % was delivered to Japan, South Korea, Taiwan, India and China, due in part to the higher demand and prices there. After the Fukushima disaster, a significant proportion of Japan's domestic power supply was generated with natural gas instead of nuclear power. These differences in demand influence LNG pricing: regional LNG landed prices per MMBTU vary from US$2.44 in USA, US$6.78 in Belgium to US$10.50 in Japan for September 2014 (estimate from US-FERC, 2014).

Indigenous natural gas production of the European Union was approximately 33 % of the total supply in 2012 (eurogas, 2013). Approximately 12 % of the European natural gas demand was covered by LNG imports (BP, 2014). In 2013 Germany imported

91 % of its natural gas consumption: 39 % of the imports came from Russia, 29 % from Norway and 26 % from the Netherlands (BAFA, 2014).

LNG terminals in Zeebrugge, Rotterdam and the UK satisfy the current LNG demand in northwestern Europe. Two terminals in Świnoujście (Poland) and Dunkirk (France) are scheduled to start operation in 2014 and 2015, respectively. Carefully located domestic liquefaction may provide added security of supply for areas in Germany remote to LNG terminals, possibly with positive effects on fuel transport costs and fuel quality (Westport, 2014).

The development of future trade relations for bulk LNG – and how much can be expected to reach European and German shores – is subject to LNG supply costs, buyers' willingness to pay at major trade hubs, and prices for competing pipeline gas from Russia.

Supply from renewable sources

Liquefied biomethane (LBM) forms a major renewable source. It can be domestically produced in Germany through the upgrading of biogas from biomass fermentation or gasification. Such options can be considered in regions with sufficient biomass availability, whether from waste/residue or agricultural biomass. Biogas production in Germany is expected to grow from 90 million MWh in 2013 to 130 million MWh in 2020 (FNR, 2014), i.e. 10 to 14 % of total natural gas consumption. To put that into perspective: in 2013 natural gas consumption in transport was approximately 2.3 million MWh; total road fuel market approx. 750 million MWh (BMU, 2014).

The overall contribution of biomethane on the German road fuel market, however, depends on its competitiveness to natural gas prices and biogas demand in stationary electricity production. The latter is favoured due to high feed-in tariffs from the Renewable Energy Law.

The second renewable option is **liquefied synthetic methane** (LSM) from synthesis of CO_2 and hydrogen produced through the electrolysis of renewable energy ("power to gas") and subsequent liquefaction. In comparison to other renewable fuels, LSM shows the highest energy yield per hectare. Furthermore, LSM can tap the high technical potentials of wind and solar power production in Germany. The areas between adjacent wind converters can be used for agriculture or similar applications. Hence, biomass production for biomethane can be co-sited with wind power.

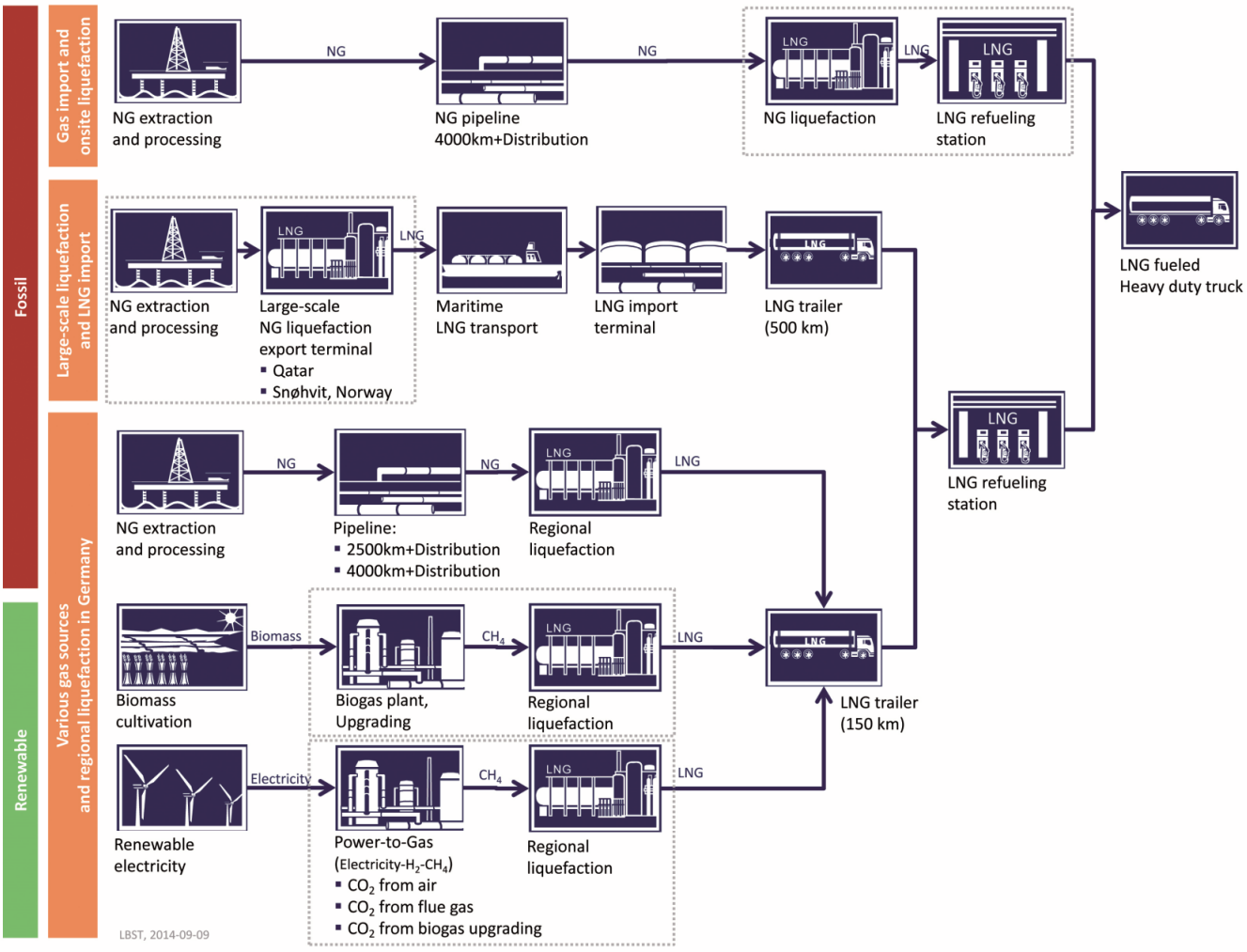

Figure 4: Overview of assessed LNG supply pathways (LBST, 2014)

3.3 Vehicle availability and technology.

Natural-gas trucks (LNG and CNG) are already available for a wide range of transport operations, including urban and distribution logistics, garbage collection and long-haul trucking operations. LNG trucks differ from CNG trucks mainly in terms of fuel storage. The engine technology is very similar for both fuels. All major truck manufacturers offer natural-gas engines, either as dedicated **(mono-fuel) Otto-cycle engines** or as **Diesel-cycle engines**. While dedicated Otto-cycle engines run exclusively with 100 % natural gas, dual-fuel engines run with methane-diesel mixtures with diesel substitution rates of 50 to 95 %.

The dedicated Otto-cycle engines of Europe are typically OEM-built and integrated into trucks (e.g. Iveco, Scania, Mercedes) or buses (MAN and Iveco). However, the latest such truck models available from the factory have power outputs up to only 250 kW, leading to restricted market potential in the logistics sector. In the future, dedicated Otto-cycle engines with minimum performance ratings of 340 kW can be expected (Engineer, 2014), which will attract more fleet operators.

Figure 5: IVECO Stralis LNG, (© Iveco)

LNG Diesel-cycle engines can either be OEM-equipped or retrofitted with engine conversion kits (from e.g. Caterpillar, Clean Air Power, Hardstaff or Westport) that can be installed either at the factory or as aftermarket solutions. Truck examples include the Mercedes Actros truck line, Renault's Magnum and Volvo's FM/FH13. MAN (formerly Volkswagen do Brazil) offers a Volksbus with dual-fuel technology for Brazil's urban bus market.

Technology development now focuses on LNG Diesel-cycle engines with diesel substitution >90 % (quasi-dedicated) and cost reduction of the expensive LNG storage.

3.4 Air quality and noise performance.

Natural gas, when combusted, surpasses the environmental performance of diesel fuel by producing fewer emissions of sulphur oxide, nitrogen oxide and particulate matter.

However, as of 2014, the new Euro VI emission limits apply to heavy-duty vehicles in the European Union, thus forcing diesel truck emissions to become as clean as those of LNG trucks. This increases the complexity and cost of trucks that use diesel fuel. Dedicated LNG Otto-cycle engines comply with the Euro VI regulations. A major advantage of these engines compared to diesel engines is the lower noise emission, which is a competitive advantage for e.g. inner-city and night-time duties (see the best-practice analysis on the Netherlands in Section 4.3).

All dual-fuel engines currently available in Europe fulfil, at best, the Euro V or EEV emission limits. According to truck OEMs, it is challenging to design dual-fuel engines that meet the Euro VI emission limits, particularly the methane emission limit. Nevertheless, the EU-market launch of very efficient HPDI diesel engines, already in operation in the USA, has already been announced by Volvo Trucks (see the fact box on page 11). Diesel substitution for this engine type is typically more than 90 % but less than 95 % (Westport, 2014).

	Cummins Westport ISX12 G	IVECO Stralis	Mercedes-Benz Econic	Scania P310 and P340	Volvo FM/FMX D13C-Gas	Volvo D13 HPDI
Engine type	Dedicated Otto-engine				Diesel-engine	
Fuel substitution	100 %				90 < 95 %	typ. <75 %
Available (year)	2012	2014	2015	2014	2015	2015 (USA)
Power (kW)	298	243	222	206/250	338	298/339
Torque (Nm)	1,966	1,400	1,200	1,350/1,600	2,300	2,372
Eng. displacement (cm^3)	11,900	7,790	7,700	<9,300	12,800	12,800
Emission class	EPA10 & Euro V	Euro VI	Euro VI	Euro VI	Euro V	EPA 10
Range (km)	-	750	-	<1,100	600-1,000	-
Source	(Westport, 2014)	(IVECO, 2014)	(Daimler, 2014)	(Scania, 2014)	(Volvo, 2012)	(Volvo, 2014) (F&F, 2014)

Table 2: Overview and characteristic of selected LNG heavy-duty vehicles

3.5 Greenhouse gas performance.

LNG is a clean fuel and a low-carbon fuel: during combustion it emits 55 g CO_2eq per MJ_{fuel}, i.e. 25 % less than diesel fuel (73 g). This over-compensates for the higher GHG-emissions during LNG production, resulting in a combined **energy-specific GHG emission** advantage over diesel of about 16 % (JEC, 2014) for a import distance of 5,500 nautical miles (see Figure 6).

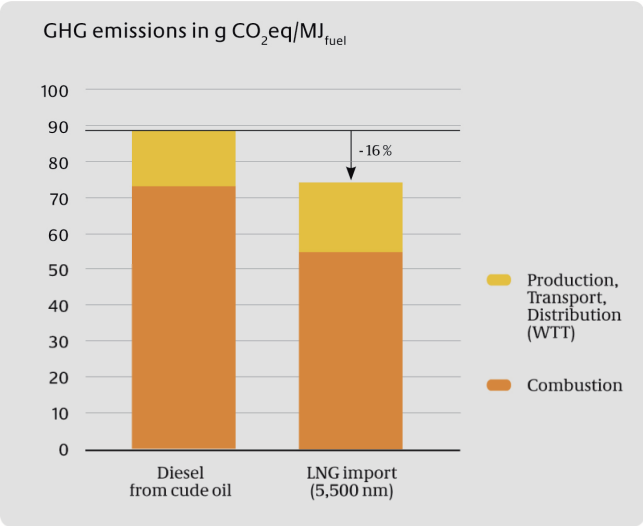

Figure 6: Energy-specific GHG-emissions of diesel and LNG (5,500 nm), complete combustion assumed; data from JEC (2014)

The performance of LNG with regard to **per-km GHG emissions** depends on a) means of production and transport (well-to-tank, WTT) and b) engine and truck technology (tank-to-wheel, TTW). In order to allow fossil LNG to realise expectations for the mitigation of climate change incurred through transport, its advantageous carbon-energy-ratio must be reaped through efficient WTT and TTW energy conversion. The authors commissioned Ludwig Bölkow Systemtechnik (LBST) with a WTT and TTW analysis for most common pathways. The results are presented below.

LNG supply pathways: Well-to-tank (WTT)

Most typical LNG fuel-supply pathways involve LNG import via sea from liquefaction sites near natural gas fields. In our analysis, the bandwidth of this path is represented by data from JEC (2014) for imports from a) Qatar and b) Snøhvit (Norway). LNG from Qatar represented 45 % of LNG imports to Europe in 2013 (LBST, 2014). LNG could also be produced in liquefaction plants within Germany (regional and onsite) using piped natural gas. This path is represented by a 4,000 km pipeline transport distance. However, it is currently not financially competitive and is not applied in Germany (erdgas mobil, 2014).

Additionally, two paths for LNG supply from renewable sources are assessed: a) from LBM (Liquefied Biomethane) and b) from LSM (Liquefied Synthetic Methane), e.g. from synthesis of methane from renewable hydrogen and CO_2 ("power-to-gas").

LNG use: Tank-to-wheel (TTW)

Truck fuel consumption will vary significantly depending on the duty cycle or weight. No official comparable fuel consumption data exists. To calculate TTW emissions, real-life fuel consumption of the company Rolande LNG in the Netherlands is taken. They operate both the Otto-engine powered Iveco Stralis 440 S 33 TP/LNG and the respective Stralis Diesel. Unfortunately, no data is available yet for LNG trucks with LNG Diesel-cycle engines, which offer improved energy efficiency. Current Euro VI LNG Otto-cycle engines are up to 30 % less efficient than diesel engines.

Fuel consumption of the Stralis LNG truck is 14.0 MJ/km or 28 kg/100 km. The reference diesel truck consumes 11.1 MJ/km or 31 l/100 km (Rolande, 2014). Respective GHG emissions tank-to-wheel amount to 798 g CO_2eq/km for the LNG version, and 828 g CO_2eq/km for the diesel version (LBST, 2014). There is a slight TTW emission advantage of 3.6 % for the LNG truck.

This advantage could be improved notably with the introduction of Euro VI LNG diesel engines with HPDI technology. According to Volvo Trucks, this could happen from year 2015/2016 in a magnitude of 10-15 % WTW advantage over diesel (see the fact box). In North America, HPDI-engines with high energy efficiency already are in operation. The resulting reductions would signify a major leap in truck efficiency in Europe, where two-digit improvements in GHG performance have been rare in the past years.

Major breakthrough announced for GHG performance of LNG trucks

Volvo has announced to introduce **HPDI technology 2nd generation** for LNG trucks in North America by the end of 2015 meeting strict EPA 10 emission standards. Parallel development is in progress for Euro VI certification in the European market. Performance and total energy consumption of the new LNG engine is announced to be identical to the comparable diesel fuel engine. With diesel substitution rates above 90 % Volvo Trucks with LNG HPDI technology could achieve a GHG emission reduction of 10 to 15 % GHG (WTW) as compared to diesel trucks. The calculations are based on JEC WTT study concerning methane slip and methane emission values in the Euro VI legislation (0.5 gCH_4/kWh). Any improvement in the chain will increase the GHG reductions (Volvo, 2014).

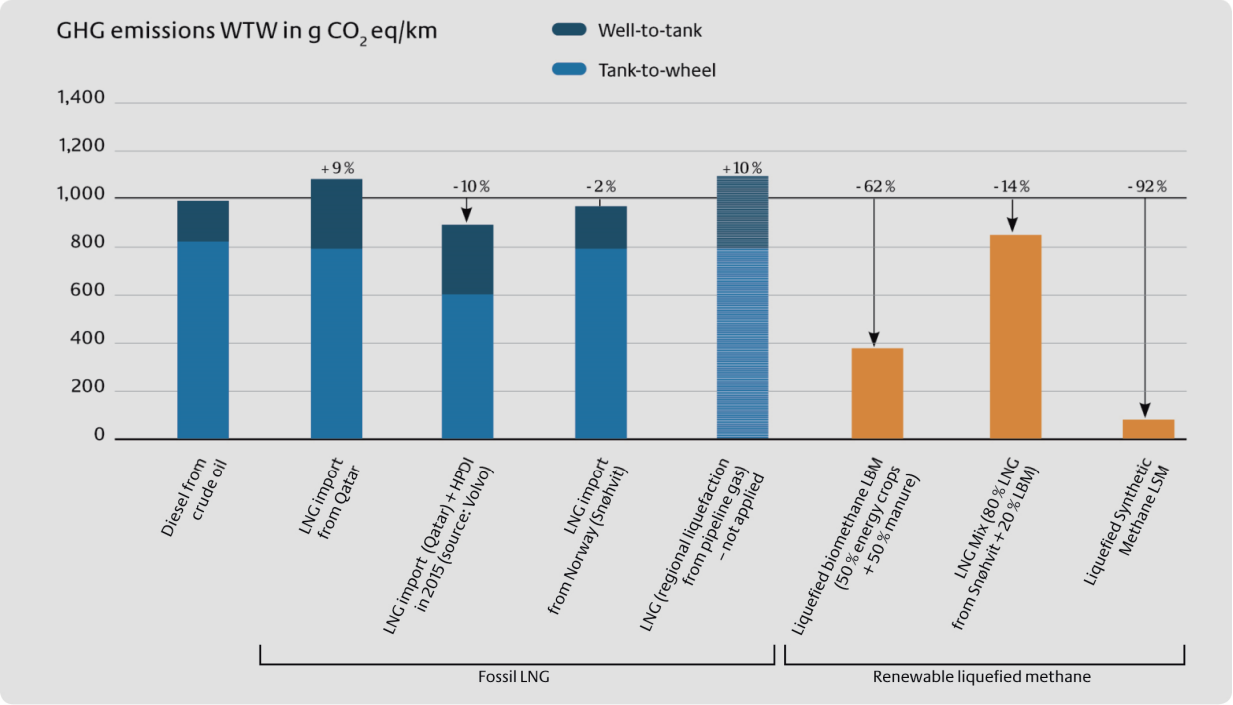

Figure 7: Greenhouse gas emissions 'well-to-wheel' for relevant pathways (diesel shown without renewable admixture; greenhouse gases considered: CO_2, CH_4, N_20; data from JEC (2014) and LBST (2014)

LNG supply and use: Well-to-wheel (WTW)

Figure 7 compares the combined well-to-wheel GHG emissions for LNG-fuelled heavy-duty trucks compared to diesel trucks on the basis of JEC (2014) and LBST (2014). The analysis reveals that under previous assumptions LNG trucks will only contribute to climate change mitigation in transport, when a) efficient HPDI Diesel-cycle engines are applied or b) LNG admixtures with LBM or LSM are used. The excellent carbon-to-energy ratio of the methane fuel is still cancelled out by the lower energy efficiency of fuel provision and current LNG engine technology. However, there is great potential to decrease GHG emissions of **fossil LNG** in the near future by shortening and optimising distribution channels and by optimising LNG engines.

LNG from close gas fields in Norway allows for a slight GHG advantage over diesel fuel already today. GHG emission advantages of **renewable LNG** vary with the biomass source. Manure-based liquefied Biomethane (LBM) is due to avoided methane emissions. LBM from domestic energy crops allows for at least 33 % GHG emission reduction compared to fossil diesel including all climate effects of fertilisation. A 50:50 mix between energy crops and manure is realistic with regard to mid-term manure availability in Germany (see Section 2). A mixture of LNG and this 50:50 LBM at an 80:20 ratio would result in a 14 % GHG advantage over diesel fuel. A mixture of LNG and LBM at a 60:40 ratio would result in a 38 % advantage.

Liquefied synthetic methane (LSM) leads to GHG emission reductions of more than 90 % (see the fact box). The electricity requirement for solar- or wind-based methane liquefaction only amounts to 4 to 6 % of the energy content of the supplied LNG (JEC, 2013; LBST, 2014). The additional benefit of this path is improved integration of fluctuating renewable power into the energy system.

Potential of synthetic methane from "surplus" renewable power in Germany

The national electricity network development plan identifies increasing amounts of surplus electricity production, referred to as "dumped energy" as a result to the expansion of renewable power plants in the course of the German "Energiewende": 0.1 TWh for 2024 to 2.1 TWh for 2034 (NEP, 2014).

Assuming a LNG fuel consumption of 16.5 MJ per km and an annual operating distance of 175,000 km this could fuel between 120 and 2,500 LNG trucks with 100 % renewable fuel at almost zero emissions.

Climate change mitigation potential from LNG

A scenario by DLR, ifeu, LBST, and DBFZ (2014) for the mobility and fuels strategy of the German Government (MFS) assumes that LNG demand from heavy-duty trucks will grow to 8 to 27 TWh final energy in the year 2030. These numbers would equal a market share of 4 % to 12 % in the total fuel market for road freight (DLR, ifeu, LBST, and DBFZ, 2014). Figure 8 shows a potential ramp-up for the conservative scenario to 4 % and the resulting GHG emission reductions for admixtures of LBM of 20 and 40 %. Resulting annual GHG emission reduction would grow to 243,000 and 667,000 t CO_2eq respectively in the year 2030: 0.4 % to 1.2 % of GHG emissions in road-freight transport. This scenario assumes that the difference in GHG emissions of diesel and LNG trucks remains at its current level.

Given the above figures, politics and industry players should strive to achieve at least 12 % market share in 2030, tripling above effects for climate change mitigation.

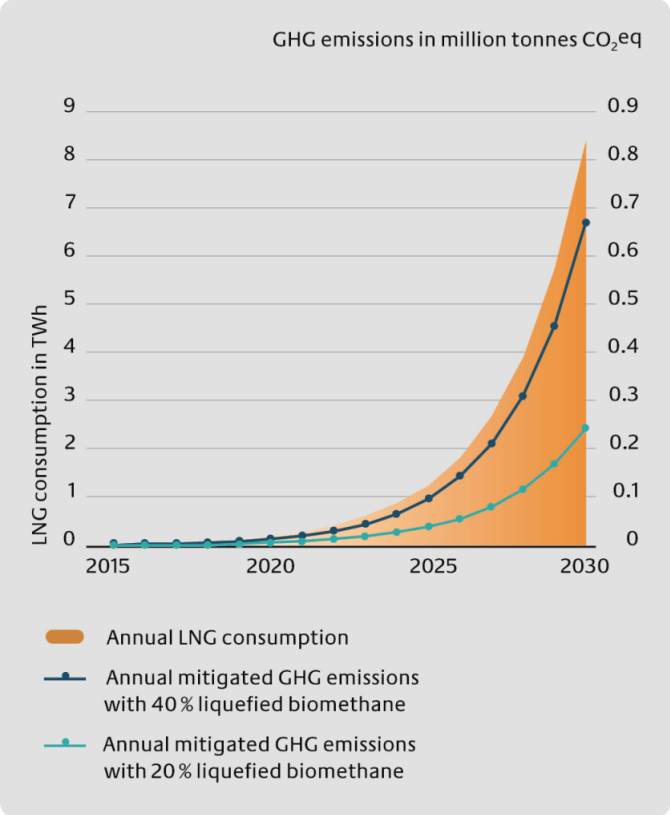

Figure 8: Development of LNG demand to 4 % market share in road freight fuel market as drafted for the German Mobility and Fuel Strategy (DLR et al., 2014) and resulting mitigated GHG emissions for LBM admixtures

Section 3 in a nutshell

LNG is a clean, relatively safe alternative fuel for heavy-duty transport. It can significantly improve energy security in this sector as it diversifies supply at low costs. Furthermore, LNG can be mixed at any rate with liquefied renewable methane from domestic biomass or electricity, thus facilitating climate-neutral transport as well as efficient storage and integration of fluctuating renewable power outputs in the energy system. The competitiveness of LNG versus diesel at German pumping stations will depend on future commercial and government pricing policies.

Several major truck-OEMs already manufacture vehicles with LNG power trains. The advantages in noise emissions make LNG trucks the better choice for inner-city delivery. With the advent of Euro VI emission regulations, LNG trucks provide an economically viable alternative to diesel trucks.

The ambitious hopes on LNG with respect to climate change mitigation in truck transport in Germany must be set in perspective. **Pure fossil LNG** will realise these hopes when improved engine technology is available, as announced for 2015. At low admixtures of **renewable methane** the market introduction of LNG trucks can already today represent an effective GHG reduction measure in transport.

4 Lessons learned from market development abroad.

The global drivers for adopting LNG in heavy-duty transport worldwide are air quality issues and security of energy supply, especially the reduction of dependence on oil, and competitive fuel pricing (i.e. reduction of fuel costs). The markets for LNG in heavy-duty transport in China, the USA and the Netherlands are analyzed with regard to current and forecasted development and applied policy instruments.

Market development for LNG in Germany is in its infancy, but markets in China and parts of the USA have already surpassed the demonstration phase and show strong supply and demand in the markets for vehicles and fuel. Scale effects are already reducing costs and thus furthering market development. Within Europe, the Netherlands is at the forefront of LNG development in road transport. Figure 9 illustrates the position of the aforementioned countries along the market-development curve.

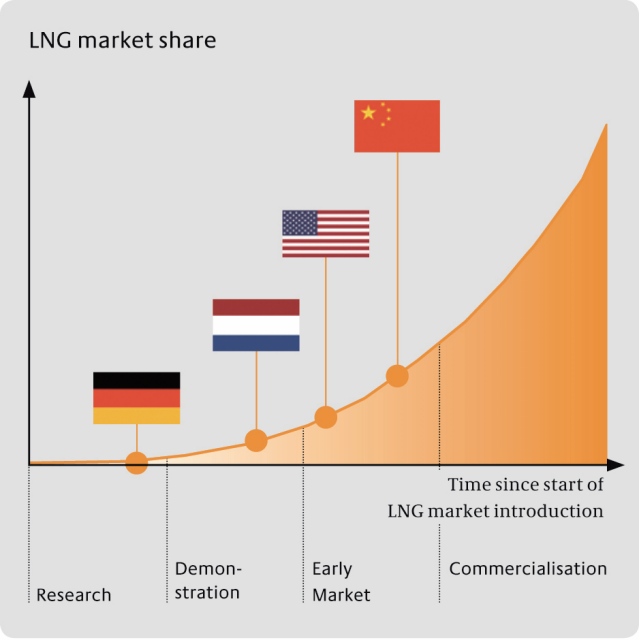

Figure 9: Estimate of the current status of market development for LNG in transport in investigated countries

4.1 People's Republic of China.

Drivers and policy framework for market development

Three basic price differentials currently create business incentives for LNG in heavy-duty transport: 1) governmental fuel price controls, 2) low additional investment costs for LNG trucks compared to diesel trucks and 3) green public purchasing that favours users of alternative fuels when deciding among competing bids. Many LNG trucks in China use retrofit engine conversions, which can be a factor in the low additional investment cost. As a result of these measures amortisation periods for LNG truck operation in China are very short: 21 months in average compared to 46 for the USA (Petroleum Economist, 2013).

As a result of current public outrage over air quality, it is likely that Chinese policy makers will continue to enact strong measures that will benefit LNG. Analysts expect a substantial tightening of exhaust gas emission standards for gasoline and diesel vehicles, particularly for PM emissions. The market for LNG trucks would benefit from this development, as purchase costs for diesel trucks would rise.

Additionally, the sulphur content of gasoline and diesel is likely to be reduced to 50 ppm in 2014 and 10 ppm in 2017 (Hong, 2013). This will probably increase the price differential between diesel and LNG in favour of the latter. Authorities are likely to enact urban access restrictions for polluting vehicles. Restricted access to cities would provide a serious competitive advantage to commercial fleets that use LNG.

Projected market development

Based on these drivers, analysts project the number of filling stations to climb from the current 1,300 to 3,000 in 2015. Likewise, the number of LNG trucks is projected to rise from 51,000 today to 247,000 in 2015 and 694,000 in 2020. This would result in an increase of the share of LNG-trucks in the total truck population from 1 % today to 6 % in 2020 (Hong, 2013; Petroleum Economist, 2013).

4.2 The United States of America (USA).

Drivers and policy framework for market development

The projected worldwide growth in natural gas supply (mostly from unconventional sources) will be particularly significant in the USA "Homemade" LNG is available at competitive prices. A number of private initiatives have stimulated LNG supply and demand in various elements of the transport value chain (see below). Key drivers for the movement are the prospect of lower operating costs, less costly compliance with emission standards, and the existence of various governmental incentives such as tax credits for constructors of alternative fuel infrastructure and excise tax credits for sellers of CNG or LNG.

Brand-name manufacturers and chains such as Nike and Wal-Mart push their suppliers to use natural gas vehicles in an attempt to achieve higher economic and environmental efficiency. UPS, FedEx and Ryder Systems among others will expand their natural gas vehicle fleets, and UPS expects natural gas to be the dominant fuel for their new heavy truck acquisitions as of 2015 (Krauss and Cardwell, 2013).

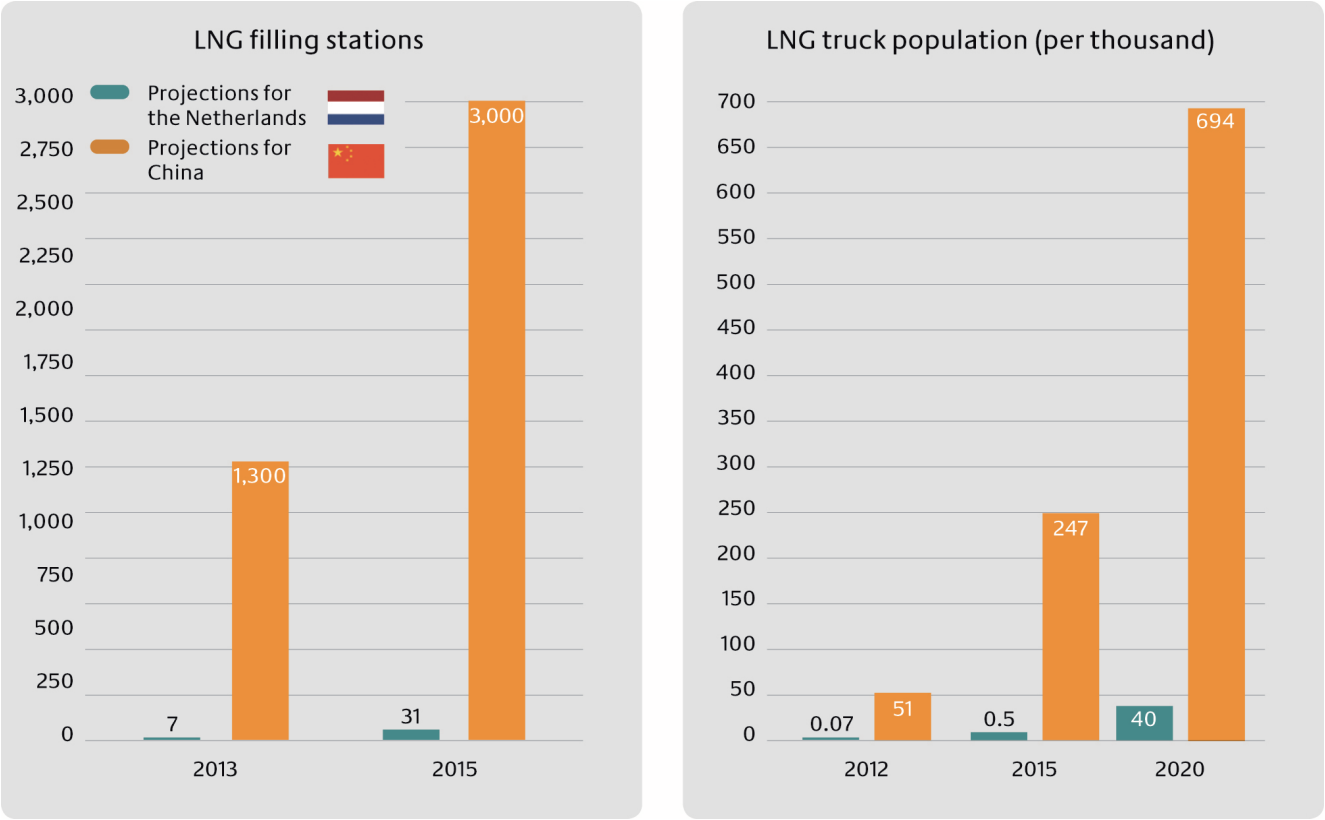

Figure 10: Estimated growth in LNG filling station and LNG truck population (Dutch LNG Platform 2014; Hong 2013; Petroleum Economist 2013)

Given the increased demand for vehicles and fuel, suppliers have become active: In 2010, 860 LNG vehicles were sold (Krauss and Cardwell, 2013). There were 56 public LNG stations in July 2014, compared to 731 public CNG filling stations (AFDC, 2014) and 157,000 gasoline ones. However, recent initiatives from the private sector have accelerated the rate of adoption. For example, Clean Energy Fuels constructed more than 70 LNG filling stations (public and fleet-specific access) before the end of 2013 (Krauss and Cardwell, 2013).

As demonstrated by a particular survey, most fleet managers believe LNG has potential in heavy-duty transport. They list a number of concerns too, namely infrastructure inadequacy, followed by higher vehicle cost and limited vehicle availability (McLaughlin, 2012). The industry believes that tax incentives aren't enough and that the buildup of liquefied natural gas infrastructure requires additional support (Krauss & Cardwell, 2013).

Expected market development

The Energy Information Administration EIA (2013) projects sales of heavy-duty natural gas vehicles to increase to 275,000 in 2035 (or 34 % of new sales) given favourable economic conditions and adequate refueling infrastructure. Other studies (Frost and Sullivan, ACT Research, National Petroleum Council) have suggested a wide range of potential adoption rates, varying from 8 to 40 % of new sales in class 7 and 8 by 2020, 24 to 50 % by 2030 (Westport, 2014).

EIA (2013) projects that natural gas consumption for heavy-duty vehicles will increase from 5 TWh in 2013 to 7 TWh in 2020, 55 TWh in 2030, and 280 TWh in 2040–a 12 % share of heavy-duty vehicle fuel consumption. The major North American truck supplier Cummins projects that nearly 30 % of its high-horsepower engine production will be natural gas engines by 2020.

4.3 The Netherlands.

Drivers and policy framework for market development

In contrast to China and the USA the Netherlands in line with the European Union and Germany has set a GHG reduction target. The Dutch government wants to reduce GHG emissions by 20 % until 2020 and 80 % until 2050 compared to 1990 levels (Rijksoverheid, 2014). A second country-specific driver is noise reduction from road transport in cities.

Main policy actions for LNG in the Netherlands include a) temporary reduction of the energy tax for LNG compared to diesel, and b) the PIEK programme, and c) strategic initiatives that bring together relevant stakeholders (see text box). The PIEK programme (engl: PEAK, means peak noise levels, in contrast to continuous noise levels) is a joint initiative of three ministries to foster low-noise emission distribution of goods.

The current energy tax reduction of LNG of almost 50 % (18 cents/kg for LNG versus 31 cents/kg for diesel) is directly translated into a competitive advantage for LNG fleet operators. Under the PIEK regulation LNG trucks are allowed for inner city goods distribution in the early morning hours. The lower noise emissions of LNG trucks thus bring forth direct competitive advantages for LNG fleet operators in the delivery business.

The Ministry of Economic Affairs commissioned a study on the economic effects of LNG, which found various spill-over economic benefits from the utilisation of small-scale LNG in the shipping and truck sectors in the Netherlands. One analysis suggests for the Dutch context that "small-scale LNG can lead to €2.7bn additional economic growth and 8,000 additional job years in the period up to 2030" (PwC, 2013).

Policy makers in the Netherlands support collaborative LNG stakeholder platforms

In 2012 the initiative "Green Deal Rijn en Wadden" set the foundation to unite the fuel and the vehicle markets with two ministries and scientific bodies to accelerate market development. Its goal is to substitute crude oil-derived fuels with 2.5 million tons of LNG by 2025, representing around 10-15 % of diesel use in the transport sector. This requires a fleet of 40,000 LNG-fuelled trucks (Kroon et al., 2013). A National LNG Platform was founded to focus specifically on LNG and projects a population of 500 LNG fuelled trucks by 2015. It calls for a working programme that is implemented by a three-pillar structure for LNG as a transport fuel, including safety/permitting, financial-economic and stakeholder dialogue.

Transport companies in the Netherlands have conducted successful pilot projects for several years now and are planning to expand their efforts. Vos Logistics, an early adopter, has identified two remaining barriers for LNG implementation: (1) the availability (and price) of LNG trucks and (2) a lack of proper regulation for constructing and exploiting filling stations. However, since the middle of 2013 a first national regulation concerning the construction and operation of LNG filling stations has been approved. Therefore, the barriers to widespread implementation of LNG in the Netherlands, particularly the coordination failure, are falling.

Expected market development

In June 2014, 231 LNG trucks were running in the Netherlands and seven LNG filling stations had been realised (Gebruikersvoorwaarden, 2014). The National LNG Platform's objective is to have 50 stations in operation by 2015, whereas conservative estimates assume 13-25 stations to be more realistic (Dutch LNG Platform, 2014).

In 2014, Gasunie and Vopak opened a LNG truck loading station at the GATE terminal. Furthermore, the terminal will be expanded until 2016 with an additional harbour basin to enable LNG distribution for small-scale use with a maximum capacity of 280 berthing slots per year (Gasunie, 2014).

4.4 Summary of market drivers and applied policy instruments in example countries.

The main drivers for using LNG in China, the USA and the Netherlands can be summarise as follows:

Country	Common drivers	Country-specific drivers
The Netherlands	Air quality concerns Energy security	Climate change mitigation National competitiveness (innovation) and job creation (green economy) EU Directive on the deployment of alternative fuels infrastructure Noise reduction in urban areas
China		High competition in logistics
USA		National low-cost production (natural gas boom) High competition in logistics Transport purchase requirements by brand-name retailers and chains (cost advantage of LNG over diesel)

Table 3: Drivers for LNG in transport in China, the USA and the Netherlands

A summary of policy options that stimulate supply and demand for LNG and LNG trucks in the subject countries is depicted in Figure 11. Many more instruments are used in other markets. For example, policy support in Sweden includes financial incentives of approximately €17,000 per vehicle in the programme "BiMe" trucks for the first 100 LNG trucks registered (Svensén, 2012).

A four-step approach for the development of successful policy intervention on the basis of international experience is recommended to accelerate LNG market development in Germany, adapted from (Bunzeck & Feenstra, 2010):

1. Define the target to be reached.
2. Investigate successful policies abroad having similar aims.
3. Identify success factors of these policies.
4. Examine what elements can be transferred and what should be replaced.

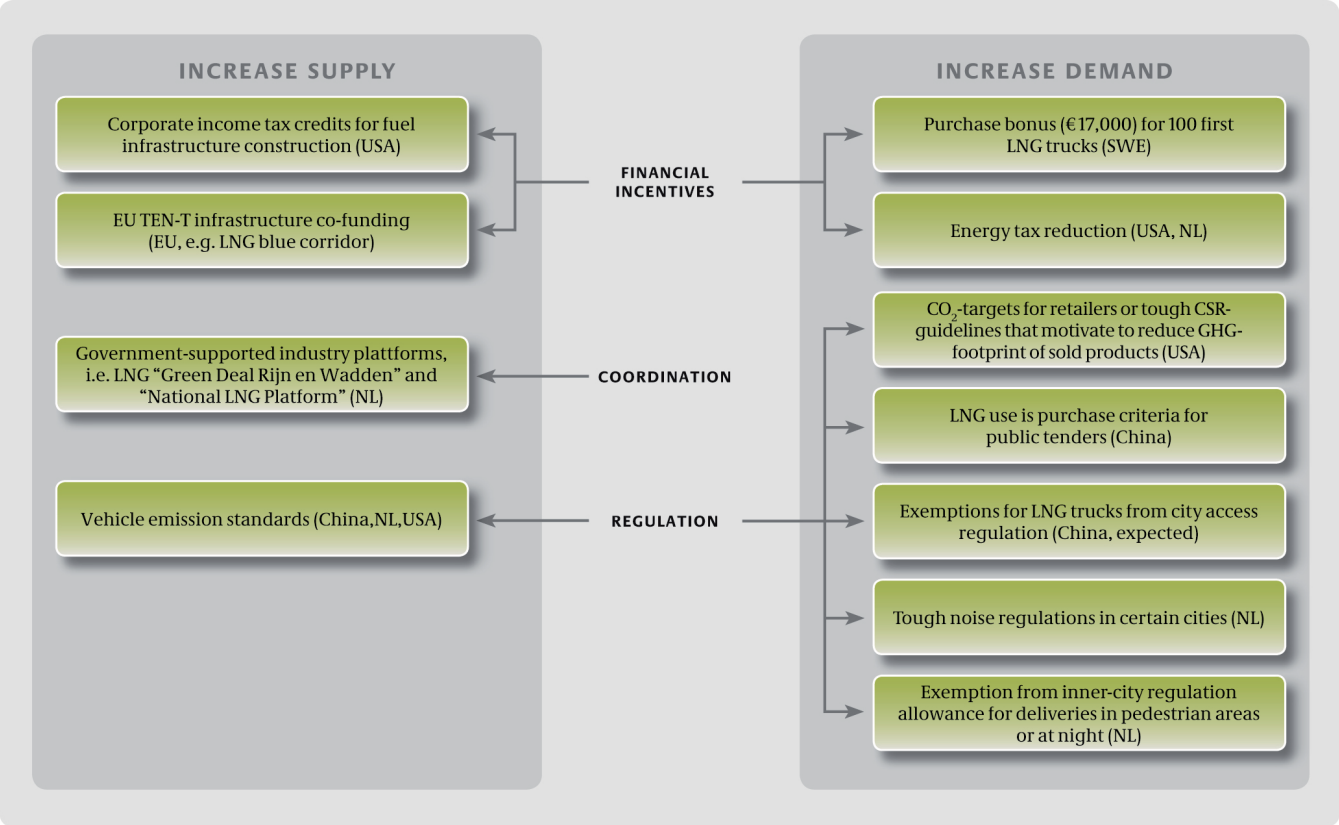

Figure 11: Public policy instruments (push and pull) in International markets for LNG in road freight transport

Section 4 in a nutshell

Market development of LNG as a truck fuel in China, USA and the Netherlands is much further than in Germany. Main market drivers include competitive LNG fuel costs, air quality issues or the political will to reduce oil dependency and enhance the global competitiveness of national businesses. Private sector initiatives as well as government intervention shape these markets. The lessons learned for German market development can be drawn especially from a) the demand created by USA retail businesses, and b) the effective mix of coordination and regulatory instruments in all three countries.

5 Central areas of action for LNG market development in heavy-duty road freight transport.

5.1 Overcoming market barriers for LNG.

Germany lags behind other economies in terms of the introduction of LNG into the truck-fuel market. The technology is available, interest from fleet owners is high, and ambitious political targets have been set (see Section 1), yet persistent inertia prevents LNG from achieving its potential as a truck fuel. Thus the question is how one can unlock this potential and break the stalemate.

Both science and international experience pinpoint the lack of a) coordination and b) information as key barriers in the early stage of LNG market introduction (see Figure 12). Coordination failure, often referred to as the chicken-egg *dilemma*, is likely to occur when development in one market (e.g. the truck market) depends on developments in another market (e.g. the fuel market). Established examples of this dilemma are the markets for electric and natural gas vehicles and their respective fuels in passenger transport. Currently, potential investors in LNG filling stations withhold investment until fleet owners invest in LNG trucks. At the same time, fleet owners require an attractive LNG filling station network before investing in LNG trucks. The existence of this well-known economic phenomenon is confirmed by the "EU Directive on the Deployment of Alternative Fuels Infrastructure" and various surveys of LNG stakeholders (Krauss and Cardwell 2013; McLaughlin 2012; Chairman of LNG Task Force 2013; Kroon et al., 2013). To overcome the chicken-egg dilemma it is crucial to focus first on early adopters: the Massachusetts Institute of Technology sees an appropriate early market in hub-to-hub transportation of goods, which uses 20 % of long-haul diesel fuel consumption in the USA (MIT, 2011).

Government-supported coordination, e.g. by means of multiple-stakeholder platforms, accelerates the identification of problems within and among stakeholders along the entire value chain of the truck and fuel markets (Peters, 2011). It increases the knowledge and information available to companies and political decision makers. Particularly in markets in an early development phase, which are characterised by weak price signals and long amortisation times, such platforms may reduce suppliers' risk by building trust between multiple stakeholders (see the Dutch "Green Deal" in Section 4).

A government-supported **national strategy platform** in heavy-duty trucking, comparable to the Dutch LNG platform, is recommended for Germany. This would drive the definition and implementation of joint targets and mitigate supply-demand insecurities along the value chains.

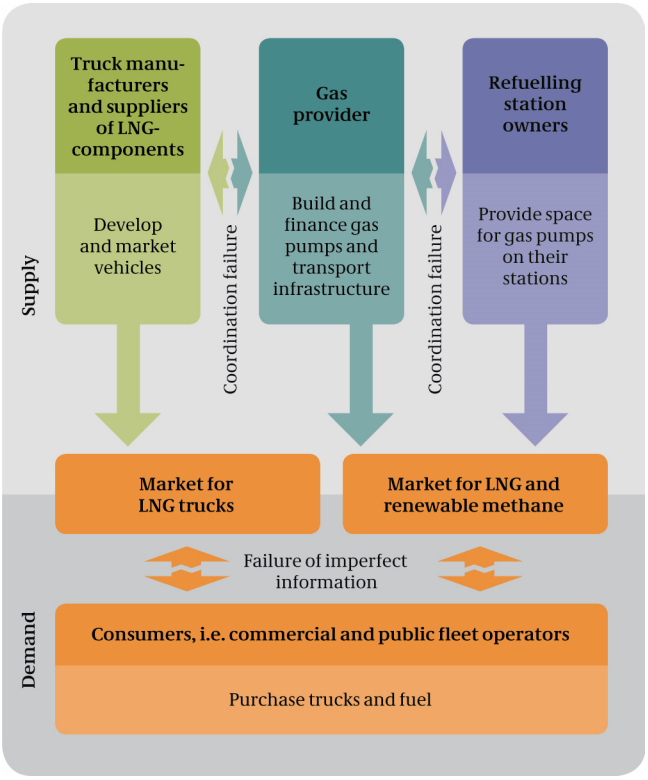

Figure 12: Illustration of stakeholders and market failures in the complementary truck and truck fuel markets; adapted from Peters (2011)

The **lack of information** about technical or financial developments or about continued governmental support induces uncertainty among suppliers and consumers. This is the case in the German LNG market and it prevents fleet managers from opting for LNG trucks. Additionally, fleets do not necessarily want to consider a onetime purchase. Even early adopter fleets have a view to the longer term, recognising that they are making significant financial and operational investments. The typical questions are:

- Will LNG be widely available in the near future and at a competitive price differential compared to diesel?
- Will the current taxation for natural gas fuel sustain long enough to allow amortisation of the higher investment cost of the LNG trucks compared to conventional diesel trucks?
- Does LNG match diesel's performance with regard to safety, handling and comfort?
- Is the truck and filling station technology safe and reliable?
- What will be the resale value of LNG vehicles in the short-to-intermediate term? Currently, Europe has no functioning market.

Clear policy targets are needed to improve the level of information and trust of suppliers and consumers. Clear signals on technology direction and competitiveness with diesel are a considerable factor in developing the comfort level needed to commit investments. As will be explained in the following chapter, an updated national fuel strategy should include a clear target for LNG in road transport and should acknowledge the mutual benefits of a joint market introduction of LNG in maritime and road transport.

5.2 Recommendations for teamwork between industry and politics.

Nike, Wal-Mart and Albert Heijn, demonstrate that a demand push can also help develop the LNG market (see Section 4). However, a supply push from truck manufacturers and infrastructure providers through strategic large-scale investments in research, development, and demonstration of LNG truck and infrastructure technology is indispensable for a successful market entry. The investments must grow substantially in the subsequent phase of market validation or "early markets".

The problem is that business models of vehicle manufacturers or filling station operators do not normally account for the attainment of policy targets such as national energy security, climate change mitigation, or noise reduction. Additionally, a competitive pricing advantage for LNG in German truck transport is expected to evolve only gradually unless major new developments occur or truck manufacturers are able to reduce truck prices by benefiting from economies of scale in markets outside Germany.

Politics and industry, above all, must **work together**: in order for LNG to contribute to a less oil-dependent, cleaner and better-diversified fuel mix, LNG market entry and development requires cooperation between regulator and investor (see Figure 13). Investment, marketing, and sales efforts by the LNG industry must be supported by a policy framework that reduces the current risk profiles for clean-fuel investments (Peters, 2011).

The authors hence recommend stopping finger-pointing and starting the necessary team work. Key industry actions and policy instruments are recommended within three central areas of action (see Table 4). The most relevant recommendations are described in greater detail below:

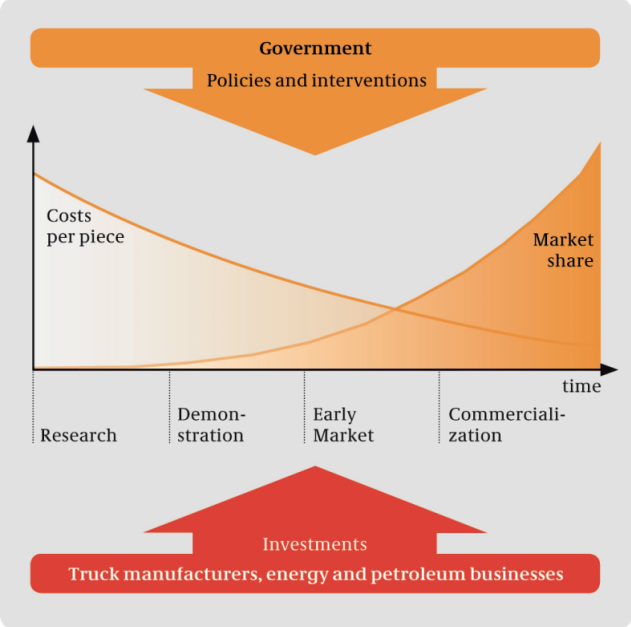

Figure 13: Recommended cooperation for LNG market development between private and governmental stakeholders; adopted from Grubb (2004)

Action I.a: Develop a national strategy for the market development of LNG as truck fuel

Increased planning security for investors will increase willingness to supply LNG infrastructure, fuel and trucks. Germany, in contrast with other countries, has no clear strategy for the use of LNG in heavy-duty transport, resulting in a lack of planning security for investors. However, the implementation of the new EU infrastructure directive requires the construction of a minimum infrastructure for LNG and a supporting policy framework.

The German government should coordinate all relevant industry stakeholders and policy makers in a strategy platform in order to develop LNG road transport. The main tasks for the platform are:

- Set a clear target and milestones for future LNG market share, e.g. 4 % share of the truck fuel market in 2030 (30 PJ) as suggested in DLR et al. (2014) to BMVI, and 10 % in new truck sales in Germany;
- Coordinate construction of LNG fuel infrastructure (see measure I.b for details) and establishment of initial fleets that ensure profitable infrastructure operation;
- Specify necessary actions for market development on the side of industry and develop a supporting national policy framework (see action I.d); and
- Align national LNG strategies with European targets and strategies, including activities regarding European priority transport corridors.

Within the LNG platform, general R&D tasks, consumer information, and infrastructure planning is shared across many shoulders. Knowledge should be effectively accrued and shared. Common sense on necessary actions can be established. DLR et al. (2014) suggest in their contribution to the Mobility and Fuel Strategy to answer the following question for a start: *"Which users may expect future benefits from LNG under which precise conditions (e.g. minimum average annual mileage, difference in price between LNG and diesel)?"*

Area of action	Recommended actions for industry stakeholders and politics	Key actors for implementation
I. Construct LNG fuel infrastructure in coordination with vehicle market	I.a) Develop a national strategy for the market development of LNG as truck fuel Coordinate industry stakeholders on national, regional and municipal levels	
	I.b) Coordinate initial LNG road infrastructure construction and reap synergies with shipping sector	
	I.c) Create pilot station projects and solve all certification and safety issues	
	I.d) Recommend a national policy framework as mandated by EU directive on deployment of alternative fuel infrastructure	
II. Increase demand for LNG trucks	II.a) Inform fleet operators about the availability and advantages of LNG and LNG trucks	
	II.b) Expand truck and engine portfolio to a relevant share of the model range, particularly for high-power Euro VI Diesel-cycle trucks	
	II.c) Improve and ease vehicle certification: update certification standards	
	II.d) Introduce green public procurement of LNG trucks, e.g. for refuse collection or street cleaning	
	Improve profitability of LNG truck operation: II.e) Reap synergies with LNG supply for shipping, economies of scale and scope to reduce costs II.f) Maintain fuel tax reduction for methane (temporary, declining) II.g) Increase R&D efforts for improved vehicle efficiency and reduced vehicle and quality costs II.h) Allow road toll exemptions for pilot fleets II.i) Allow the use of clean vehicles in city areas of public interest (pilot fleets) II.j) Introduce tax credits on vehicle purchase to compensate for high upfront invests for pilot fleets II.k) Introduce labelling for green logistics and on consumer goods (incl. food) in order to increase willingness to admix liquefied biomethane (LBM)	
III. Improve the environmental impact of LNG truck operation	Improve the environmental performance of LNG trucks: III.a) Optimise engine efficiency (TTW) III.b) Admix liquefied biomethane from waste and/or e-methane (power-to-gas)	
	Increase attractiveness of trading biomethane as a fuel: III.c) Raise the competitiveness of biomethane and e-methane in national bio-fuel regulation (BImSchG) III.d) Ease trade with biomethane for transport e.g. by improved control regimes (see dena biogas register)	
 *National LNG strategy platform*	 *National and regional government*	 *EU-government*
 *Refueling station businesses*	 *LNG suppliers*	 *Truck manufacturers*
 *Biogas industry*		

Table 4: Recommended actions for market development by industry stakeholders and policy makers

The relevant stakeholders to be included in this platform are fuel suppliers, filling station operators, fleet operators, and truck manufacturers. Reference examples that can inspire the development of the platform include the Dutch "National LNG Platform," "Initiative Erdgasmobilität–CNG und Biomethan als Kraftstoffe," and H2 Mobility. It might be sensible to unite market development activities for LNG in road freight transport and in shipping in one single national platform.

Last but not least, the strategy process can contribute to a successful German Mobility and Fuel Strategy (MKS/MFS) and "Energiewende": By means of the platform policy makers are approached with one common voice and proposal in contrast to individual and partly opposing approaches from companies or branch organisations.

Action I.b: Coordinate initial LNG road infrastructure construction and reap synergies with shipping sector

The chicken-egg dilemma described in Section 5 can only be overcome by simultaneously increasing supply and demand in the vehicle and fuel markets. The construction of an initial infrastructure for LNG truck refueling must be coordinated. According to DLR et al. (2014) for the national fuel strategy the LNG platform should "draft an agenda scheduling the development of the refueling infrastructure, the required approval and authorisation procedures and the establishment of additional necessary framework for planning and construction" of LNG infrastructure. Because the utilisation of filling stations in the early market stage is generally low, accidental positioning of filling stations too close to each other would hamper economic viability. This is true particularly for the truck fuel market, where territorial coverage of the network is more important than density. Therefore, a coordinated approach to define locations for an initial LNG filling station network at a few high traffic locations is suggested. Once this core network is established, investors would be asked to fill the gaps in between.

The authors commissioned Ludwig-Bölkow Systemtechnik (LBST) with the development of an initial German station network for LNG (see Figure 14). This demand-oriented proposal defines fourteen key areas, highlighted in blue, as preferred locations for initial filling stations. The proposal shall serve as a starting point for detailed planning as opposed to being considered the final version. A major part of German long-haul transport could be served by these stations. In addition to other criteria, truck freight flows, international road transport corridors, and existing plans for LNG infrastructure as part of the European TEN-T LNG port expansion (green and white triangles) were taken into account.

The minimum suggested infrastructure in the highlighted areas cannot be implemented at the same time, however. Organic, economic growth is much more reasonable, and the market development between filling stations and LNG trucks will grow in parallel. The initial market phase is characterised by single, isolated filling stations which will be implemented to meet minimum demand by a small number of fleet operators. For increased economic viability fleets with point to point long-haul operations should be involved in station planning. Increased demand in the second market phase will lead to an interconnection of the truck routes and accordingly the fuel infrastructure.

The EC targets to make LNG available in TEN-T seaports (2020) and in inland ports (2025): Public and private investors and decision-makers should look for synergies between shipping and trucking when building the LNG refueling infrastructure. Seven locations (highlighted with red circles) were found to be in proximity to TEN-T inland shipping ports. Installing LNG pumps at motorway filling stations close to these ports could:

a) Allow safe, economical LNG supply to motorway filling stations via rivers and canals; and

b) Optimise the business cases for the operation of both the LNG filling stations at the inland port (barges) and the motorway (trucks).

The infrastructure buildup is very complex and should consider the practical needs of stakeholders from the shipping and truck sectors. Therefore, it is critical to ensure a coordinated approach to exchange the information and necessities from both sectors to achieve optimal infrastructure solutions. A national LNG platform could serve this purpose and facilitate the planning of an economical sustainable LNG infrastructure.

Action I.c: Build a public pilot station to solve the remaining certification issues and demonstrate viability

So as to assess LNG supply costs, certification issues and environmental impacts in Germany, a pilot LNG station should be built. It should be situated at a motorway prime location with typical demand profile. A feasibility study should investigate different supply scenarios (LNG ship and/or LNG trailer supply as well as onsite generation from fossil and/or renewable sources) and draw "lessons learned" for application to other locations and demand profiles.

Action I.d: Recommend a national policy framework as mandated by the EU

The EU Clean Power for Transport strategy, in conjunction with its associated EU Directive on the deployment of alternative fuels infrastructure, asks EU Member States to develop national policy frameworks to support deployment of alternative fuel infrastructure by increasing fuel demand. The LNG platform should support the German government in developing recommendations for an attractive, economically sensible national policy framework, aligning a long-term technology strategy with long-term regulation clarity. The key elements to be provided are:

- Assessment of status quo and future development for alternative fuels and infrastructure;
- Definition of national targets and appropriate measures; and
- Designation of the areas which will be equipped with CNG filling points.

Policy recommendations should be technologically neutral, i.e. attractive for LNG, electricity, and hydrogen as transport fuels. European policy harmonisation can be achieved with the support of the Network of European Energy Agencies (EnR).

The authors also recommend that industry stakeholders formulate specific measures describing how they will contribute to the construction of the LNG infrastructure in EU Member States. This could be done either by means of a publicly presented and regularly monitored "declaration of intent" or by negotiating a contract (as pursued in the German H2 Mobility project.

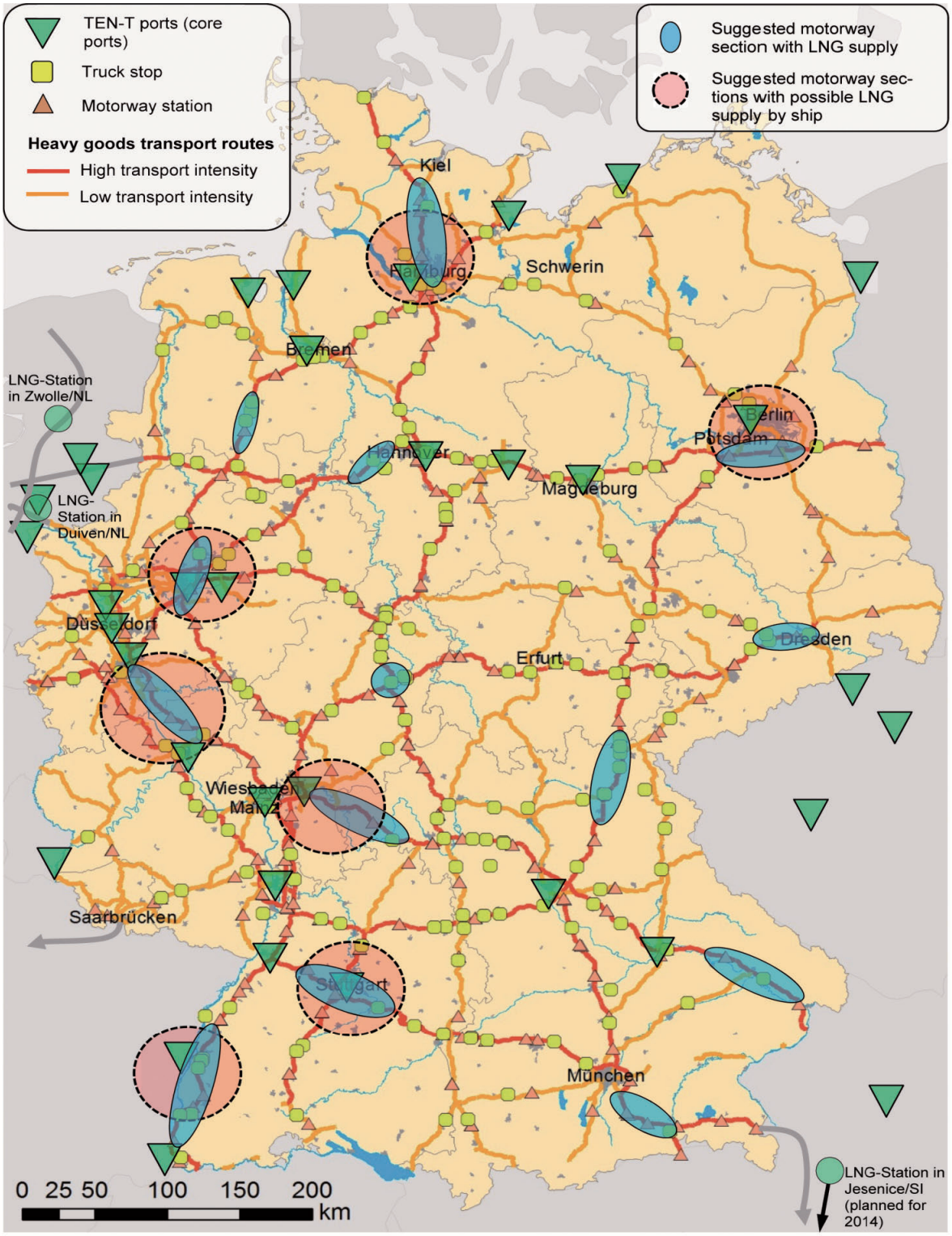

Figure 14: Plan for an initial LNG filling station network with 14 stations in the blue areas (LBST, 2014)

Section 5 in a nutshell

The market for LNG in road transport in Germany will not develop without government intervention. The reasons are:

- Failure of coordination: the chicken-egg dilemma between vehicle sales and filling station construction
- Information failure: lack on information on availability, viability and competitiveness of LNG trucks and infrastructure

Four main actions are recommended:

1. Develop a national strategy for the market development of LNG as truck fuel
2. Coordinate initial LNG road infrastructure construction and reap synergies with shipping sector
3. Build a public pilot station to solve remaining certification issues and demonstrate viability
4. Develop a national policy framework for LNG as mandated by the EU Directive on alternative fuels infrastructure

6 Conclusion on policy recommendations for successful LNG market entry and growth.

Dismantling market barriers in the LNG market will require a carefully planned policy regime. This section is concluding previously discussed policy instruments. Three key principles should guide the design of efficient policy instruments:

1. They must be adapted to the target market (road freight)
2. They are long-term commitments and must be adapted according to the state of the market
3. Outright subsidies are expensive and should be confined to early phases (R&D and demonstration)

The application of three categories of policy instruments based on the state of market development is recommended:

Phase I: Investment support instruments.

In the early phases of the LNG market, market players should make investments in R&D in LNG vehicle technology, filling station construction and LNG supply. To encourage these investments despite the very long investment horizon, financial or coordination instruments can be applied. Financial instruments for investment support can take the form of R&D subsidies, tax incentives or loan guarantees.

Coordination of the different suppliers, e.g. in a national LNG strategy platform, is one of the most cost-effective instruments to enhance the information flow and build trust among suppliers (see Section 6), particularly before any large-scale commercialisation phase.

Phase II: Production and use support instruments.

In the phase of early markets, policy instruments should be designed to make using LNG more attractive to market players (fleet owners, filling station operators, fuel providers) to factor in fuel diversification and emission reduction goals. Such instruments can be fiscal, either in the form of tax rebates for vehicle purchase, a reduction (or suppression) of vehicle taxes (purchase, use, road tax, congestion charge, etc.), or a reduction (or suppression) of fuel taxes. A financially attractive but politically challenging variation is to finance LNG energy tax differentiation by reducing tax rebate on the fuel that policy makers want to displace, i.e. diesel.

Supply-side subsidies for LNG fuel production, LNG truck development and filling station construction should be avoided in this phase. These can miscalculate consumer demand or discourage cost-effective fuel or vehicle supply. One example is the unfortunate allocation of many CNG filling stations in Germany far from major traffic flows in the 1990s (Peters, 2011).

It is preferable, and more effective, to incentivise fuel demand. A demand-driven placement of filling station in close coordination with infrastructure providers is recommended (see Section 5).

Green public procurement is recommended as a cost-efficient instrument for LNG market introduction, as public fleets form an easily accessible, i.e. a highly regulated, early market. This instrument can be direct, by acquiring vehicles or buying fuel for public fleets as recommended in the EU Clean Vehicle Directive 2009/33/EC. It can also be indirect, e.g. by requiring private municipal service suppliers to use a certain percentage of LNG trucks. Both instruments can significantly reduce emission and noise levels in municipalities.

Finally, regulatory policy instruments can be adopted, such as allowing access to city areas where diesel trucks are temporarily or permanently forbidden (e.g. early-morning delivery services).

Above instruments should be implemented at the very beginning of the early markets stage and be phased out once LNG technology becomes competitive with existing ones, such as diesel (commercialisation phase).

Phase III: Performance rewards instruments.

The Dutch energy think tank ECN sees the main obstacle to the LNG market achieving its full potential in the improper accounting of negative externalities. Policy makers must ensure that all costs to the environment, energy security or noise pollution of city residents are included in the costs seen by the fuel consumer. All instruments at this stage must be technology-neutral and focused on the actual benefits delivered, e.g. minimising the climate impacts of road transportation.

Appropriate instruments can take the form of emission standards, emission trading schemes, bonus/malus fuel or vehicle taxation. These instruments can be complemented by a mandate to provide detailed information to the end customer of the transported goods. Recommended information instruments are public campaigns and product labelling. This would provide higher transparency with respect to the impacts of all fuel options and would encourage policy targets to be pursued more proactively.

The recommended policy instruments for phases I and II are summarised in Figure 15.

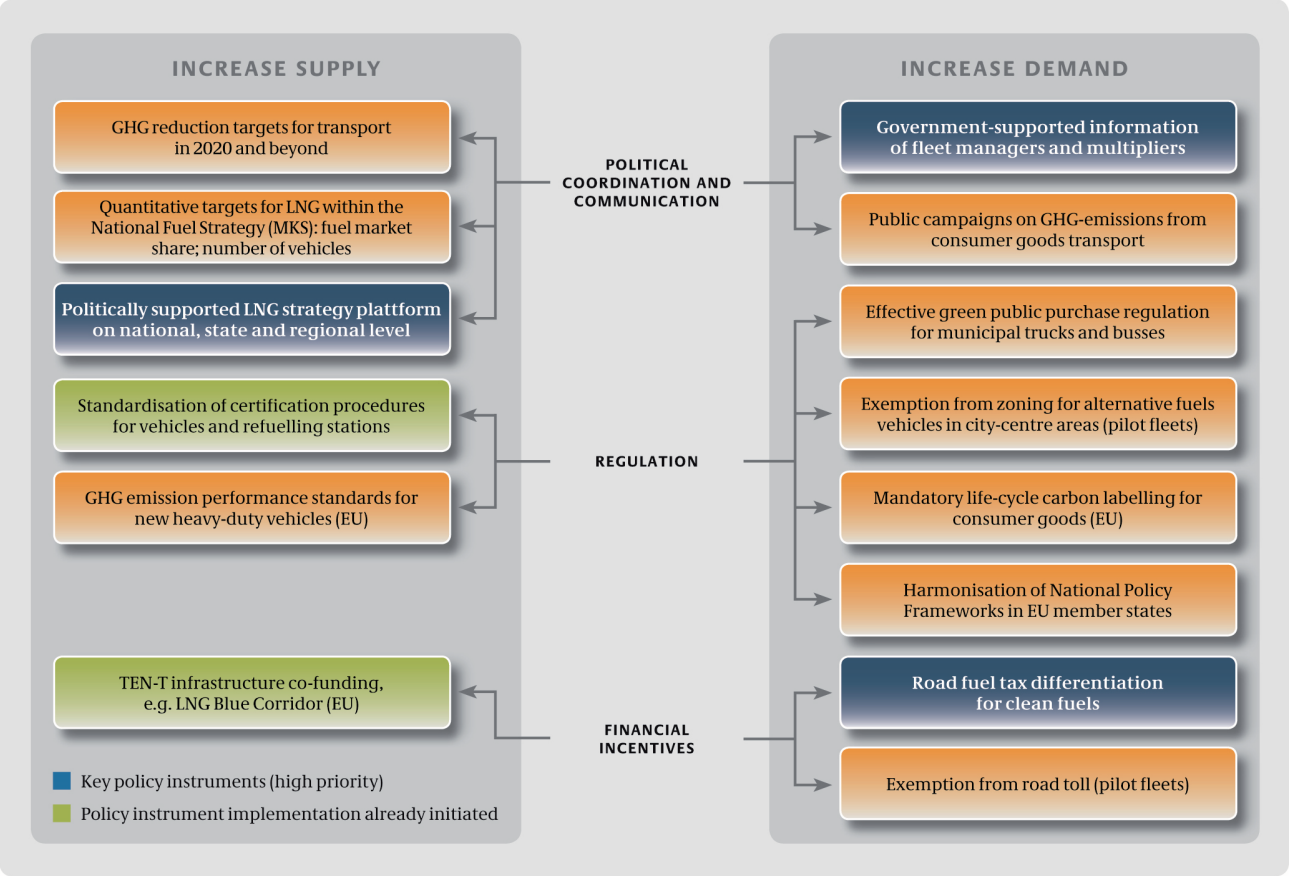

Figure 15: Policy instruments to encourage innovation and investments for LNG during market entry and early development

Finally, even with this effective set of policy instruments there is no guarantee for the LNG market to flourish as economic benefits might shrink due to external factors. Careful evaluation for necessary adaption of the policy framework is therefore recommended at all stages in order to ensure the sensible allocation of resources.

Section 6 in a nutshell

A specific set of policy instruments is recommended to effectively overcome market failure in the fuel and vehicle markets for LNG in Germany and finally release private sector investments. Both supply-side (push) and demand-side instruments (pull) are needed to facilitate a successful market entry. The main policy instruments are:

1. Government support for a national strategy platform for LNG in road transport (including active government participation);

2. Government-supported information of fleet managers and multipliers; and

3. Road fuel tax differentiation for clean fuels.

It is recommended that these instruments be considered in the national policy framework for the deployment of alternative fuel infrastructure in Germany as required by the respective EU Directive for the deployment of alternative fuels infrastructure.

Acronyms and abbreviations.

Bcm	Billion cubic metres
BImSchG	Bundes-Immissionsschutzgesetz
CH_4	Methane
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
CPT	EU Clean Power for Transport Package
dena	Deutsche Energie-Agentur
EURO	European Emission limits
EEV	Enhanced environmentally friendly vehicle
GHG	Greenhouse gas
HC	Hydrocarbon
HDV	Heavy-duty vehicle
IPCC	Intergovernmental Panel on Climate Change
JEC	JRC, EUCAR, CONCAWE consortium
km	Kilometer
LBST	Ludwig-Bölkow-Systemtechnik GmbH
LFL	Lower flammability limit
LNG	Liquefied natural gas
LBM	Liquefied biomethane
LSM	Liquefied synthetic methane
MFS/MKS	German National Mobility and Fuel Strategy
MJ	Megajoule
MPa	Megapascal (1 MPa = 10 bar)
N_2O	Nitrous oxide
NOx	Mono-nitrogen oxides, i.e. NO (nitric oxide) and NO_2 (nitrogen dioxide)
OEM	Original equipment manufacturer
PM	Particulate matter
ppm	Parts per million
SO_2	Sulphur dioxide
tkm	Tonne kilometers
TTW	Tank-to-wheel
WTT	Well-to-tank
WTW	Well-to-wheel

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