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Regulatory implications of new developments in the gas supply chain

Final Report

Submitted by:

Kantor
Management Consultants

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Regulatory implications of new developments in the gas supply chain

Final Study Report

Submitted by:

Kantor Management Consultants

Project Team:

Project Director	Evangelos PENGLIS	Head of Energy & Infrastructure Unit, KANTOR
Project Manager	Fotis THOMAIDIS	Senior Consultant, KANTOR
Project Team	David MOISSIS	Associate Director, KANTOR
	George KOUTZOUKOS	KANTOR Associate
	Dimitris STEFANOU	Analyst, KANTOR
	Elli KASTRINAKI	Senior Analyst, KANTOR

TABLE OF CONTENTS

ABBREVIATIONS

Abbreviation	Name
ACER	Agency for the Cooperation of Energy Regulators
AFI	Alternative Fuels Infrastructure Directive
CNG	Compressed Natural Gas
DMA	Danish Maritime Authority
DNV	Det Norske Veritas
DOE	US Department of Energy
DSO	Distribution System Operator
DSR	Demand Side Response
EC	European Commission
ECA	Emission Control Area
EIA	US Energy Information Administration
ENTSOG	European Network of Transmission System Operators for Gas
EV	Electric Vehicle
EU	European Union
FERC	Federal Energy Regulatory Commission
FES	Flywheel Energy Storage
FOB	Free On Board
FSRU	Floating Storage & Regasification Unit
GCV	Gross Calorific Value (of a fuel)
GDP	Gross Domestic Product
GHG	Green-House Gas emissions
GIE	Gas Infrastructure Europe
HDV	Heavy Duty Vehicle
HFO	Heavy Fuel Oil
ICCT	International Council on Clean Transport
IFO	Intermediate Fuel Oil
IMO	International Marine Organisation
IWT	Inland Waterways
LDV	Light Duty Vehicle
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MCA	Multi Criteria Analysis
MGO	Marine Gas Oil
mtpa	million tonnes per annum

NGV	Natural Gas Vehicle
NOx	Nitrogen Oxide
NRA	National Regulating Authority
NUTS	Nomenclature of Territorial Units for Statistics
OEM	Original Equipment Manufacturer
OPEX	Operating Expenses
P2G	Power-to-Gas
PEM	Polymer Electrolyte Membrane
RES	Renewable Energy Sources
R&D	Research & Development
SECA	Sulphur Emission Control Area
STS	Ship to Ship
SOx	Sulphur Oxide
TEN-T	Trans European Transport Network
TPA	Third Party Access
tpd	Tonnes per day
TPS	Terminal-to-Ship
TSO	Transmission System Operator
TTS	Truck-to-Ship
WTW	Well-to-Wheel emissions

1. INTRODUCTION

1.1 Definition of new developments in the gas supply chain

Over the past decade there have been major technological developments in the natural gas sector, leading to new applications (new markets) for gas, new means of gas supply, new methods of gas storage and new ways to combine the gas and electricity markets. These include the supply of CNG and LNG to final consumers and remote regions, a boost in the use of gas in the land transport sector, the promotion of LNG as an environmentally friendly fuel in water transport and the use of gas as a storage medium for renewable energy. As these developments are commercially available - or are at the verge of becoming commercially available - and are being applied in several natural gas markets worldwide, their role in the EU energy market has to be assessed.

The scope of this study was to analyse the potential of the aforementioned *new developments in the gas supply chain* and identify any regulatory issues that will have to be taken into account in ACER's "Energy Regulation: A bridge to 2025" and Gas Target Model.

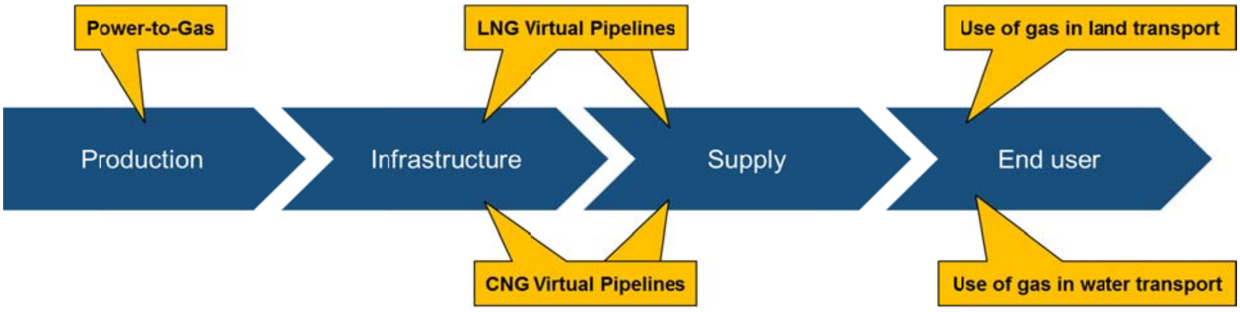
The new developments examined in this study include:

- Virtual pipelines (non-piped gas supply)
  - CNG virtual pipeline (non-piped supply of CNG)
  - LNG virtual pipeline (non-piped supply of LNG)
- Use of gas for land transport
  - Cars and light duty vehicles (Natural Gas Vehicles using CNG)
  - Heavy duty vehicles (Natural Gas Vehicles using LNG)
  - Rail sector (LNG-fuelled locomotives)
- Use of gas for deep sea trading vessels and inland waterways (LNG-fuelled vessels)
- Power-to-Gas (use of excess electricity to produce hydrogen and/or synthetic gas which is then injected in the natural gas system)

Gas hydrates were also initially examined in the study, as a potential storage medium for natural gas. However, in agreement with ACER, this technology was not examined further in detail by the Consultant, as it is still at a research stage and will require well over 10 years for its commercial application.

Not all the developments mentioned above are new technologies or applications. For example the use of compressed gas in vehicles goes back to the beginning of the 20th century and virtual pipelines have been used in certain markets for many decades. The term "new" is used in this study to characterise all these developments, in the sense that despite some disperse uses in some countries, none of the developments has achieved a widespread EU-wide or worldwide application so far, though currently there seem to be prospects for growth for some of these developments.

Figure 1: New developments in the gas supply chain



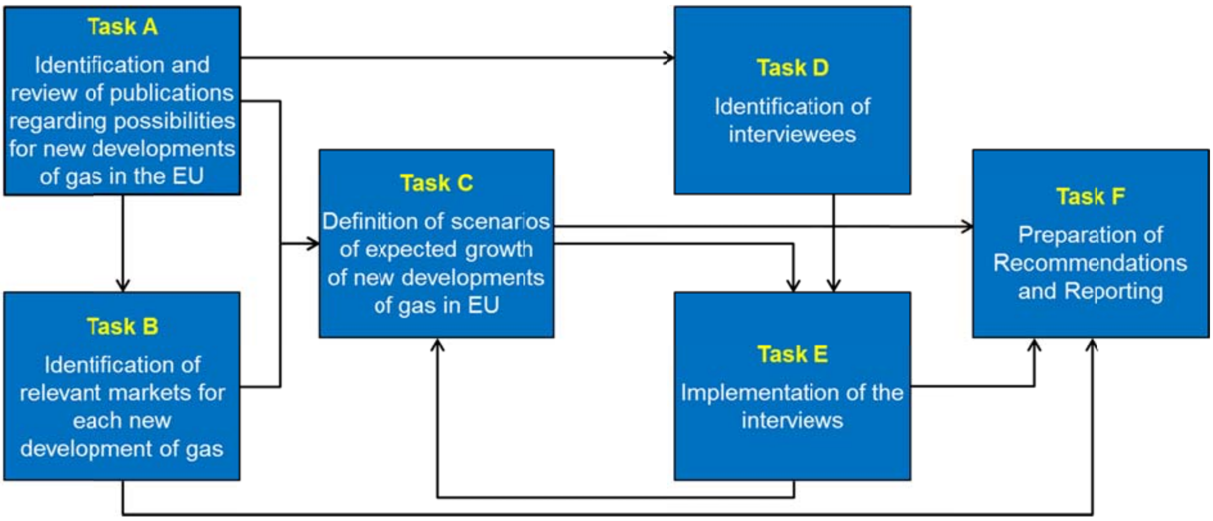
As shown in the figure above, the new developments have different roles in the natural gas supply chain. However, as all are new developments in the sector, they are examined under the same study. Furthermore, virtual pipelines are closely related to the development of the use of CNG and LNG in transport, as the former can provide the required gas supply for the latter.

1.2 Methodology of the study

The main objectives of the study are to assess the prospects for the new developments in the gas supply chain, identify any regulatory barriers that hinder their applications and propose recommendations for their removal.

The study involved six interrelated tasks (Figure 2).

Figure 2: Tasks of the study and their interrelations



The information required for the implementation of the study was sourced from the literature review (Task A), the examination of markets applying the new developments (Task B), and the elaboration of interviews with stakeholders involved with their rollout and application (Tasks D & E).

The interviews played a crucial role in the understanding of the current status of the new developments, the identification of barriers and the collection of up-to-date information. In total 25 stakeholders were interviewed, covering the whole range of the gas industry and including gas suppliers, infrastructure operators, NRAs, the EC, gas associations, technology promoters, manufacturers of NGVs, end users (ship owners and NGV users). A list of the interviewed stakeholders is presented in Annex I.

A detailed description of each new development is provided in Chapter 3. In Chapter 4 the prospects for further growth of the developments (including description of the applied methodology) are presented. In Chapter 5 the identified barriers and recommendations are discussed.

2. LEGISLATIVE FRAMEWORK

2.1 EU Regulatory Framework for natural gas

The EU regulatory framework for the natural gas sector, which was taken into consideration in the scope of this study, includes the following:

- Gas Directive 2009/73/EC setting the common rules for the internal EU gas market;
- Regulation 715/2009 (including Decision 24/8/2012 amending the Annex I of the Regulation) setting the conditions for access to the gas transmission systems;
- Regulation 713/2009 establishing ACER;
- Regulation 312/2014 concerning a Network Code on balancing in gas transmission systems;
- Regulation 984/2013 (including draft amendments on incremental capacity) concerning a Network Code on capacity allocation mechanisms;
- Regulation 347/2013 defining the rules for selection of Projects of Common Interest;
- Draft Network Code on interoperability and data exchange rules;
- Draft Network Code on harmonised gas transmission tariff structures.

2.2 Other Directives relevant to this study

Other EU Directives, currently in place or being drafted, that are relevant to the study, are presented below.

Directive on the deployment of alternative fuels infrastructure

The Directive on the deployment of alternative fuels infrastructure (AFI Directive) was adopted by the European Parliament and the Council on 29 September 2014 and is expected to be published within the last quarter of 2014. The Directive establishes a common framework of measures for the deployment of alternative fuels infrastructure in the EU. The fuels covered in this Directive are electricity, hydrogen, biofuels, synthetic and paraffinic fuels, CNG, LNG and LPG.

The AFI Directive:

- Requires Member States to develop national policy frameworks, which define the national targets for the market development of each alternative fuel and their infrastructure. The policy frameworks shall be submitted to the EC two years after entry into force of the Directive, i.e. by the end of 2016;
- Foresees the use of common technical specifications for recharging and refuelling stations. Specifically for CNG and LNG the technical standards to be applied by the Member States are to be developed by the relevant European or International Standards Organizations;
- Sets specific targets for the timing of development of each infrastructure (Table 1).

Table 1: Timing for development of alternative fuels' infrastructure

Fuel	*Coverage*	*Timing*
Electricity in urban/suburban and other densely populated areas	Appropriate number of publically accessible points	End-2020
CNG in urban/suburban and other densely populated areas	Appropriate number of points	End-2020
CNG along the TEN-T core network	Appropriate number of points	End- 2025
Electricity at shore-side	Ports of the TEN-T core network and other ports	End-2025
Hydrogen in the Member States who choose to develop it	Appropriate number of points	End-2025
LNG at maritime ports	Ports of the TEN-T core network	End-2025
LNG at inland ports	Ports of the TEN-T core network	End-2030
LNG for heavy-duty vehicles	Appropriate number of points along the TEN-T core network	End-2025

Directive on sulphur content of marine fuels (Directive 2012/33/EC)

The Directive 2012/33/EC (amending Council Directive 1999/32/EC) relates to the reduction of the sulphur content of heavy fuel oil, gas oil, marine gas oil and marine diesel oil used in the European Union, in line with the reductions foreseen in Annex VI of MARPOL 73/78[1]. The regulation imposes the application of the following limits for the share of sulphur in the marine fuels used:

- In SOx Emission Control Areas[2]: sulphur content in the fuel must not exceed 1.00% until 31 December 2014; the limit is further reduced to 0.10% as from 1 January 2015;
- In any Member State's territorial sea: sulphur content in the fuel must not exceed 3.50% as of 18 June 2014; the limit is further reduced to 0.50% as from 1 January 2020.

Energy Taxation Directive and new proposal

The Energy Tax Directive currently in force (Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity), foresees favourable taxation levels for natural gas. In 2011 the EC (DG Taxation and Customs Union) put forth a proposal for a revision of the Energy Tax Directive [COM(2011)169], which proposes to update the rules for setting minimum tax rates for fuels. According to the proposal, which has not been accepted, the minimum tax imposed on all motor fuels would consist of two parts:

- the energy part, which was proposed to be the same for all fuels (in €/GJ); and
- the CO_2 part, taxing gas emissions at 20 €/tn

[1] MARPOL 73/78 is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978

[2] Sea areas in which stricter controls for Sox emissions are applied

The energy part would be calculated so that all fuels are taxed at the same level as petrol, which is currently the most heavily taxed fuel. Considering the current minimum tax on petrol (359 €/1000 lt) and subtracting the corresponding part for CO_2 (45.5 €/1000 lt petrol), the current energy part of the tax on petrol was calculated to be 9.6 €/GJ. The proposal then undertakes to apply this level of minimum taxation on all motor fuels. Taking into account the fuels' heating values and adding the CO_2 part of the tax, according to the CO_2 emissions caused by each fuel, the taxes proposed are as presented in Table 2, below. The current minima are also listed for comparison.

Table 2: Minimum taxes on motor fuels with the proposed energy taxation Directive (Source: EC)

Energy Product Motor Fuels	*Current minima*	*Minima proposed in current ETD units to be reached by 2018*	*Unit*	*New minimum tax per GJ*	*% Change*
Petrol	359	360	€ per 1000 l	10.95	0.3%
Diesel	330	390	€ per 1000 l	11.08	18.2%
Kerosene	330	392	€ per 1000 l	11.05	18.8%
LPG	125	500	€ per 1000 kg	10.87	300.0%
Natural Gas	2.6	10.72	€ per GJ	10.72	311.5%

3. DESCRIPTION OF NEW DEVELOPMENTS IN THE GAS SUPPLY CHAIN

3.1 Virtual Pipelines

3.1.1 Introduction

New technological solutions in the compression of natural gas, particularly related to the compression rate and the CNG storage media, have made CNG available to final consumers for uses other than as a transport fuel. In addition, the cost reduction in small scale and micro scale LNG applications has allowed direct supply and storage of LNG at the premises of final consumers, alongside its regasification and injection in the gas system.

A virtual pipeline is defined as the supply chain transporting natural gas to final consumers in the form of CNG or LNG, using road and sea means of transportation, such as trucks, vessels, and rail. Typically, a virtual pipeline supply chain consists of the CNG or LNG production/supply and loading terminal, the transportation method and the unloading terminal at the final consumer(s).

When compared to conventional gas transmission systems, the virtual pipelines have the following advantages and disadvantages:

Table 3: Advantages & disadvantages of virtual pipelines compared to physical pipelines

Advantages	Disadvantages
+ Flexibility in the transportation routes to final consumers. + Versatility in the location and dispersion of final consumers. + Small investment costs compared to large pipeline systems. The number of consumers can be expanded without significant additional investments. + Access to remote and dispersed consumers for which construction of transmission and/or distribution systems is not cost effective or technically feasible (e.g. mountainous areas, islands). + Application of micro scale CNG and LNG solutions which can transport gas to small consumers. + Any excess capacity at the CNG/LNG terminals can be exploited as fuel for NGVs.	- High investment costs at the site of the final consumer, as apart from the typical equipment of an internal installation, unloading facilities are also required. Particularly in the case of the LNG virtual pipeline model the LNG storage tanks and regasification installations increase overall costs. - Capacity is generally smaller than that of physical transmission systems, due to limitations in the loading terminals and storages. Economies of scale for the whole supply chain have a smaller effect on the costs, compared to the case of gas networks. - The operation of the supply chain requires intensive and complex logistics. - Higher health and safety standards, which are particularly related with the use of trucks.

As a result of these differences between the two modes of gas transportation, and particularly the characteristics of consumers that are typically targeted by virtual pipelines, the operation of physical and virtual pipelines is usually complementary. Virtual pipelines are mainly used either as a first step for the gasification of regions, to create a critical mass of gas consumption prior to the construction of pipelines for the connection to the transmission system or in cases for which construction of pipeline systems is not cost effective or technically feasible (e.g. supply to remote consumers or exploitation of stranded gas reserves). In rare cases, virtual pipelines are used to supply end-users connected to the transmission system, if piped gas flows have been disrupted due to system maintenance or other reasons.

The selection between the CNG and LNG virtual pipeline models is carried out on a case-by-case basis. Factors affecting such a decision include:

- Location of the end users: LNG virtual pipelines are usually applied for the supply of consumers at larger distances, due to the larger gas volumes that can be transported per shipment. Additionally, LNG supplies are preferred in the case of islands, as there are currently no CNG vessels available in the market.
- Size of the market: The availability of LNG storages of various sizes usually favours the supply of LNG to large consumers. On the other hand, the need for storage and regasification equipment at the site of the end users, might make the supply of LNG to small consumers uneconomical and the use of CNG preferable.
- Type of consumption: The selection is dependent on the consumption profile; e.g. in cases of seasonal demand or need for large periods of autonomy, storage of gas in LNG tanks at the site of the end user may be preferred. Furthermore, to supply CNG or LNG filling stations a relevant virtual pipeline may have to be developed.
- Availability of existing LNG storage facilities: If storage capacity is available at LNG facilities, there is no need for construction of a costly liquefaction facility, significantly reducing the costs of the virtual pipeline.

The advantages of the CNG and LNG virtual pipelines are summarised in Table 4 below.

Table 4: Advantages of CNG and LNG virtual pipelines

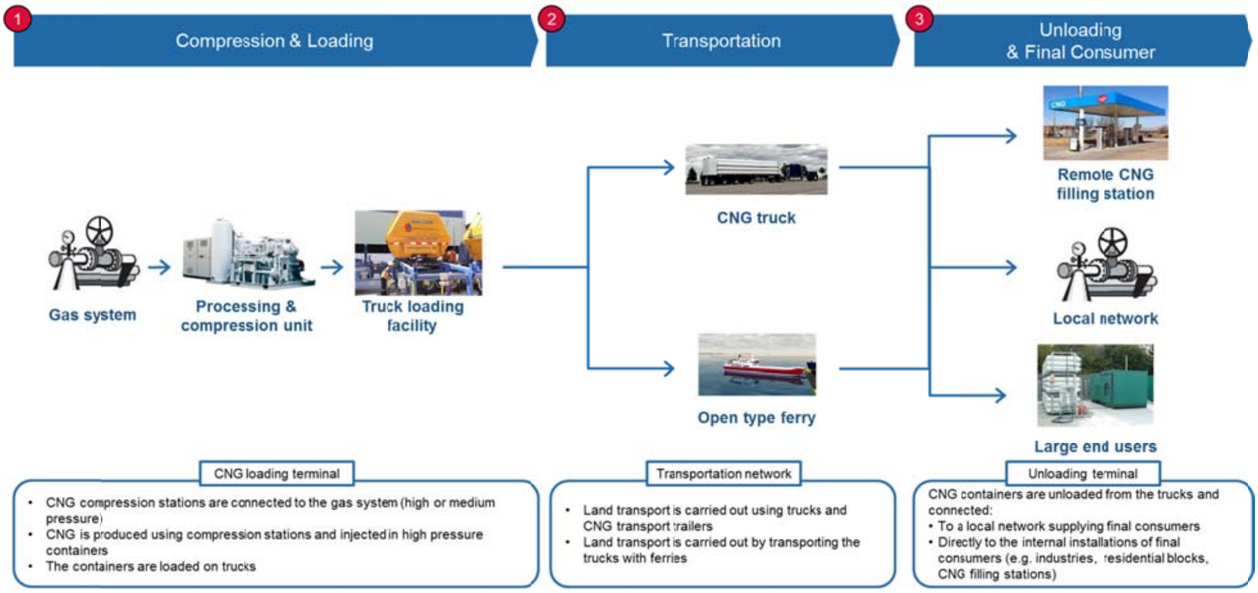
Advantages of CNG	Advantages of LNG
+ Construction of the required infrastructure for CNG is faster than for LNG, due to the higher complexity of the latter. + Investment costs for the unloading facility of CNG at the site of the final consumer are lower than those of the LNG model, as the latter requires the construction of LNG storage and regas facilities. + The CNG compression and loading terminal can be installed at any point of the transmission system. Moreover, expansion of capacity can be achieved with the installation of additional compression units. This flexibility and modularity allows the placement of the terminal in areas that can provide strategic advantage and economies of scale. + The tanks used for the transportation of CNG are unloaded at the site of the final consumer and are used as a storage medium. Different canister sizes can be supplied depending on the consumption of the end user.	+ The capacity of the LNG virtual pipeline is larger than that of the CNG pipeline, as the higher LNG density allows larger gas quantities to be transported per shipment. + The small scale LNG vessels allow the transportation of gas to islands. + Existing LNG facilities (liquefaction or import) can be used as part of the virtual pipeline for the loading of LNG, reducing the overall cost of the infrastructure. + The use of rail for the transportation of LNG tanks, if a suitable railroad route is available, largely increase the LNG volumes transported. + LNG storage facilities, if connected to the gas transmission system, can be used for peak shaving.

3.1.2 CNG Virtual Pipelines

Overview

The concept of the CNG virtual pipelines includes the compression of natural gas in facilities connected to the gas system, the transportation of CNG using high pressure containers and the unloading of the containers at the sites of the final consumers. The overall supply chain of the CNG virtual pipelines is presented in the figure below.

Figure 3: Overview of CNG virtual pipeline supply chain



The supply chain is the same for all CNG virtual pipelines, although the "capacity" of the virtual pipeline (i.e. the CNG volumes transported) can range widely, depending on the size of the targeted consumers. Alternative solutions are available from different technology providers, especially related to the containers used for storing and transporting CNG, without however significantly changing the overall supply chain.

Description of the technology applied

The main characteristics of each section of the CNG supply chain are described below.

1. Compression & Loading

The production of CNG and its loading on trucks is carried out in a single terminal. The compression and loading terminal is usually combined with CNG filling stations for road vehicles, in order to exploit the economies of scale. The terminal typically includes:

1. Connection to the gas system: The CNG loading terminal is connected to the high or medium pressure gas system. Connection to the high pressure transmission system reduces the amount of compression required, and consequently lowers the compression costs.
2. Gas processing and compression unit: Natural gas is dehydrated and then injected in the compression station, where it is compressed to a pressure reaching 250 – 300 bar (depending on the technical specifications of the container in which it will be stored and the

amount of gas to be transported). Depending on the size of the compressor, the production rate of CNG varies, and can exceed 80 m^3/min. The unit is equipped with small CNG storage capacity to facilitate the process.

3. CNG containers: The produced CNG is stored in special high pressure containers. There are many alternative solutions for CNG containers available from different technology providers, ranging from large tubes with capacity of 600 m^3 to small cylinders of 35 m^3 interconnected within larger modules.
4. Docking bay: The containers are filled with CNG at the docking bay and loaded on trailers, so as to be transported to the final consumers.

The technology applied is modular, and the capacity of the CNG loading terminal can be increased by adding compression units and docking bays.

2. Transportation

The storage of CNG in containers allows its transportation with trucks as any other cargo. Trailers which are towed by trucks are used to transport the containers. The CNG containers are either permanently installed on the trailers or are loaded at the docking bay. The number of containers per trailer depends on their size and weight. A typical capacity of a CNG truck is 10,000 m^3 to 13,000 m^3.

Sea transportation of CNG is currently not possible as there are no CNG vessels in operation. Although there were plans, since 2007, for the development of CNG vessels with capacity reaching 5-20 mcm, no such ship has been commercially built to date. The main reasons are safety concerns, as well as the lack of cost effectiveness when compared with small scale LNG vessels. As a result, for the purpose of supplying consumers in islands, CNG trucks can only be transported using open type car ferries (closed type ferries are not used for safety reasons).

3. Unloading & Final Consumer

The CNG containers are unloaded from the trucks at a receiving and injection terminal that is connected either to a distribution network supplying final consumers or directly to the internal installations of final consumers. End users that directly receive CNG shipments mainly include industrial and commercial consumers, remote CNG filling stations (not connected to the gas system) and large residential blocks with small local distribution networks. The demand of end users served by a CNG virtual pipeline ranges typically from less than 5 mcm/yr to 40 mcm/yr.

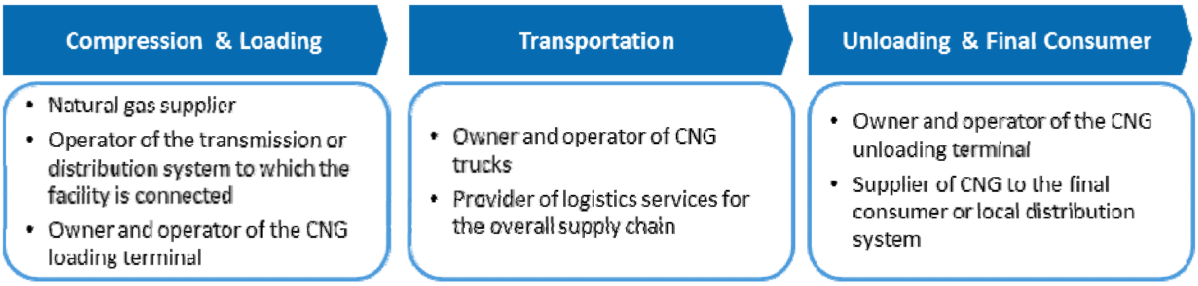
The CNG containers are used as a natural gas storage medium at the receiving and injection terminal. A pressure regulation station, connected to the containers, is used to reduce the gas pressure and allow its injection into the distribution network or the internal installation. The flow capacity of the regulation station depends on the consumption profile of the end users and typically ranges from 200 m^3/hr to 10,000 m^3/hr.

Due to the small volumes of natural gas transported by each CNG shipment, the logistics for ensuring sufficient supply of the final consumers is quite complex. Usually, IT solutions are applied by the suppliers, to remotely monitor the gas volumes remaining in the CNG tanks of each consumer, and appropriately arrange truck deliveries to replace them.

Main stakeholders involved in the supply chain

The main stakeholders involved in the application of a CNG virtual pipeline include the supplier of gas to the virtual pipeline, the TSO or DSO to which the loading facility is connected, the owner(s) and operator(s) of the loading terminal, the CNG trucks and the unloading facilities, and the supplier of the final consumers. The logistics of the of the supply chain are complex and are usually handled by the CNG supplier. An overview of the key actors is presented in the figure below.

Figure 4: Main stakeholders of a CNG virtual pipeline



According to the stakeholders interviewed, in a usual set-up of a CNG virtual pipeline, the owner and operator of the compression and loading terminal also acts as the supplier of CNG to the final consumers. The CNG trucks are either owned by the supplier or outsourced to specialised companies. The equipment of the unloading terminal may be owned by the final consumer or leased by the supplier to the final consumer.

Economics

The cost effectiveness of the CNG virtual pipelines depends on the size and location of the final consumers supplied (distance from the loading terminal and availability of road routes); in general the supply of an end user or distribution network by a virtual pipeline is economically viable up to a distance ranging from 150 to 300 km. Indicatively in the case of Bulgaria, according to CNG Module Systems Ltd, the transportation cost of CNG (including compression, storage, transportation and off-loading) up to a distance of 150 km ranges from 80 to 100 €/1000 m^3, depending on the complexity of the transport route.

The costs for development and operation of a CNG virtual pipeline vary, depending on the capacity of the pipeline and the technological solutions applied. The costs are particularly affected by the size and production rate of the compressor station as well as the type and number of CNG containers and trailers required. There are significant economies of scale for the implementation of the loading and unloading terminals, but not for the transportation of CNG.

As an example the costs of a CNG virtual pipeline in Canada accommodating an annual demand of around 60,000 MWh (two thirds of which distributed using CNG trailers and one third consumed locally), are presented in Table 5 below.

Table 5: Indicative costs for the development and operation of a CNG virtual pipeline (Source: Pacific Northern Gas Ltd)

Item	*CAPEX (€)*	*OPEX (€/year)*
Loading terminal land and site preparation	658,000	-
Compression and injection station	757,500	88,000
CNG containers and transport trailers (2 trailers)	1,284,000	204,000
Unloading terminals (2 terminals)	77,000	23,000

As seen in the indicative costs above, the largest part of the investment costs are required for the land, equipment and construction of the loading terminal (51%) and for the procurement of the CNG containers and trailers (46%). The largest components of the operating expenses are the transportation costs, and particularly the fuel cost of the trucks.

Current applications of CNG Virtual Pipelines

CNG virtual pipelines have been developed worldwide, including regions in North and Latin America, Australia, Russia and China. The CNG supply chain has mainly replaced the construction of a physical gas pipeline, where this was not economically feasible, due to the dispersion of the final consumers and the difficult terrain. Most of the CNG volumes appear to be supplied to remote CNG filling stations, not connected to the gas system.

In Europe, representative cases of CNG virtual pipeline applications include the supply of CNG to remote consumers in Italy and Bulgaria.

In Italy, as the gas system is widely developed, CNG virtual pipelines are used to supply small local distribution systems, the connection of which to the national transmission system is not economically viable. The suppliers are usually operators of CNG filling stations that own CNG trucks, used for delivering CNG to the local networks. Third party access to the CNG filling stations in not allowed.

In Bulgaria a compression and loading terminal is operational in the southern part of the country, serving 74 unloading facilities located within a radius of 150 km. The virtual pipelines deliver CNG to industries and to local distribution systems, with annual consumption ranging from 4 to 40 mcm/yr.

In the scope of this study, two markets that apply CNG virtual pipelines were examined in detail; Argentina and USA. Case studies for these two markets are presented below.

Case Study: Operation of CNG Virtual Pipelines in Argentina

Argentina is the world leader in the use of CNG of road transportation, having approximately 1,500,000 CNG-fuelled vehicles and 2000 CNG filling stations nationwide. The penetration of CNG boomed in 2003, with a large spike in vehicle conversions. This is attributed to incentives provided by the Argentinian Government, as despite the huge devaluation of the Argentine peso during that period, and the resulting steep increase in fuel prices, a Governmental regulation prevented a relevant surge in the natural gas price, making CNG significantly more competitive compared to petrol.

The development of the CNG market moved in pace with the development of CNG filling stations. This was facilitated by the wide gas transmission and distribution network in the country. Argentina has become one of the leaders in the CNG equipment manufacture industry, covering the full range from tanks and compressors to loading terminals and dispensers. This industry includes one of the major technology providers for the development of CNG virtual pipelines, Galileo, which has provided equipment and turn-key solutions to several countries worldwide.

The CNG virtual pipelines have been developed in Argentina mainly to facilitate the further expansion of the CNG filling station network to regions without access to gas transmission and distribution networks. To a lesser extent the virtual pipelines are also used to supply industrial, commercial and residential consumers.

Indicatively, in the region of South Cordoba a wide virtual pipeline has been set up, supplying 8 towns with a total of 25,000 m^3/d. The consumers include 8 CNG filling stations, 40 industries and 5400 households. Virtual pipelines have also been applied to supply remote consumers, such as the case of an isolated mine in Patagonia, that receives around 40,000 m^3/d.

There are several technical and market regulatory provisions for CNG in force in Argentina, particularly related to CNG stations. The country's energy regulator, ENARGAS, is responsible for the technical regulations and standards framework for CNG. ENARGAS has issued a large number of regulations for CNG, including detailed safety procedures and technical specifications for the complete supply chain of the CNG virtual pipelines.

The Secretariat of Energy, of the Ministry of Planning, is responsible for the regulatory framework regarding the operation of the CNG filling stations. To avoid vertical integration in the sector, the operation of CNG filling stations is unbundled from the activities related to gas production. The Secretariat of Energy, in cooperation with ENARGAS, examines the prices of CNG at filling stations, to monitor the margin applied by each CNG seller.

Despite the development of CNG virtual pipelines, LNG virtual pipelines have not been developed in the country. This could be attributed to the lack of availability of on-shore LNG terminals that could be used as storage facilities, as both import terminals of the country are Floating Storage and Regasification Units (FSRU).

Case Study: Operation of CNG Virtual Pipelines in USA

The CNG virtual pipelines are a new and emerging market in the USA, with small projects being implemented since 2012. Current areas of interest for most of the companies supplying CNG are mainly New England and New York, where the market for deliveries of CNG and LNG is estimated (also including lower Canada) at around 140 – 330 mcm per annum.

The CNG loading terminals are connected to high pressure pipelines and serve consumers that are within a range of 150 – 300 km from the terminal. The compression capacity of the terminals reaches up to 200 m^3/h. Currently, there appears to be no interstate trade of CNG, especially due to limitations resulting from the distance between loading terminals, thus all deliveries are implemented locally.

Existing clients of the CNG virtual pipelines include small industries, such as paper mills and asphalt plants, commercial enterprises, and public buildings such as schools and hospitals. Gas consumers with larger demand tend to prefer the supply of LNG, because, although it is a more costly conversion, it has potential for greater savings. Most CNG end users have installed equipment with dual fuel capability; as a result, in order to be more competitive than the alternative fuel, most CNG suppliers offer price incentives through interruptible services at a discounted price.

In most of the cases so far, in order to set up a CNG virtual pipeline, a technology provider cooperates exclusively with a single CNG supplier; the former builds and operates the loading terminal while the latter undertakes the transportation of CNG and supply of final consumers. To date, only one loading terminal operator is providing free access for all CNG suppliers to their facility. The loading terminals are supplied with gas from the transmission system by a separate entity, usually through interruptible contracts.

The approvals for the implementation of the CNG infrastructure are carried out at State level, with the projects examined to assess whether the service provided should be regulated. In one of the first cases, examined in the State of Vermont, concerning the development of a CNG virtual pipeline by NG Advantage (CNG supplier) in cooperation with Clean Energy Fuels (technology provider), the Public Service Board ruled that the services provided should not be regulated because:

- The supply chain lacks the characteristics of a natural monopoly, as the supply company will have no physical connection with customers;
- The supply company does not have an economic monopoly, as a competitive market already exists with fuel supply options (LNG, propane, diesel, other CNG suppliers) that allow fuel and supplier switching;
- The services of suppliers of other fuels are not regulated.

Factors affecting development

The future development of the CNG virtual pipelines is dependent on technical, market and regulatory factors. The most important of these that have been identified following the literature review and the interviews with stakeholders involved in the sector are the following:

- Permitting process: As this is a new mode of gas supply, the permitting process, particularly for the construction of the loading and unloading terminals, may not be streamlined, causing delays to the implementation of the project. Especially health and safety requirements, including emergency response plans, will have to be specified.
- Price & Taxation: The CNG virtual pipelines will have to compete with alternative fuels which are traditionally used by final consumers. Therefore, the fuel price differential is crucial for the penetration of CNG in the market. The taxation level of CNG affects its

competitiveness against other alternative fuels. In this respect, the lack of any taxation incentives for CNG in the national legislation, to promote it as a clean fuel, may hinder its penetration in the market.

- Network coverage: In countries with dense gas network, the use of CNG virtual pipelines will only be limited to some cases of consumers which are not close to the network. Large scale applications are expected in regions which are lacking network coverage.
- Profile of the consumers: The demand, location and consumption profile (e.g. seasonal or continuous) directly affect the deployment of the CNG virtual pipelines, particularly related to the capacity of the compressor and the location of the terminal, number of trucks used, and the potential need for construction of local networks.
- Safety regulations for road transport: As CNG is transported using trucks, any regulations related to transportation of cargo using trucks affect the development of the virtual pipeline. For example, cases of limitation in the weight of transported cargo reduce the CNG volumes that can be loaded on each trailer, having an impact on the economies of scale and cost effectiveness of the virtual pipeline.
- Clarity of regulatory framework: Regulatory issues, such as licencing and third party access, will have to be clear, so potential investors are not disincentivised to participate in the market. The regulatory issues are discussed in detail in Chapter 5.

In addition, the widespread use of CNG in vehicles (discussed in section 3.2 below) can have an impact on the growth of CNG virtual pipelines. This impact, however, is expected to be limited, because it is expected that the large majority of CNG filling stations will be connected to the gas network.

3.1.3 LNG Virtual Pipelines

Overview

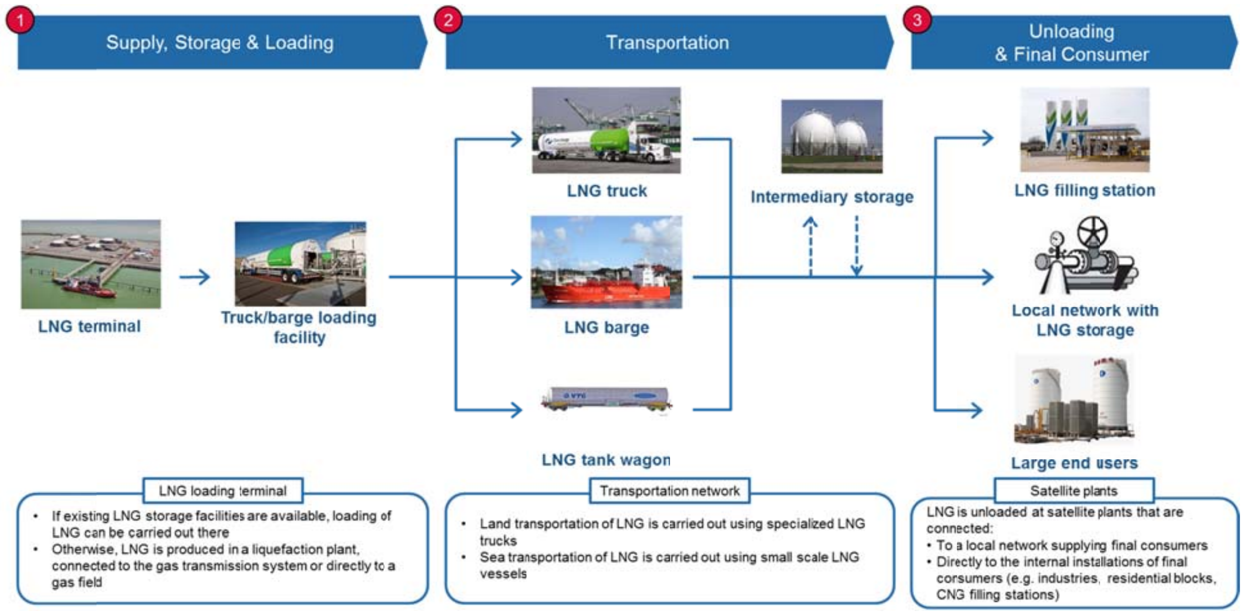
The development of small scale and micro scale LNG applications, related to liquefaction, transportation and storage of LNG, have led to the development of LNG virtual pipelines with a wide range of size/capacity, depending on the markets that they address. There are markets that have been using virtual pipelines for many years, such as Spain, while others, like France and Sweden have recently commenced non-piped gas supplies.

The development of LNG virtual pipelines is closely connected to the development of LNG filling stations, as this is the only supply option for stations located away from LNG terminals. The installation of liquefaction units at the filling stations is not applied for the supply of LNG, as this would require large capital investments.

The concept of the LNG virtual pipelines includes the storage of LNG, its loading and transportation using LNG trucks, small scale LNG vessels, or potentially rail, depending on the location of the consumers, and its unloading at satellite plants, that are equipped with small scale storage tanks and regasification units. The sourcing of LNG for the virtual pipeline depends on the availability of existing LNG infrastructure in the market. If an LNG storage facilities are already in place (e.g. at an LNG import terminal), these can be used for the loading of the LNG trucks or vessels. Otherwise, implementation of a small scale liquefaction plant is required to supply LNG to the virtual pipeline.

The overall supply chain of the LNG virtual pipelines is presented in the figure below.

Figure 5: Overview of LNG virtual pipeline supply chain



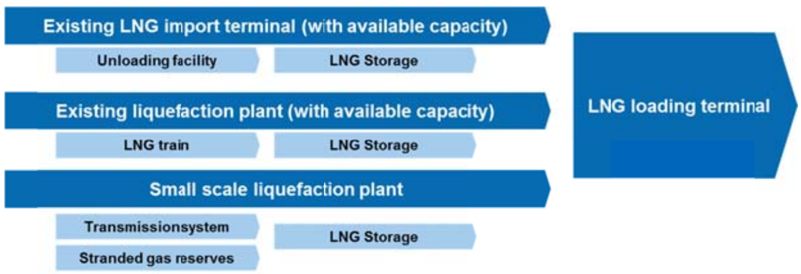
Description of the technology applied

The main characteristics of each section of the LNG supply chain are described below.

1. Supply, Storage & Loading

The source supplying LNG to the virtual pipeline may be an existing import terminal or liquefaction plant, with sufficient capacity to serve the pipeline, or a new small scale liquefaction plant dedicated to the supply of the virtual pipeline (Figure 6). The selection of the source depends on the availability and location of existing LNG infrastructure, as its utilisation would increase the cost effectiveness of the virtual pipeline.

Figure 6: Options for supply of an LNG virtual pipeline



In the absence of existing LNG storage facilities that can be utilised for the virtual pipeline, a small scale liquefaction plant can be constructed to supply LNG. The plant is either connected to the gas transmission system or to a gas production field (usually stranded). The facilities of the small scale plant resemble those of a large scale terminal. The LNG production rate depends on the size of the targeted market, and for a small scale plant can range from 150 - 725 tpd of LNG, although LNG trains with even lower liquefaction rates are available in the market. The capacity of the LNG storages is defined by the size of the liquefaction train, and usually ranges from 10,000 m^3 of LNG to over 100,000 m^3. According to the stakeholders interviewed, there seem to be no prospects for the development of small scale liquefaction terminals in the EU.

Regardless of the sourcing of LNG, the storage facilities are connected to an LNG loading terminal, which is used to inject LNG to the trucks or vessels of the virtual pipeline. The terminal is equipped with a loading assembly of pumping and piping equipment which is suitable for handling the low temperatures of liquefied gas. The loading terminal includes one or more docking bays, at which the LNG trucks or vessels are loaded. Loading of LNG trucks can be carried out at a rate of around 50 m^3 LNG/hr.

The expansion of the loading facility can be modular with the installation of additional truck loading bays and pumps. It can be however limited by the available space in the LNG terminal and the capacity of the LNG storage facilities.

2. Transportation

The transportation of LNG is carried out using cryogenic tanks, installed on trucks and vessels. The capacity of the tanks varies, depending on the targeted consumers.

For the road transportation of LNG, trucks towing trailers equipped with cryogenic tanks are used. The capacity of the tanks typically ranges from 30 to 50 m^3 LNG. The tanks are usually filed up to 85% of the maximum load, for safety reasons and potentially to comply with transported weight restrictions imposed by the national legislation.

The sea transportation of LNG, in the context of virtual pipelines, is carried out with small scale LNG vessels, either ships with build-in tanks or barges equipped with tanks, towed by tugboats. The capacity of the vessels ranges widely, from 1,000 m^3 LNG up to 40,000 m^3 LNG. The vessels are used either to directly supply satellite plants located in coastal areas or to reload LNG to trucks, so as to be further transported to the final consumers. An alternative way of sea transportation of LNG is the use of ferries to transport LNG trucks; this however has the disadvantage of transporting much less volumes of gas compared to the LNG vessels.

Another mode of LNG transportation is the utilisation of freight trains and the railroad network. LNG tank wagons can be loaded at an LNG terminal and transported up to the final consumers if such infrastructure is available (railroad from the terminal to the consumer). Alternatively, bulk LNG containers are loaded to the freight train; in this case trucks may be used to transport the containers from the LNG terminal to the rail station and from the destination station to the site of the final consumer. The main advantage for the use of rail is that large volumes of LNG can be transported with each shipment.

3. Unloading & Final Consumer

The unloading of LNG is carried out at satellite plants, which are connected either with a local distribution system or directly with end users. The satellite plants consist of LNG storage facilities, a regasification unit and a regulation station. The size of the LNG storage depends on the gas demand served by the plant, and usually ranges from 5 to 500 m^3 LNG. Depending on the type of the final consumer and the space available in their site, the storage facilities can either be a stack of small storage tanks, or a single build-in facility. The send-out capacity of the regasification unit depends on the peak consumption and may reach 6,000 Nm^3/hr.

Intermediary LNG satellite storages, located along the route of the virtual pipeline, may be used as buffers, in case the distance covered for the LNG supply is large.

Main stakeholders involved in the supply chain

The main stakeholders involved in the application of a LNG virtual pipeline include the supplier of LNG at the LNG terminal (shipper), the operator of the LNG import facility or liquefaction plant that feeds the virtual pipeline, the operator(s) of the loading terminal, the LNG trucks or vessels and the satellite plants and the supplier of the final consumers. As in the case of the CNG pipelines, the logistics of the of the supply chain are complex and are usually handled by the LNG supplier. An overview of the key actors is presented in the figure below.

Figure 7: Main stakeholders of an LNG virtual pipeline

According to the stakeholders interviewed, usually the supplier of the final consumers is responsible for the procurement of the LNG at the terminal, its transportation and delivery to the storage facilities at the site of consumer. In some cases the supplier is the shipper that imports LNG to the terminal. The service of truck loading is provided by the operator of the LNG terminal (the regime of the service is regulated or unregulated depending on the country). The LNG trucks may be owned by the operator of the LNG terminal, the supplier or outsourced by the supplier to specialised companies. The LNG storage and regasification unit at the satellite terminal may be leased by the supplier to the final consumer or directly owned by the final consumer.

Economics

The construction and operation of a liquefaction plant constitutes a large part of the overall costs of the LNG virtual pipeline. There are large economies of scale as the capacity of the plant increases; as a result micro liquefaction plants have significantly larger unitary costs than mid-scale ones. Indicative costs of recently implemented small scale and micro scale liquefaction plants in USA are presented in the table below.

Table 6: Indicative costs of liquefaction plants (Source: GNA)

Liquefaction capacity (tpa)	*Cost (mil. €)*
60,000	40
160,000	60
4,000	6

In this respect, the utilisation of existing large scale LNG infrastructure would increase the cost efficiency of the virtual pipeline, as the cost for the use of infrastructure can be lower than the depreciation of a new liquefaction plant.

The largest cost of the LNG trucks is attributed to the cryogenic LNG tank; according to Repsol, the LNG tank amounts to 55% of the overall cost, while the remaining 45% is the truck chassis-engine. Costs of LNG trucks appear to have been reduced in the recent years, from around 205,000 € in 2009 to 160,000 € in 2013.

The satellite plants build at the premises of the final consumers increase the cost of the internal installation, in comparison with the typical installation required for supply of piped gas. The cost of the LNG storage is estimated at 2,500 €/m^3 LNG, while the regasification unit and overall site preparation can be estimated at 5 times the LNG storage investment.

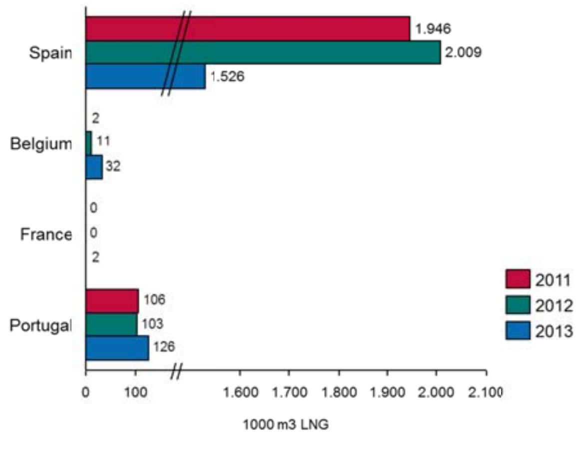
The distance up to which an LNG virtual pipeline is cost-effective can vary significantly, depending on multiple factors, such as the size and distance of large customers, the availability and coverage of the road network, etc. According to various sources, from the literature review and the interviewed stakeholders, an effective radius of an LNG loading terminal can range from 400 to 1000 km.

Current applications of LNG Virtual Pipelines

LNG virtual pipelines have been widely developed in USA, Russia and China, particularly for the supply of consumers that are located in a large distance from the transmission system and for the exploitation of small stranded reserves. Small scale LNG technologies are also applied in Japan due to the very large LNG import capacity. Norway is widely using LNG virtual pipelines with small scale vessels to supply coastal satellite plants. The technology has been applied to a lesser extent in Australia, while there are plans for broad applications in S.E. Asia.

In Europe Spain, due to its large LNG import capacity, has truck loading terminals in most of its LNG import facilities and has been using road transportation of LNG for many years. Virtual pipelines were used to build demand in regions without network coverage, and following the successful penetration of gas, a transmission system was constructed, to replace LNG supply with piped gas.

Figure 8: Annual LNG volumes loaded on trucks at EU LNG terminals (Source: GIE)



Virtual pipelines are also developed in the UK, where LNG is produced at gas fields, using liquefaction terminals and transported to the final consumers using trucks. Additionally, LNG truck loading terminals are available in Belgium, France, Netherlands and Portugal. Figure 8 and Figure 9 present the current situation of LNG loading terminals in the EU. On the other hand, currently there appears to be no utilisation of small scale LNG vessels in the EU.

Figure 9: EU LNG Terminals with truck loading facilities (Source: GIE)

Cross-border transportation of LNG is currently taking place in Europe. For example LNG shipments from the Zeebrugge terminal in Belgium are delivered to the Netherlands, Poland, Sweden and the UK, and LNG from Spain to filling stations in France and Italy. No significant cross-border issues and barriers were noted by the interviewed stakeholders.

Virtual pipelines with rail transportation of LNG are also being applied in the EU. Freight trains are used in Sweden to transport LNG directly to the site of industrial consumers that have switched from LPG to gas. According to GIE, freight trains can be used to deliver large LNG volumes from the LNG terminals in Western Europe to the Eastern EU countries, in order to strengthen their security of supply.

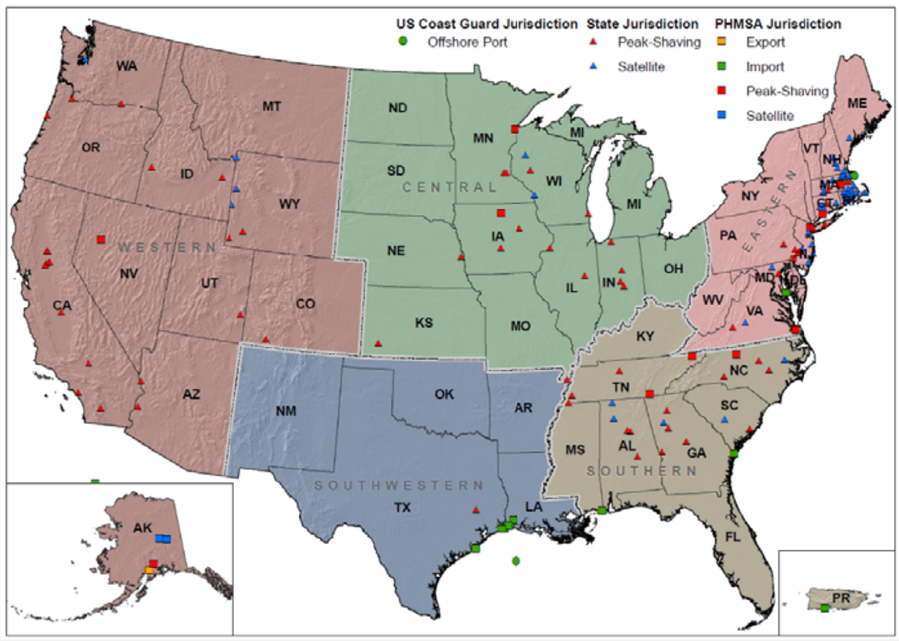
In the scope of this study, three markets that apply LNG virtual pipelines were examined in detail; Norway, USA and Japan. The case studies for USA and Japan are presented below. The case of Norway is presented in Chapter 3.3, in conjunction with use of LNG in sea vessels.

Case Study: Operation of LNG Virtual Pipelines in USA

LNG is used in USA as a storage medium for peak shaving reasons, as well as a fuel for industries, local distribution networks and LNG vehicles. A large number of LNG storages are operational across the country (Figure 10). These are divided into two types of plants:

- Peak shaving plants: small liquefaction plants, connected to the transmission system that are used to produce and store LNG. The plants are used to reinject gas to the system in cases of high demand, to supply LNG virtual pipelines or as LNG filling stations.
- Satellite plants/storages: LNG storages without liquefaction capabilities. The storages are supplied using virtual pipelines.

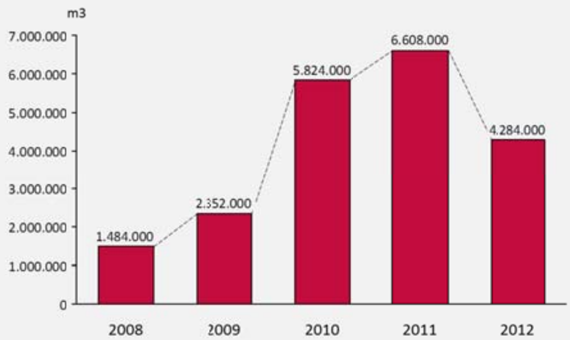
Figure 10: LNG storages in USE (Source: US Department of Transportation)



Apart from the liquefaction plants connected to the transmission system, there are also plants used to exploit stranded reserves of conventional and shale gas.

The LNG virtual pipelines are mainly used to supply satellite storages, remote consumers and LNG filling stations. Apart from interstate and intrastate trade, USA is also having limited LNG trade activities using trucks with Mexico (Figure 11).

Figure 11: USA LNG exports to Mexico using trucks (Source: EIA)



In order to obtain a licence for the construction and operation of an LNG liquefaction plant, storage or loading terminal, the interested party submits an application to the pertinent authorities. As there are LNG facilities providing various services in USA, depending on location and use, a facility may be regulated by several federal agencies and by state utility regulatory agencies. The Federal Energy Regulatory Commission (FERC) is responsible for authorizing the siting and construction of onshore and near-shore LNG import or export facilities, and also issues certificates of public convenience and necessity for LNG facilities engaged in interstate natural gas transportation by pipeline.

Any cross-border trade using LNG virtual pipelines requires the approval of the US Department of Energy (DOE), in the form of a blanked authorisation. The authorisation specifies the countries of import or export, the maximum gas volumes to be traded and the duration of supply. Detailed reporting of each transaction will have to be provided to the DOE.

Stakeholders of the LNG industry have identified barriers that will have to be resolved in order to further facilitate the development of the LNG virtual pipelines. Some of the most important ones include:

- The taxation of LNG is based on its volume instead of its energy content. This overtaxes LNG compared to diesel by a factor of 1.7. The National Conference on Weights and Measures examined the standardisation of LNG on a diesel gallon equivalent; however the proposal was not approved in July 2014.
- There are tax implications for interstate transactions of LNG.
- There are weight restrictions imposed by the US Department of Transportation for the road transport of cargo by trucks, which limit the LNG load per truck to around 38 m^3 LNG. Some states do not apply this regulation.
- The definition of "LNG facilities" in the National Gas Act does not cover the case of LNG virtual pipelines. This creates and uncertainty to stakeholders for the involvement in such activities.

Case Study: Operation of LNG Virtual Pipelines in Japan

Japan depends on LNG imports for almost all of its natural gas consumption, and is the world's largest LNG importer. In order to accommodate this large LNG demand, there are 33 LNG receiving terminals across the countries, with receiving capacities ranging from 80 to 9,500 ktpa LNG and storage capacities of 35 to 2,660 m^3 LNG. Most of these terminals are used to import LNG from international markets, while 5 of them are secondary LNG terminals receiving domestic LNG vessels (Table 7).

Table 7: LNG terminals in Japan for domestic LNG vessels (Source: Tokyo Gas)

Terminal Name	*Operator*	*LNG handled annually (tpa)*	*Commissioning*
Hakodate Minato	Hokkaido Gas	56,000	2006
Hachinohe	JX Nippon Oil & Energy	60,000	2007
Okayama Gas Chikko	Okayama Gas	57,000	2003
Shikoku-Gas Takamatsu	Shikoku-Gas	104,000	
Shikoku-Gas Matsuyama	Shikoku-Gas	24,000	2008
Kushiro	JX Nippon Oil & Energy	100,000	2015 (planned)

Japanese gas supply companies, such as Tokyo Gas and Osaka Gas have taken advantage of the huge available capacity of LNG storage, and use the LNG import terminals as hubs to develop LNG virtual pipelines. LNG supplies are mainly targeting industries and local distribution networks operating with coke and town gas, which are located in low-demand areas, and situated away from existing LNG import terminals. The transportation of LNG is carried out with:

- LNG trucks, supplying consumers located within a distance of 200 km from the LNG terminals;

- Small scale LNG vessels transporting LNG to the secondary LNG terminals described above;
- Freight trains transporting bulk LNG containers. LNG is loaded into a container at the terminal and carried to the railroad station by truck, where it is loaded onto a freight train. After the container is carried to the destination railroad station, it is loaded onto a trailer truck again to be transported to the final consumer.

Although not common in other countries, transportation of LNG with freight trains is used in Japan as a result of the wide rail network. Use of freight trains has the advantage of ensuring a stable and scheduled delivery of the containers, not affected by any weather conditions. In addition it allows larger LNG volumes to be transported per shipment, and can cost effectively reach locations as far as 400 km from the terminal. However, trucks are still required to transport the bulk containers to and from the railroad station.

Factors affecting development

The future development of the LNG virtual pipelines is dependent on technical, market and regulatory factors. Some of these factors are similar to those of the CNG virtual pipelines, while others are related to the LNG technology. The most important factors that have been identified from the literature review and the interviews with stakeholders involved in the sector are the following:

- Permitting process: As the wide application of small scale LNG is relevantly new, the permitting process, particularly regarding truck loading terminals and small scale satellite plants, may not be streamlined, causing delays to the implementation of the project.
- Uncertainty of LNG prices: As in the case of CNG virtual pipelines, LNG will have to compete with alternative fuels which are traditionally used by final consumers. The fluctuations in the global LNG market may have a strong impact in the LNG price offered to final consumers, affecting the project's cost effectiveness or its competitiveness against the competing fuels.
- Taxation: The taxation of LNG affects its cost-effectiveness and competitiveness against other fuels. For example, in USA LNG is being taxed by volume instead of its energy content, which leads to an overtaxation in comparison to diesel.
- Network coverage: In countries with dense gas network, most of the large end-users, which could be supplied with LNG virtual pipelines, are already receiving piped gas. As a result, large scale applications are expected in regions which are lacking network coverage.
- Profile of the consumers: The demand, location and consumption profile (e.g. seasonal or continuous) directly affect the deployment of the LNG virtual pipelines, particularly related to the loading of trucks required and the potential need for construction of local networks.
- Availability of infrastructure: The operation of truck loading facilities and the LNG terminals (or bunkering facilities for sea transportation of LNG) is essential for the development of the virtual pipelines. There are cases of LNG terminals where the cost for the development of such facilities is large (e.g. due to the need of large upgrades or site preparation at the terminal or lack of storage capacity) or not technically viable (e.g. FSRUs). The need for suitable roads from the LNG terminal up to the main road network of the country is also

significant and may incur large costs for the development of the virtual pipeline if road works are required.

- LNG filling stations: The supply of LNG filling stations requires the development of LNG virtual pipelines. Therefore the two types of infrastructure should be developed together.
- Safety regulations for road and marine transport: Any limitations imposed by the national legislation in the weight of cargo transported by trucks have a strong impact in the LNG volumes that can be transported by a truck. Taking into consideration the energy content of LNG, any reduction of the transported volumes would affect significantly the economics of the project. Regulations specifically related to the transportation of LNG with trucks and vessels will have to be in place to facilitate the operation of the virtual pipeline.
- Clarity of regulatory framework: Regulatory issues, such as licencing and third party access, will have to be clear, so potential investors are not disincentivised to participate in the market. The regulatory issues are discussed in detail in Chapter 5.

3.2 Use of gas as a fuel in land transport

3.2.1 Introduction

Natural gas has been considered a fuel in the automotive industry since the 1930s. Petrol (gasoline) and automotive diesel were however eventually established as the two dominant fuels for road transport, using internal combustion engines. The current price of natural gas, which competes favourably to those of oil products, and the policies of the EU to reduce drastically air pollution by road vehicles have resulted to gas gaining significant ground as an alternative fuel option, alongside other options (Electric Vehicles (EVs), hybrid EVs, biofuels and hydrogen fuel cells).

Natural gas can be stored in a vehicle in either compressed or liquefied form. The choice of storage depends mainly on the vehicle usage and location of operation. Each form of storage has its advantages and disadvantages:

- CNG is more easily available, especially in urban areas, as it can by supplied to filling stations connected to the gas transmission and distribution network. In contrast, supply of LNG requires a virtual pipeline, which is economical at a certain distance from LNG terminals; as a result, LNG filling stations are more expensive and much more scarce than CNG ones. Thus, CNG is preferable for vehicles moving exclusively or mostly within a city or other limited areas.
- On the other hand, LNG, being liquid, has a density that is triple that of CNG, i.e. it contains in the same volume three times as much gas as CNG; as a result, it offers higher autonomy, which is especially important for vehicles covering long distances, such as trucks.
- Another disadvantage of LNG is the so-called “boil-off”: LNG is supplied to the vehicle as a fuel at -162°C and is stored in insulated tanks carried by the vehicle. As the temperature in the tanks gradually increases above -162°C, part of the liquid is vaporised and the two phases (liquid and vapour) are at equilibrium. As long as LNG is consumed in the vehicle’s engine, LNG vaporisation absorbs heat and keeps the temperature low and the LNG’s vapour pressure at acceptably low levels. If the vehicle engine remains out of operation for a significant time (a few days) then the vapour pressure in the LNG tank increases and, as a

result, part of the fuel is lost in the atmosphere; this is undesirable both because the fuel is lost and because of its climate change impact, as methane (which makes most of the NG) is a greenhouse gas much more potent than CO_2. Consequently, LNG cars should not remain idle for a long time or, if they do in exceptional cases, they must empty their fuel.

Gas is utilised in either dedicated natural gas engines or dual-fuel engines, which originally burned petrol or diesel. In the past drivers had to retrofit their vehicles in order to burn natural gas (CNG or LNG). Today some vehicle manufacturers offer new standard dual-fuel models.

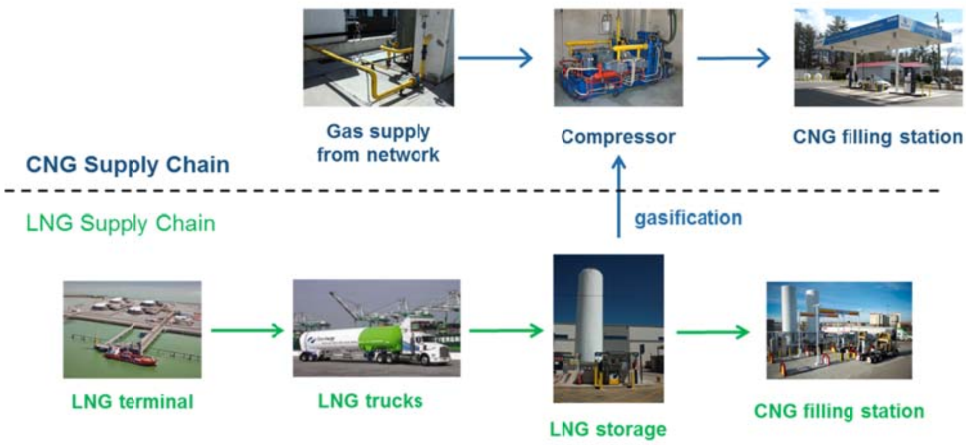
In this study the road vehicles are distinguished into two market sections:

- Light Duty Vehicles (LDVs): These include cars and other vehicles of net weight under 3.5 tonnes. LDVs include most buses.
- Heavy Duty Vehicles (HDVs): These include vehicles of net weight over 3.5 tonnes, which are generally known as “trucks”.

Given the comparative merits of CNG and LNG discussed above, CNG is the storage form of choice for LDVs. On the other hand, HDVs mostly use gas in the form of LNG, although there are also cases of HDVs using CNG, especially buses and trucks moving exclusively within the confines of a city (e.g. delivery trucks and garbage collection trucks).

The supply chain of both CNG and LNG for road transport is presented schematically in the following Figure 12.

Figure 12: Supply chain for CNG and LNG for road transport



3.2.2 Light Duty Vehicles

The establishment of CNG as a significant alternative fuel for cars and LDVs requires a dedicated supply chain for CNG, as the existing refuelling stations are not able to accommodate CNG vehicles. The CNG refuelling stations require either a direct connection to the gas (transmission or distribution) network or delivery of CNG containers through virtual pipelines if a connection is not available.

Technology considerations for CNG vehicles and filling stations

CNG Vehicles

Petrol and diesel internal combustion engines are able to burn natural gas (i.e. dual-fuel engines), provided that specialised parts are added to the vehicle's engine system. In both configurations the driver is able to switch between fuels at any time.

Natural gas requires a spark plug so as to be ignited inside the engine's cylinder. Petrol engines, that are already equipped with spark ignition, only require the addition of a new fuelling pipeline and fuel management system. In diesel engines, which use compression ignition without spark plugs, the lack of spark ignition is compensated with the addition of a small share of diesel in the fuel mix, so that the natural gas is ignited. Thus the diesel acts as a "virtual spark plug" for the gas.

CNG is stored in tanks. For cars the CNG tanks have usually a capacity of 60 lt, which offers an autonomy of approximately 200 km. For larger vehicles larger tanks are used. For example, urban buses may use 6-8 tanks of 180 lt capacity. The tanks are located either in the visible or in the hidden storage areas of the vehicle or on the roof in the case of buses. There are different technologies regarding the material from which the tanks are built. Technical characteristics have improved over the years to accommodate the need of lightness and durability. Older tanks used metal, simple or covered by some protective material, whilst newer technologies use tanks of hard plastic material, covered by a mixture of glass carbon fibre. The latter tanks are much lighter but also considerably more expensive.

The investment cost for retrofitting a car with dual-fuel engine in the EU is on average 2,000-2,500 €.

Alternatively, new dual-fuel vehicles are also on offer. Car manufacturers that currently offer dual-fuel models in Europe are Fiat, Opel, VW, Audi and Mercedes. Bus manufacturers include MAN, Scania, Mercedes, Solbus and IVECO. The cost of a new dual-fuel model is also typically about 2,000-2,500 € more expensive than the respective single fuel (petrol or diesel) model.

Filling stations

There are two types of technology applications for CNG filling stations, depending on the process of storing and handling the fuel:

- CNG-only filling stations: These are dedicated to refuelling only CNG vehicles (not LNG ones) and are usually directly connected to the gas network. Stations are equipped with compressors that compress natural gas to 200-250 bar and then pressurised dispensers fill the vehicle tanks.
- L-CNG filling stations: These are equipped with an LNG storage tank, which supplies the required gas volumes. The tank is supplied through an LNG virtual pipeline. There is also a facility that allows the LNG to vaporise before passing through a compressor, which compresses it to the required 200-250 bar. As a rule, such filling stations provide also LNG to LNG-powered vehicles and are usually – though not always – located in areas that are not connected to the gas network, often along the highways, to serve trucks.

The investment required for the construction of a CNG-only filling station is currently 400-500,000 €, which is several times higher than that of a filling station for conventional liquid fuels. The investment cost of an L-CNG station is about twice as much, 800,000-1,000,000 €.

Table 8 below presents the indicative capital and operating expenses for different types of CNG and LNG filling stations, as a function of its supply capacity.

Table 8: Indicative costs of CNG filling stations (Source: Oxford Institute for Energy Studies)

	CNG station		*LNG station*		*L-CNG station*	
Size (kg/d)	CAPEX ('000 €)	OPEX (€/MWh)	CAPEX ('000 €)	OPEX (€/MWh)	CAPEX ('000 €)	OPEX (€/MWh)
500	200	21	90	13.1	190	21
1,000	250	12.3	120	7.9	250	12.3
5,000	440	7.1	330	2.7	630	10.4
10,000	880	6	440	2.7	1000	7.9

In addition to CNG and CNG/LNG stations there are available compressors, which allow filling at one's own premises (e.g. at home or work). Such systems are on sale in the USA and the UK.

As regards the speed of filling with CNG, there are two types of filling stations, fast filling and slow filling (or time filling). Fast filling is usually applied at public CNG stations, where light-duty vehicles (cars, vans, pickups etc.) arrive randomly and need to fill up quickly. In fast-fill stations the CNG produced from the compressor is stored in a series of storage vessels, so that the fuel is ready to go for a quick fill-up. The time for fast-filling is generally less than 5 minutes, comparable to that of petrol. There is a penalty to fast filling, however, as the compression heats up the tank and reduces its capacity by as much as 30%. Time-fill stations are used primarily by fleets and work well for vehicles with large tanks that refuel at a central location every night. At a time-fill station, contrary to fast-fill stations, vehicles are filled directly from the compressor, not from fuel stored in tanks. The time it takes to fuel a vehicle depends on the number of vehicles, compressor size and the amount of buffer storage, and ranges from several minutes to several hours. The advantage of time-fill is that the heat of recompression is less so a fuller fill is obtained than with fast-fill. In addition, one can take advantage of lower electricity prices to run the compressor, for example at off-peak hours at night.

Application of CNG vehicles worldwide and in the EU

There are currently around 17.73 million NGVs worldwide, 92% of which are LDVs. 79% of the worldwide fleet is concentrated in just 7 countries (Table 9), with Iran being the world leader in the use of NGVs, followed by Pakistan and Argentina, while China is an emerging market for NGVs with the most extensive infrastructure worldwide already in place. The only EU country (in fact the only OECD country) in the list is Italy (about 5% of the world's fleet), which has a long history of use of CNG cars and where incentives promoting the use of natural gas in the transportation sector have long been applied.

Table 9: NGVs worldwide and in the main EU countries

Country	Total NGV population (road transport only)			No. of filling stations		
	Total NGVs	% of total vehicles in the country	% of total NGVs worldwide	CNG stations	L-CNG stations	LNG stations
Iran	3,300,000	27.09%	18.61%	1,992	0	0
Pakistan	2,790,000	79.67%	15.74%	2,997	0	0
Argentina	2,244,346	17.53%	12.66%	1,916	0	0
Brazil	1,743,992	4.97%	9.84%	1,793	0	0
China	1,577,000	1.53%	8.89%	3,350	400	1,330
India	1,500,000	3.53%	8.46%	724	0	0
Italy	846,523	2.07%	4.77%	959	7	0
…………………………	…………	……….	………..	……….	……..	……..
USA	250,000	0.10%	1.41%	1,438	0	46
Germany	96,349	0.20%	0.54%	915	0	0
Bulgaria	61,270	1.83%	0.35%	106	0	0
…………………………	…………	……….	………..	……….	……..	……..
Total EU	**1,098,902**	**0.40%**	**6.20%**	**2,969**	**34**	**43**
Total World	**17,730,433**	**1.64%**		**22,162**	**441**	**1433**

Europe has been experiencing a significantly slower growth rate in NGVs from 2001 to 2011 compared to Latin America and Asia Pacific, but higher than North America. Penetration of CNG in the transport sector of the EU is limited, as only 0.42% of the cars and LDVs are NGVs. Italy and Bulgaria are the Member States with the highest penetration of NGVs (2.1% and 1.8% of the total vehicle population respectively). In absolute numbers Italy and Germany (with 96,000 cars and 0.20% penetration) have the most NGVs in the EU.

The European NGV industry has already invested around € 2 billion to create a network of refuelling stations for NGVs. Italy and Germany have by far the most CNG filling stations in the EU (Figure 13). However, in most EU Member States the number of NGVs per filling station remains very low (Figure 14), denoting the limited penetration of natural gas in road vehicles. The comparison of Italy with Germany is especially telling in this regard; although the two countries have about the same number of CNG filling stations, the number of NGVs (mainly CNG cars in both countries) in Italy is 9 times as much as in Germany. For comparison purposes, the average number of vehicles per conventional (petrol & diesel) filling station in the EU is about 2,500.

The network of L-CNG filling stations remains very limited in the EU. Spain (12 stations) and the UK (9 stations) have the most facilities in Europe.

Figure 13: Number of CNG-fuelled NGVs and CNG filling stations in the EU (Source: NGVA Europe)

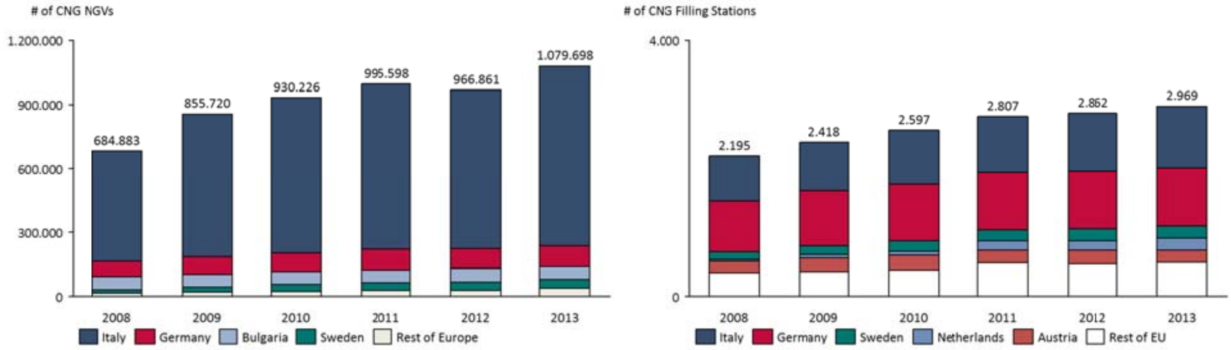
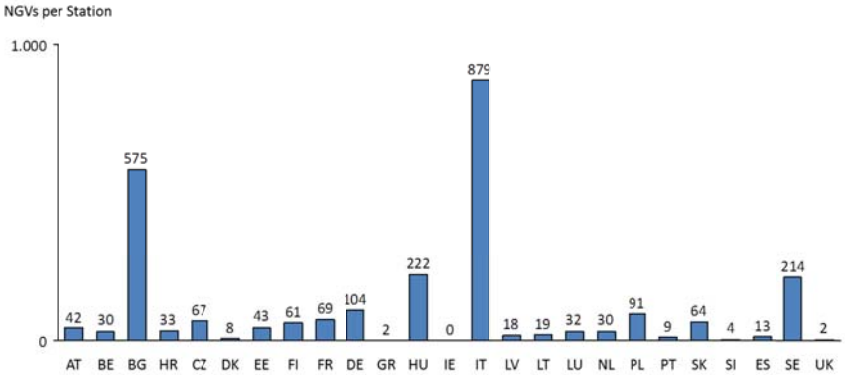


Figure 14: Number of NGVs per CNG filling station in the EU (Source: NGVA Europe)



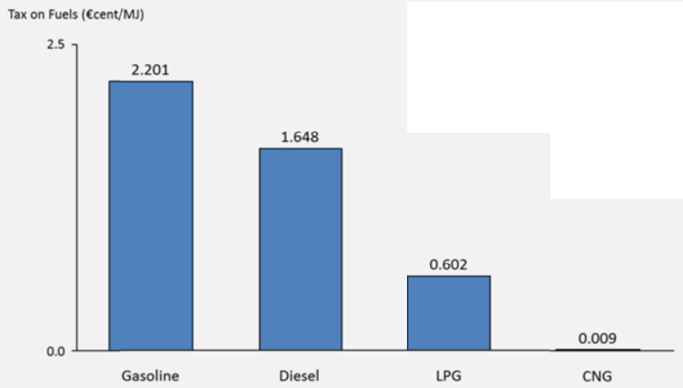
In regard to buses, there is a total fleet of 748,000 vehicles in the EU of which 1.76% is being powered by natural gas. Urban buses are a prime market for CNG, because they have generally a small area of operation and they return to the depot area daily, so they are not dependent on public refuelling infrastructure and can be served by private infrastructure inside their depots. Consequently, use of CNG in buses has seen substantial growth in many EU cities, driven by city initiatives to use cleaner fuels. The same is true for garbage collecting vehicles. An additional benefit for both types of vehicles is the lower level of noise that they emit and lower vibration, which are appreciated by both drivers and passengers. An inhibiting factor for the wider use of CNG is the 15-20% price premium for CNG powered buses and longer refuelling time (15 min vs. 3 minutes for liquid fuel).

Case Study: Use of gas in the transport sector of Italy

NGVs have had a strong presence in Italy for the past 30-40 years due to the very active retrofit conversion industry in the 1970s and 1980s. An additional boost came in the 1990s, when popular small and medium-sized vehicles became available as ex-factory CNG conversions.

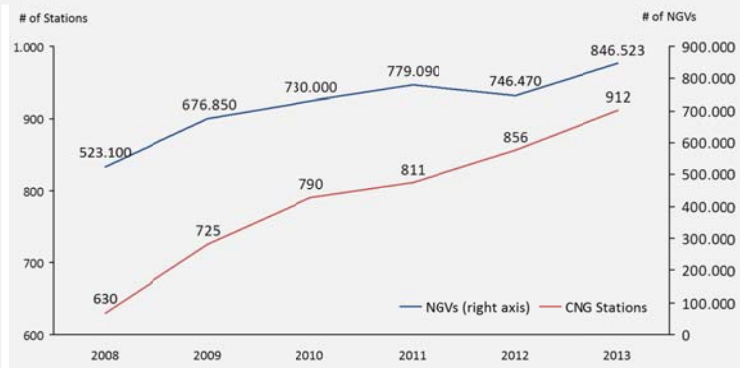
According to NGVA Europe, Italy has the largest fleet of NGVs in Europe reaching 850,000 (77% of Europe's fleet) with 912 public CNG filling stations (2013). This is a direct result of the government's promoted conversion programme through which 24.8 million € became available in the form of subsidies and were provided for retrofits at specialised workshops or purchase of NGVs from car dealers. The financial incentives ranged from 650 € to 2,400 € per vehicle depending on its type. An additional incentive is the favourable taxation of CNG, compared to gasoline, on which the tax is among the highest in the EU. This differential in taxation allows increased cost saving on fuel consumption when using NGVs. The taxation of fuels in Italy is presented in the figure below.

Figure 15: Fuel taxation in Italy (Source: NGVA Europe)



The specific programme for the period 2008-2013 resulted in a 62% increase of NGVs and 45% increase in stations, as shown in the figure below.

Figure 16: Number of NGVs and filling stations in Italy (Source: NGVA Europe)



Large vehicle manufacturers in Italy have adapted to the users' changing demand. For instance, Fiat offers several models with dual-fuel engines without the requirement of any retrofit. However, the scaling back of incentives in 2010 and the uneven distribution of filling stations within the country has stalled further expansion of NGVs.

The main operator of CNG filling stations is Metano, a subsidiary of ENI. Associations also exist, such as Federmetano, which promote cooperation of the owners of stations that distribute natural gas for automotive use.

In regards to LNG, there are a small number of filling stations in Italy (only 7 in 2013), as currently there are no truck loading facilities at Italy's LNG import terminals and the stations are supplied with LNG from other countries (mainly Spain). As a result, HDVs using LNG are very few, and the penetration of natural gas in the transport sector is limited to LDVs.

Case Study: Use of CNG in Madrid's urban service vehicles

The city of Madrid is a pioneer in the use of natural gas (CNG) as a fuel for urban service vehicles. In the early 90s the Madrid Municipality defined as a priority a severe reduction in exhaust emissions of the vehicles carrying out the municipal services, including passenger transport, cleaning services, waste collection and other. The target was to reduce these emissions much more than the near future legal homologation limits. Moreover, Madrid's Municipal Policy already in that time was to be in the forefront of innovative and alternative technologies regarding urban transport fuels and tractions.

Waste collection fleet running on CNG

Madrid, as most large Spanish cities, contracts refuse collection service to private companies. The use of CNG in waste collection trucks started in 1993 and its development is the result of a four-party cooperation, involving the City of Madrid, the waste collection company FCC (which has won most of the tenders for waste collection in the last 20 years), the truck manufacturer IVECO and Gas Natural Fenosa, the largest Spanish gas provider.

In a joint effort that started in 1993, the IVECO 240E26 6x2 RSU CNG (EEV), an innovative 3 axle truck with CNG engine, was developed. After a four year period of intensive testing with two prototypes (including the vehicle itself but also regarding the filling station, driver acceptance, maintenance and mechanics training) a scale-up took place in 2000, with the introduction of 40 CNG waste collection trucks. After successful large-scale operation, the City of Madrid decided that the entire waste collection fleet had to be eventually operated in CNG. In 2003 FCC purchased 266 IVECO trucks as part of its fleet renewal, thereby completely switching the fleet to natural gas. Today the company operates its entire fleet of 468 trucks on CNG. The total annual gas consumption of CNG is in excess of 10 mcm.

Residents of the Spanish capital benefit from cleaner air, as black smoke has been completely eliminated, and reduced noise levels. The IVECO truck achieved a reduction in emission of 1.5 tons of NOx and some 2 tons of CO_2 annually, compared to Euro 3 diesel trucks and their respective emission levels at the time the gas trucks started operating. In addition, the utilisation of gas-powered vehicles produces significant savings in fuel cost. Although cost data are not published, it is estimated that the fuel bill is 30% lower compared with diesel operated trucks, whilst the total costs during the complete truck life, including all the investments for the gas compression station and the trucks chassis extra cost, are still about 15 % lower than in the case of diesel.

Municipal bus fleet partly running on CNG

The company responsible for Madrid's municipal transport is Empresa Municipal de Transportes (EMT). EMT services 427 million passengers per year with its 216 transit lines. It operates a fleet of 2000 vehicles, out of which 791 buses (40%) currently run on CNG. From 2005 to 2014 the number of EMT's gas-powered vehicles increased almost five-fold from 165 to 791 units. The total annual gas consumption exceeds 20 mcm. In line with the Madrid City's vision and policies, EMT has decided to further increase the share of NGVs.

EMT's fleet includes 23 hybrid vehicles that are powered by CNG and electricity. Currently unique in

Europe, these buses were produced by two Spanish manufacturers according to EMT's specifications and 13 out of 23 are plug-in units able to run 45 minutes in pure electrical mode, which is useful when operating in Madrid's city centre. Apart from new CNG buses, EMT has three dual-fuel buses, developed in 2013 by converting conventional buses to dual-fuel operation (diesel and CNG). These retrofitted vehicles are able to utilise both fuels simultaneously in the combustion process, with CNG reaching up to 50% in the mix.

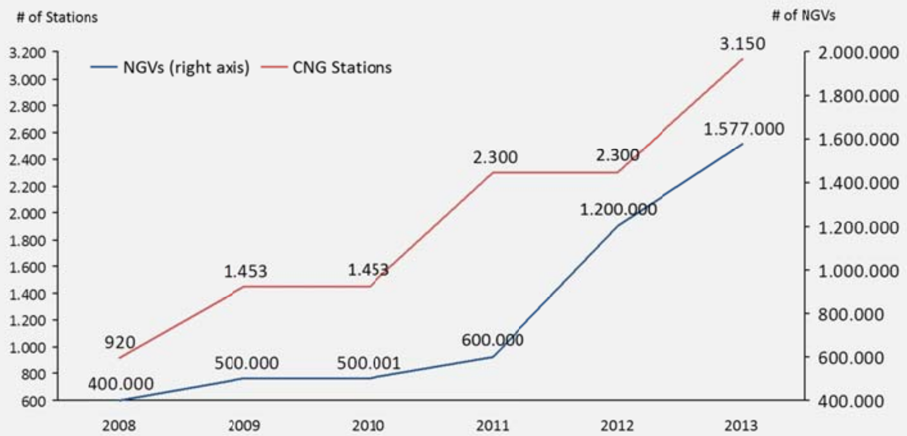
To service the needs of the buses, EMT has built and operates the largest CNG bus refuelling facility in Europe, at Sanchinarro, Madrid, which currently serves as a depot and refuelling station for 372 CNG buses.

Case Study: Use of gas in the transport sector of China

China has shown interest in the NGVs applications since the 1950s, when it initiated R&D programmes. In the end of the 1980s the technology reached an adequate maturity and companies initiated imports of retrofit equipment for vehicles and filling stations. The use of natural gas in the transport sector had a slow growth over the years, even though vehicle manufacturers introduced cars and other LDVs powered by CNG in the market. As the adoption rate of consumers was low, the vast majority of NGVs were introduced by the Government in the public buses and taxi companies. The two main drivers for the use of NGVs have been economic advantage of substituting petrol and diesel with natural gas and the reduction of air pollution.

NGVs in public transportation are now present in more than 100 cities among 31 provinces. In some cases 95% of the fleet of taxis and buses are powered by CNG. During the period 2008-2013 the number of NGVs and stations soared, increasing by 294% and 242% respectively. As a result China’s share in the world fleet of NGVs was propelled to 8.89% in 2013. That significant increase was mainly due to the introduction of the “12th Five –Year Plan for Transportation”, which promotes reduction of emissions and energy saving.

Figure 17: NGVs and filling stations in China (Source: NGVA Europe)



As a result, China has today (2013) the largest number of both CNG and LNG stations in the world. Its 3350 CNG stations are 15% of the world total, while its 1730 LNG stations are an impressive 92% of the world total. Moreover, models of new LNG or dual-fuel trucks are on offer by Chinese manufacturers.

China's target is to have 5% of its vehicle fleet running on clean fuel by 2020. The concern however lies on the availability of the required infrastructure for further growth. Due to the growing urbanisation of recent years, there is lack of land to build filling stations in some big cities and developers are considering dual-fuel stations to accommodate the growing demand.

Environmental performance

Energy efficiency standards and emission limits generally favour CNG vehicles over gasoline and diesel ones. CNG has a high hydrogen to carbon ratio which presents the potential of 20-30% tailpipe reduction in CO_2 emissions, relative to gasoline for passenger cars. If one considers the well-to-wheel (WTW) cycle, the reduction in greenhouse gases (GHG) relative to petrol engines is only 6-11%, due to methane leaks during production. In the EU, cars manufacturers are obliged to ensure that their new car fleet does not emit more than an average of 130 g CO_2/km by 2015 and 95 g by 2020. This compares with an average of almost 160 g in 2007 and 135.7 g in 2011. Standards for heavier vehicles are more permissive.

In the US emission standards for new vehicle fleets are slightly less stringent. They are expected to result in levels of 101 g CO_2 /km in reference year 2025. (This would require a consumption of 4.3 lt/100km if achieved exclusively through fuel economy improvements.) Today's CNG engines combined with hybrid technology could probably meet these future GHG emission standards.

Figure 18: WTW GHG emissions for energy forms used in transport (Source IVECO)

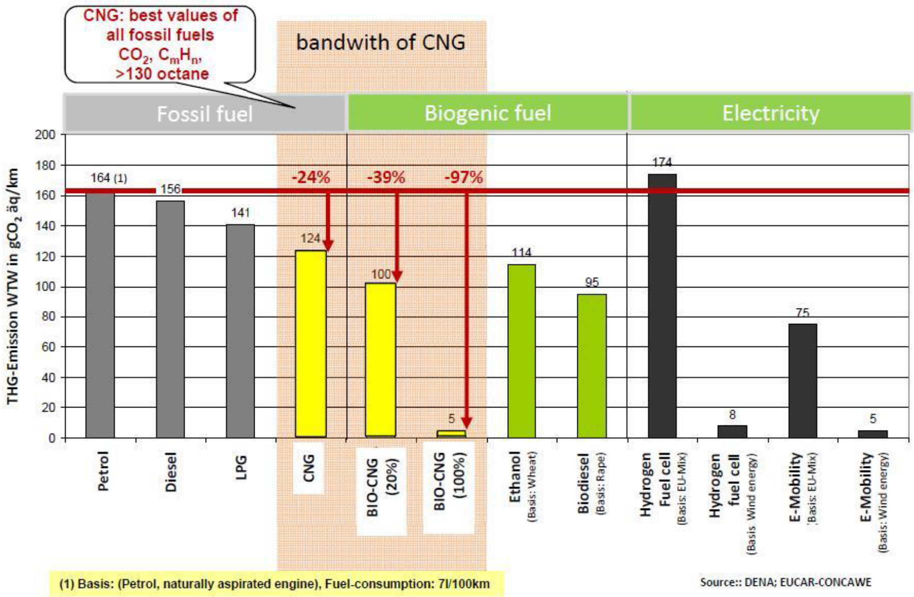


Figure 18 compares the performance of Well-to-Wheel (WTW) total GHG emissions for different types of fuels. It is clear that natural gas (CNG) has the best performance among all fossil fuels. In addition, bio-CNG (including 20% biogas) has a performance comparable to that of biodiesel and ethanol, whilst avoiding the controversy relating to the production of those biofuels. It is interesting, however, that EVs have a superior performance as regards GHG emissions, even if the electricity is based on the basic EU-mix.

Emission standards also concern regional pollutants such as NOx, SOx, and local pollutants such as particulate matter (PM), carbon monoxide (CO) and various volatile organic compounds (VOCs). In the US, upcoming Tier 3 standards, to be in effect in 2017, emphasise reduction in SOx emissions, an area in which existing CNG engines are superior. Although Tier 3 standards relevant to CNG engines are not finalised at this time, it is clear that CNG vehicles will easily meet the general sulphur emission limits, giving CNG engines an advantage over gasoline and diesel. In the EU, the passage from Euro-V to Euro-VI emission standards, taking effect in September 2014, emphasises reduction in NOx, a pollutant mainly associated with current diesel engines, which is to be reduced from 2 g/kWh to 0.4 g/kWh. The new NOx standards require adaptation of the combustion system as well as extensive adjustments to the exhaust gas after-treatment system.

3.2.3 Heavy Duty Vehicles

The supply chain of LNG used in transport has an important difference from the CNG one; the stations do not require a direct connection to the natural gas network, as the capital and operating expenses to liquefy the gas locally would lead to very high costs. Instead, LNG is transported to the filling stations using virtual pipelines. Natural gas is either liquefied in local facilities or, more commonly in Europe, is directly imported in liquid form and stored in LNG terminals.

LNG is preferred to CNG in heavy duty NGVs (trucks), as it provides higher autonomy for the large distances travelled by HDVs.

Description of the technology applied

LNG vehicles

The major difference in the LNG technology applied in vehicles, in comparison with CNG-fuelled ones, lies in the process of using the LNG, due to its liquid state at -162°C. During transportation and storage, specialised insulated tanks are installed in the NGV, along with specialised fuel dispensers. In terms of burning LNG, the process is identical to CNG, with the difference that the fuel is transformed from liquid to gaseous state before being introduced into the combustion chamber.

In dual-fuel vehicles (trucks), the LNG storage tanks on board of the vehicle are additional to the diesel tanks and have a capacity of 620 lt, which provide autonomy of approximately 600 km.

As in the case of LGVs, it is possible both to retrofit a truck and to procure a new one, from some manufacturers. It is estimated that a new truck costs approximately 20,000-40,000 € more than its diesel counterpart, with the higher value relevant to heavier trucks. The main manufacturers in the European market are IVECO, Scania and Mercedes. Models include both dual-fuel and single fuel (LNG-only) engines. Single-fuel engines have superior performance (and fuel efficiency), because the compression ratio is optimised for natural gas, rather than a mixture of gas and diesel.

It is interesting to note that the range of LNG trucks available at the EU market stops at a power of 330 HP and does not include the heaviest trucks (450 HP), although such trucks are available in the USA and China. This is due to several reasons, including low/uncertain demand combined with high R&D costs, and technical problems with the engine design. From preliminary information from the industry, it appears that combustion efficiency is very sensitive to the composition of natural gas (good efficiency requires a very high methane content) and the engines are thus difficult to certify by the Euro-VI standards. The industry is currently conducting R&D on such models and it is likely that, if demand prospects are good, such models will appear on the market in 2016-17.

LNG filling stations

LNG filling stations are dedicated to providing LNG to trucks, while L-CNG stations, described above offer both LNG and CNG, by transforming LNG to CNG on the spot. The equipment installed in the stations includes LNG storage facilities and a specialised pumping and piping system used to dispense LNG into NGVs. As shown in Table 8, the CAPEX of L-CNG stations is more than double that of an LNG-only station, due to the expensive gasification equipment and compressor that the L-CNG station requires.

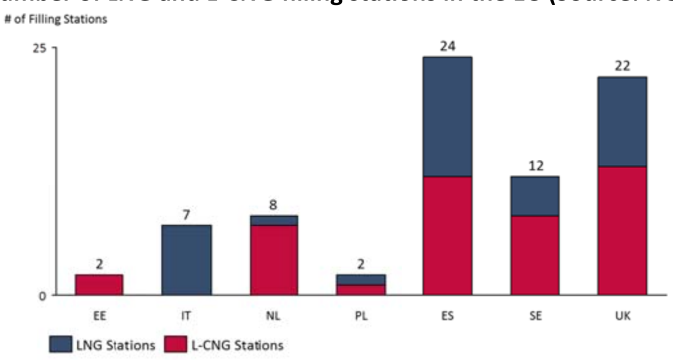
The stations are refuelled by LNG trucks and are able to accommodate 40-50 vehicles per hour. The refuelling rate is similar to that for conventional liquid fuels but refuelling requires special training by the operator.

Application of LNG vehicles worldwide and in the EU

According to NGVA 2013 data[3], there are only 368,000 natural gas trucks worldwide (medium and heavy duty). Out of these, 346,000 are concentrated in just 7 countries (in descending order): Ukraine, China, Thailand, Armenia, Bangladesh, Japan and Russia. In the USA there are 4,000 gas trucks. In EU-28 there are about 5,500 trucks, of which 3,500 are registered in just three countries, Spain, Italy and France. The total number of gas trucks in the EU is an insignificant percentage (0.04%) of the 13.5 million HDVs registered in the Union.

According to the same NGVA data, there were 1874 LNG stations worldwide in 2013, out of which 1730 in China. In the USA there are 46 LNG stations, all of them LNG-only. In EU-27 there are 77 LNG stations, of which 43 are LNG-only and 34 are L-CNG. As shown in Figure 4, the stations are located in 7 countries, with the great majority being in Spain (24), the UK (22) and Sweden (12). It is notable that in 2013 there were no LNG stations in Germany and France. In France the first LNG station opened in September 2014, but it is dedicated to a single company, not a public one.

Figure 19: Number of LNG and L-CNG filling stations in the EU (Source: NGVA Europe)



[3] The data do not specify whether the trucks run on LNG or CNG, so it is logical to assume that the numbers for LNG trucks are smaller. In particular, it is not reasonable to assume that there is a significant number of LNG trucks in France, as there were no LNG stations at the end of 2013.

A large part of transportation of goods in Europe is interstate, so trucks registered essentially anywhere in the EU are expected to travel throughout the EU. The uneven distribution of LNG stations in the EU, and especially the lack of stations in France and Germany, is an important barrier to the growth of LNG trucks.

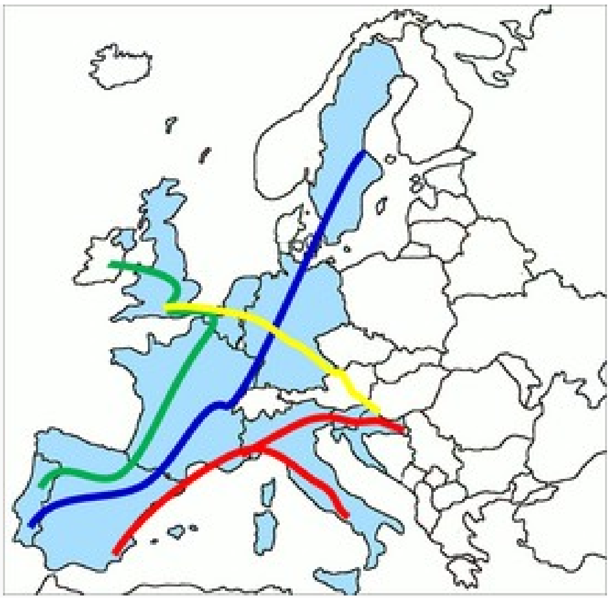
It should be noted here that, apart from transportation trucks, LNG can be used in agricultural and mining machineries. In these cases, virtual pipelines are used to supply LNG to the equipment.

The Blue Corridors Project

The LNG Blue Corridors project seeks to contribute to overcoming the uneven availability of LNG stations, by coordinating and mobilising the joint expertise of key market actors in LNG transport and infrastructure technology. It aspires to represent the first phase in the roll out of LNG refuelling stations and a broad market development for heavy duty vehicles running with LNG. To this aim, the project brings together 27 partners from 11 member states, HDV manufacturers, gas suppliers, gas distributors and fleet operators, and coordinates their cooperation. The project was launched in May 2013 and is expected to run for 4 years. Its aim is to demonstrate operation of four LNG “Blue Corridors”, connecting 12 member states (Figure 20). This includes building 14 new LNG or L-CNG stations and establishing a fleet of about 100 LNG Heavy Duty Vehicles which will operate along these corridors. The project involves total investments amounting to 14.33 mil. € and financed by the EU Seventh Framework Programme (FP7) with the amount of 7.96 mil. €.

So far three refuelling stations have already been built, in Piacenza (Emilia-Romagna, Italy), Örebro, (Sweden) and Kallo (Belgium, in the Port of Antwerp). The next 7 stations, which have been approved by the Member States, are expected to be built in Malaga (Spain), Lisbon (Portugal), Lyon (France), Paris (France), Porto (Portugal), Jesenice (Slovenia) and Brussels (Belgium).

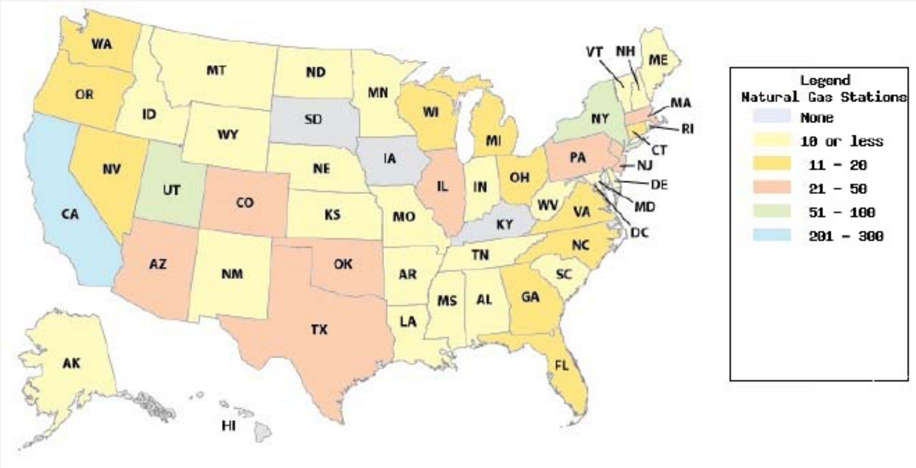
Figure 20: Map of the LNG Blue Corridors



Case Study: Use of gas in the transport sector of USA

The penetration of NGVs in the transport sector of the USA is limited at the moment, as in 2013 the USA had only 1.41% of the world's fleet of NGVs, of which CNG-powered LDVs were only 231,400. Moreover, the number of filling stations was disproportionate to the country's size and fuel consumption. Public CNG stations were 535 and private ones were almost double, both summing to 903 in total. Hence, NGVs were utilised more by organisations that possess large fleets of vehicles that return to depot centres, such as courier companies, municipality vehicles and school buses. The following map demonstrates the availability of CNG filling stations in USA.

Figure 21: CNG filling stations in USA (Source: Argonne)



The use of LNG in transport is also small. In 2013 only 46 public LNG stations were operational, servicing the 18,600 MDVs and HDVs. The total number of LNG stations, taking also into consideration the private facilities, summed close to 100. As in the case of CNG, private users accounted for the largest percentage of usage.

Even though the number of HDVs and filling stations is very limited and geographically confined (over 70% are registered in the State of California), the significantly low price of LNG along with the feasible exploitation of shale gas reserves and plans of expanding the station network, establishes a promising future for the use of LNG in long-haul driving.

The development of the LNG refuelling network requires detailed planning for positioning stations along highways, establishing regulations for inter-state transportation of LNG using virtual pipelines to refuel the stations and harmonise technical standards and specifications for safety and equipment, concerning both HDVs and filling stations.

3.2.4 Economics of Natural Gas Vehicles

The economics of CNG and LNG filling stations have been discussed above. This section discusses the economics of CNG and LNG vehicles.

As stated above, the retrofitting of an existing CNG or LNG vehicle requires an initial investment. Likewise, the purchase of a new CNG or LNG vehicle involves an extra cost over the investment made on the corresponding petrol or diesel model. In both cases, the investment is expected to be paid back through the saving achieved by using gas (CNG or LNG) in place of oil derivatives (petrol or diesel). Clearly, the economic feasibility (attractiveness) of this additional or incremental investment hinges on the interplay of three parameters:

a. The initial or incremental investment: For a new model, the incremental investment depends on the size and model of the vehicle and is the same everywhere. For retrofitting, however, the initial investment varies around the world and seems to be cheaper in countries with lower income and lower environmental standards. For example, the cost of retrofitting of a new car is about 2,000 € in Spain or Germany but is reported to be about 300 $ in Pakistan. Such a large difference may have a strong impact on the attractiveness of switching to gas.
b. The price differential between gas and the fuel it replaces: This differential varies considerably from EU country to EU country, as it is strongly influenced by taxation policies. It also has the potential to change in the course of time, as prices of oil and gas change, while taxation can also be adapted to new policies and conditions.
c. The intensity of utilisation of the vehicle (km/year), which may change notably from case to case, depending of the use the vehicle is put to.

Consequently, prospective buyers/investors have to examine carefully the attractiveness of the investment for their own case. A number of indicative examples follow.

<u>CNG vehicles</u>

The Oxford Institute for Energy Studies has provided an analysis of CNG-fuelled vehicles by examining the investment costs and depreciation for models of Mercedes B200 and VW Golf powered by CNG and diesel. The manufacturers' list price for the CNG-fuelled models was 2,000 € higher for both cars. The calculations, based on fuel prices in Germany and assuming an annual usage of 20,000 km, concluded that the simple (undiscounted) payback time for the incremental investment would be 3 years for the Mercedes and 6.7 years for the VW model. For an annual usage of 30,000 km the respective payback times are 2 years and 4.5 years.

An alternative example is presented below, based on the fuel prices recorded on the same day (20/9/2014) at a particular filling station in Athens, Greece (which sells petrol, diesel, LPG and CNG). The example is based in the following assumptions:

Petrol-fuelled car with a retrofitting cost of 2000 €

Fuel consumption (petrol): 6 lt/100 km

CNG consumption: 7% higher than the equivalent petrol amount (in terms of energy content)

Cost of fuels: Petrol: 1.624 €/lt; CNG: 0.963 €/kg

Properties of petrol: Density: 750 kg/m^3; Calorific value (GCV): 45.7 MJ/kg

Properties of gas (normal conditions): Density: 0.78 kg/m^3; Calorific value (GCV): 38 MJ/m^3

Calculations demonstrate an economy of 0.9 €/lt of petrol equivalent. This means that the initial investment will be paid back when 2225 lt petrol equivalent are consumed, which corresponds to about 37,000 km. If the car utilisation is 12,000 km/yr, the payback period is 3 years. It is clear that more intensive utilisation of the car leads to shorter payback periods. For example, for a taxi driving 40,000 km/yr or more, the payback period is under one year. This indicates that urban taxis are a prime target for conversion to CNG dual vehicles, provided that there exist a sufficient number of CNG refilling stations appropriately distributed within the taxi's area of operation.

It is also noted that the payback period is considerably lower than in the German example. This is due to the higher price differential in Greece, compared with Germany. The price differential is largely affected by (comparative) taxation of motor fuels. This partly explains why CNG vehicles are most in use in Italy, which has one of the highest taxes on petrol in the EU.

To demonstrate the effect of taxation, the same example is considered, assuming that the tax on CNG is increased by 8.1 €/GJ, while tax on petrol remains constant. This scenario is in accordance with the minimum taxation suggested in the fuel taxation Directive proposal, issued by the EC in 2011. Assuming further that this increase passes directly to the CNG price (no price policy change by the gas supplier), the resulting new price of CNG is 1.36 €/kg. The same calculations result in a payback period of about 4.5 years, which is a significant deterioration (50% increase) compared to the initial 3 years. The effect of taxation on attractiveness of switch is even more adverse for smaller price differentials.

LNG trucks

The Oxford Institute for Energy Studies provides a breakeven analysis of LNG-fuelled HDVs. It was assumed that the dual fuel truck had an incremental capital cost of 50,000 € and incremental maintenance costs of 5,000 €/yr over its diesel equivalent. It was further assumed that the truck uses 75% LNG and 25% diesel for an annual travelled distance of 100,000 km. Under those assumptions, the payback period was found be 8.3 years, provided that the price of LNG would be 35% lower compared to diesel. If the truck used 100% LNG, the corresponding payback period was 5.5 years.

The example presented here has some slight changes in the assumptions, to adjust to values that are closer to reality. The assumptions are the following:

Dual-fuel truck capital cost: 40,000 € more than diesel equivalent

Incremental maintenance costs: 4,000 €/year more than the diesel equivalent

Fuel consumption (diesel): 32 lt diesel/100 km

Fuel consumption (LNG): 27 kg LNG/100 km

Cost of fuels: Diesel: 1.30 €/lt; LNG: 1.05 €/kg

Two scenarios: (A) Truck uses 100% LNG; (B) Truck uses 75% LNG

The results of the payback calculations are presented in the Table 10 below.

Table 10: Simple payback period (years) for LNG truck (dual fuel)

Annual usage (km)	*Scenario A (100% LNG)*	*Scenario B (75% LNG)*
75000	6.7	11.6
100000	4.3	6.7
125000	3.2	4.7
150000	2.5	3.7

Given that the average lifetime for a truck generally exceeds 10 years, LNG appears an attractive option, provided that an annual usage above 100,000 can be assured, that the fuel differential is not reduced over time and that there is adequate infrastructure along the truck's expected itinerary, to allow it to refill.

3.2.5 Stakeholders and factors affecting spread of NGVs

The main stakeholders involved in the NGV market are:

- the suppliers of natural gas;
- the owners and operators of the refuelling stations;
- vehicle manufacturers;
- retrofitters of petrol or diesel vehicles, so that they can run on dual fuel;
- the owners/drivers of the vehicles;
- lawmakers and policymakers (local, national and EU-wide).

Additional (secondary) stakeholders are the operator of the transmission or distribution system to which the refuelling stations are connected (for CNG stations) or respectively the operators of the virtual pipeline (for LNG / L-CNG stations).

Vehicle owners/drivers

Clearly, the spread of CNG vehicles rests ultimately upon the decision of the large body of vehicle owners/drivers, who are presented with a range of alternatives regarding the fuel/energy form powering their new vehicles as well as the prospect of retrofitting their existing vehicles. Thus, NGVs compete with both the "incumbent" fuels (petrol and diesel) and other alternative energy forms and technologies, including ethanol and electric vehicles (EV). Studies[4] have shown that consumers' decisions are driven by the following criteria, in order of importance:

1. Economic advantage (lower total cost of ownership that other alternatives)
2. Confidence and comfort (reliability, lifetime of vehicle, performance, autonomy, availability of filling stations, security, environmental performance)
3. Technology and innovation, manufacturer's guarantee.

Although these criteria are valid for all vehicle buyers/owners, they are especially relevant to professional vehicles. Concerning buses, owners/operators assess the suitability of CNG by

[4] IVECO, presentation June 2014

considering the procurement of the bus, such as capital and operating expenses, operational effectiveness, comfort of driving, attractiveness to passengers and compliance with environmental legislation.

Vehicle owners usually demonstrate a range of behaviours as regards the willingness and initiative to apply new, not widespread technologies. In principle, users that are large enough to achieve economies of scale or dispose of some money to experiment (generally large fleet operators) can justify the increased capital investment and move first, at least to try the new technologies on a pilot scale. On the other extreme lie risk-averse users (i.e. individuals owning passenger vehicles) that are not willing to invest without the existence of an extended infrastructure network and assured fuel price differentials.

Clearly the choices of vehicle owners/buyers are influenced by the actions of the other stakeholders.

Vehicle Manufacturers

The offering of NGV models by most manufacturers is typically highly correlated to the buyers' maturity and the existence of adequate filling stations. With the exception of Fiat, car manufacturers offer a very limited number of NGV models to specific EU countries. Concerning buses and trucks, manufacturers with the exception of IVECO and Volvo, are generally reluctant to produce new models due to the low volumes, high R&D costs which result to high vehicle costs, and localised markets. Substantial scale manufacturing of trucks and buses is most often driven by large orders from large operators (e.g. for city service vehicles).

Infrastructure Providers

The existence of filling stations (CNG or LNG depending on the type of vehicle) has a definite role in the purchase decision of end users as well as in new product development by manufacturers. Currently there are 3000 CNG stations in the EU, 84% of which are open to public, but remain largely underutilised (Figure 14). Under such conditions, the only infrastructure providers that are willing to proceed with the construction of infrastructure are relatively large gas suppliers who have a substantial prospective market and dispose of the funds necessary for the building and operating some filling stations, even at a loss for a period of time. Nevertheless the further spread of NGVs is subject to a classical "chicken-egg dilemma" among car buyers and infrastructure developers, which in reality becomes more complex because it also involves vehicle manufacturers. This vicious cycle can be broken by appropriate policy measures targeting all three categories of stakeholders.

Policymakers and lawmakers

The literature examined as well as the interviews highlighted the role of policymakers and especially that of the European Commission as pivotal role in lifting the barriers and promoting the use of natural gas in the transport sector, through appropriate policies. Some of the stakeholders interviewed underlined that what is mostly required is a clear and unequivocal signal from the EC that it promotes the use of gas as the automotive fuel of choice, at least in some applications, such as long distance driving of heavy vehicles (LNG) and urban service vehicles (CNG), where natural gas is currently the only available and possibly viable alternative to petroleum products. (In cars moving within a city, stakeholders recognise that there is competition to gas from EVs and LPG). On one hand the EC (DG MOVE) has expressed its support, which has materialised with the Alternative Fuels

Infrastructure (AFI) Directive[5]. In addition, the EU emission standards currently in force (Euro VI standards, discussed above) favour alternative fuels, including gas, over conventional ones, though other solutions are also available (such as improved diesel engine configurations). On the other hand, the uncertainty regarding taxation of natural gas used as a motor fuel has been recognised by all stakeholders as an important barrier. Such taxation is currently low or zero in most EU countries but stakeholders fear that, as the NGV market becomes important, EU member states will be tempted to increase taxation. Such a decision has already been taken in France. To compound things, the EC proposed in 2011 a revision of the EU Energy Tax Directive (see Chapter 2), whose net effect, as regards gas, would be to increase the minimum taxation of natural gas as a motor fuel fourfold, from 2.6 €/GJ to 10.7 €/GJ. Although the proposal has not been adopted, it is still under discussion and creates an uncertainty regarding the future tax regime, which, in the view of virtually all stakeholders, undermines the growth of the NGV market.

In addition to fiscal incentives, there are a range of other potential policies/incentives that promote NGVs, including the following:

- Decision by city administrations to switch urban service vehicles to CNG (as in the case of Madrid).
- Additional "administrative" incentives by city administrations to alternative fuel drivers (including CNG vehicles), such as driving in fast lanes, entering the city centre, etc.
- Tax breaks for CNG and LNG vehicles and for retrofitting costs (as in the USA).
- Funding of relevant projects (such as the Blue Corridors project) by appropriate EU programmes.
- Co-financing of R&D expenses of car manufacturers by EU programmes (e.g. Horizon, Intelligent Energy).
- Moving towards the adoption of harmonised (EU-wide or international) standards for NGVs and filling stations.

Regarding standards, in particular, as it usually happens at times of innovation, standards have been developing on a piecemeal basis and on a national scale, struggling to keep up with technology developments and industry practice. Standards are particularly important in network industries to ensure inter-operability, safety and compliance, and economies of scale. Harmonisation across the EU (at least) is important for making end-users and infrastructure developers more eager to invest in NGVs.

EU Standards for LNG and CNG vehicles have already been issued (Regulation R-110, June 2014). In regards to the remaining technical standards and specifications, the proposed actions have been to:

- harmonise filling stations standards for refuelling;
- harmonise approval of procedure for dual-fuel applications;
- establish standards for CNG and LNG repair and closed parking facilities;

[5] Some stakeholders, however, consider that support to natural gas could be made more focused rather than being "diluted", including support to other alternatives that do not constitute viable alternatives at least for the time being (hydrogen, electricity, LPG etc.).

- establish EU standards for biomethane.

According to the AFI Directive the EU shall pursue the development by the relevant European or international standardisation organisations of: (a) a standard, including detailed technical specifications, for refuelling points for LNG for maritime and inland waterway transport; (b) a standard, including detailed technical specifications, for refuelling points for LNG and CNG motor vehicles. The development of international standards for NGV and CNG filling stations (ISO/PC 252) is already in progress, expected to be published in April 2016.

3.2.6 Rail sector

Technological considerations and applications

The rail sector can be divided into two distinguished categories: freight and passenger locomotives, using either diesel or electricity. For the scope of the specific study, only diesel locomotives will be considered for the potential use of LNG as fuel. The reason is that electric locomotives use specialised rail infrastructure to power the engine and, as a result, modifications in the rail network would also be required, making the replacement project not cost effective.

Locomotives have been an established mode of transporting goods and passengers for almost two centuries and the propulsion system has radically evolved. Nowadays, usually train propulsion systems contain a diesel engine that powers an electric drive system. A freight train carries 19,000 lt of diesel on board enabling it to travel for 1,900 km. However, due to the need of reducing emissions, minimizing dependence on oil and reducing operating expenses, locomotive companies are considering the substitution of diesel with LNG.

Evidently LNG powered locomotives require the establishment of a network of stations across the main rail pathways. These stations would be refuelled by cryogenic trucks transporting adequate amounts of LNG to fill passing trains. Specialised equipment and procedures need to be established for the train refuelling.

The capacity and location of filling stations would be determined by the frequency of passing trains and their location in respect to the rail network. As in the case of vehicles, the refuelling time of an LNG tank is similar to that of conventional liquid fuels.

In the case of existing locomotives a retrofit would be required to enable the diesel engine to burn LNG, making it dual-fuel. This would include the addition of a cryogenic tank and a fuelling system to the propulsion system. For future locomotives, new engine designs would be required for the train to run solely on LNG.

The first locomotives powered by LNG have been put to use by the company Ferrocarril Central Andino in Peru, operating in the Central Andes. Russia has also built an LNG gas turbine-powered locomotive, to make use of its abundant gas reserves.

Piloting programmes are expected to run in North America starting in 2016.

Challenges and prospects for the use of gas in the rail sector

Although widespread application of LNG in the rail sector has not taken place yet, the two largest railroad operators in the United States – Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) – are planning to initiate piloting phases to test the feasibility of this potential fuel. Apart from the significantly positive environmental effects, the major driver for adopting LNG in the rail sector is the extensive quantity of shale gas available in the USA that is now technically extractable, and the consequently low gas prices. Studies have predicted that by 2020 the North American rail sector will consume 160 GWh/d of LNG and that worldwide by 2040 all freight trains will be converted to have a LNG capability. Total rail LNG consumption is forecasted to reach 43 TWh in 2040 from 0.15 TWh in 2017.

Due to the complexity in the application of the LNG technology in the rail sector, rail operators in the USA expect to face numerous challenges. However, all stakeholders recognise that any decisions are to be taken by the railway companies. In this regard, the high concentration of ownership in the US rail sector can enable rapid growth, once one of the large companies decides to switch to gas. The major challenges and concerns identified in the literature, as cited by locomotive/rail industry representatives are the following:

- Economic uncertainties: Unknown long-term price spread between diesel and LNG creates uncertainty in the application of the technology. In addition, the lack of commercial applications leads to lack of economic data regarding procurement, operation and maintenance of the locomotives, personnel and infrastructure.
- Supply of LNG and infrastructure: Sufficient supply is required to accommodate widespread use of LNG. As infrastructure does not currently exist, its development will require significant capital expenses and planning.
- LNG engine technology: There is uncertainty concerning the performance, costs, warranty and conversion of existing engines to dual-fuel type.
- Regulations and Standards: Environmental standards and safety regulations for usage and refuelling procedures do not exist.

These challenges are valid not only for North America but also for the EU. There are additional challenges in the EU, which make the application of LNG locomotives more uncertain and less probable than in North America (or Russia):

- A large percentage of the locomotives (about 50%) are electrified and thus are not target for replacement.
- Europe does not have abundant production of gas as the USA and Russia have. The exploitation of shale gas in Europe is an uncertain prospect and, at best, a very long term one.
- Gas is much more expensive in Europe than in the USA.
- Contrary to the Unites States, interstate travel in Europe requires the agreement among railway operators of several countries, the coordinated construction of infrastructure along the main rail pathways in all concerned countries and the harmonisation of regulations and standards for locomotives, infrastructure and procedures. These are uncertain and very time-consuming processes.

Considering the above, it is possible that LNG locomotives may be used on isolated ("off-road") rail pathways in Europe, especially in areas that combine abundance of gas/LNG with strong pressures for environmental protection. This, however, will remain a marginal use and it is unlikely that a market of a considerable size will emerge in the foreseeable future.

3.3 Water transport

3.3.1 Deep-sea trading vessels and inland waterways

The growing need for clean fuels in water transport

The International Maritime Organization (IMO) is the governing body of world maritime transport. It enforces regulations and supports initiatives that have a worldwide effect. To reduce the pollution caused by ships, the IMO has set restrictions of NOx and SOx emissions from ship exhausts through the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78. The requirements set are split into two categories: global requirements and more stringent ones applicable in Emission Control Areas (ECAs). The ANEX VI amendment of MARPOL establishes that in the ECAs the limit of sulphur content in marine fuel exhaust gases has to be limited from 1% in 2010 to 0.1% in 2015 and in 2020 the global sulphur content has to be lowered from the current 3.5% to 0.5%. The EU applied the new sulphur limitations imposed by MAROPOL 73/78 through the Directive 2012/33/EU. The map below demonstrates the present (Baltic Sea, North Sea, North America and United States Caribbean Sea) and the possibly future ECAs areas (Scandinavia Sea, Mediterranean Sea). Current large EU ports within the ECA areas include Rotterdam, Gothenburg, Hamburg and Antwerp.

Figure 22: Current and possible future ECA areas (Source: Gas Infrastructure Europe)

Ship owners have three choices in order to meet the new IMO requirements:

- Continue to use HFO and install an exhaust scrubber. This solution is still not environmentally friendly, due to the production of waste water with high sulphur concentration;

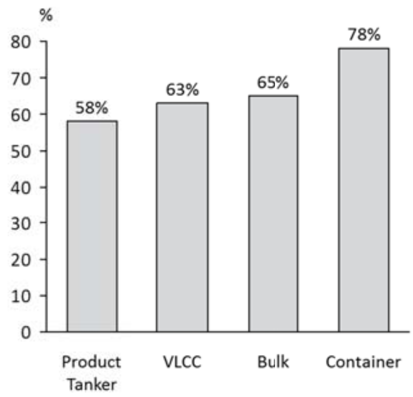
- Switch to MGO or other low sulphur fuel, such as Ultra-Low Sulphur Fuel Oil;
- Switch to LNG. CNG is not applicable for ships due to its technical characteristics and storage technology. This option is the focus of the present study.

Apart from the regulations set by the IMO, the European Commission is also pursuing to promote the use of natural gas for water transport, with a view to reducing pollution and the EU dependency on imported oil. The AFI Directive requires the establishment of LNG refuelling facilities for ships at maritime ports by the end of 2025 and at inland ports by the end of 2030.

Alternative fuels in maritime transport

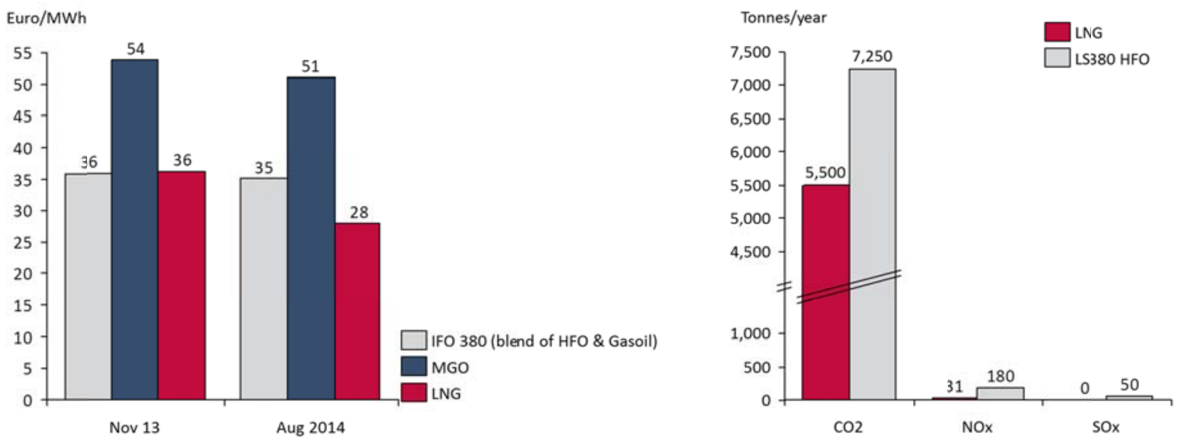
The two basic fuels currently used in the maritime sector are Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO). There are numerous grades of these fuels with somewhat different compositions and physical properties. Usage depends on the vessel's area of operation and the fuel prices. As the figure below demonstrates, fuel accounts for a significant proportion of a vessel's operating expenses.

Figure 23: Fuel as a proportion of a vessel's daily operating expenses (Source: DNV SOx Reduction)



Ship owners are aiming at reducing the vessel's daily OPEX by utilising lower cost fuels, which are however less environmentally friendly. International legislation, such as the MARPOL, drives the need to operate, at least in certain regions, on more expensive but less polluting fuels. The following figure demonstrates the price and emission differences between IFO, MGO and LNG.

Figure 24: Prices and emissions of IFO, MGO and LNG (Sources: Golden Union for IFO, MGO and HFO, ICIS Heren estimated FOB price for reloading at Zeebrugge for LNG)



As demonstrated in Figure 23 and Figure 24, LNG is an attractive option to be used in ECAs, as it provides very low sulphur emissions at prices lower than MGO. Oil companies are currently offering HFO with 0.1% sulphur content at a similar price to MGO. However, due to the limited supply, it cannot meet current demand.

Description of the technology applied

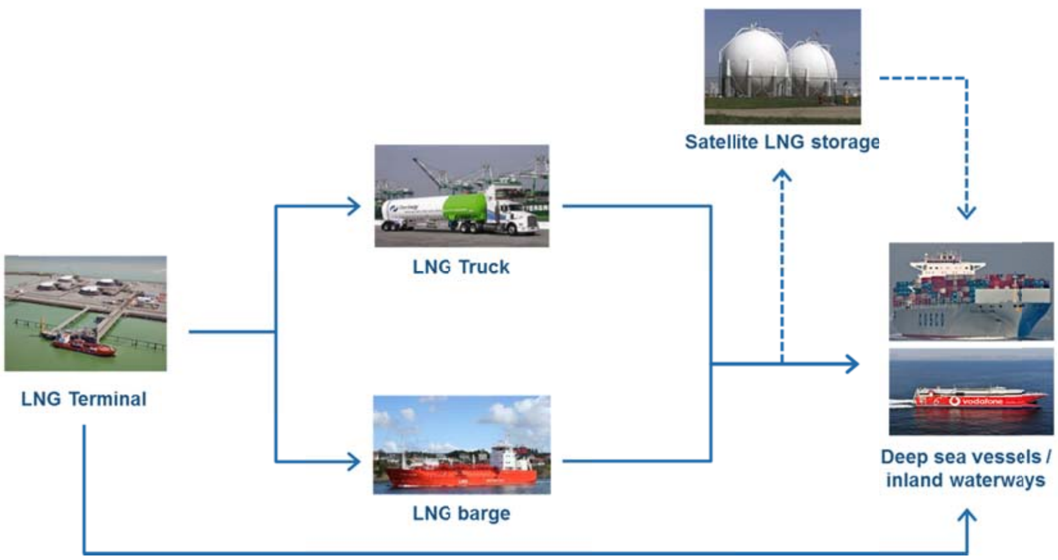
All vessels for deep-sea trading and Inland Waterways (IWT) utilise diesel (i.e. compression ignition) engines due to their technical characteristics and thus burn HFO and MGO. As in the case of NGVs, the engines of the vessels have to be converted into dual-fuel to be capable of utilising LNG.

The retrofit required mainly consists of a large LNG tank, new fuelling lines and new fuel management system, all leading to intensive capital expenditure. Taking into account the current and forecasted lower price of LNG compared to MGO and HFO, ship owners are expected to be able to compensate the investment for LNG-fuelled ships.

Deep-sea trading vessels refuel in large ports, along their trade route. The bunkering facilities supplying LNG to such vessels can be fed either directly from a nearby LNG terminal, an LNG barge or a cryogenic truck (as part of a LNG virtual pipeline), the choice usually depending on the available facilities and the required quantity of fuel. In the case of IWT, due to the small distances covered by the vessels and their significantly lower fuel needs compared to deep-sea vessels, the refuelling can be carried out either directly by LNG trucks at ports, or from LNG storage tanks located at regional stations supplied through small LNG carriers or cryogenic trucks (as part of an LNG virtual pipeline).

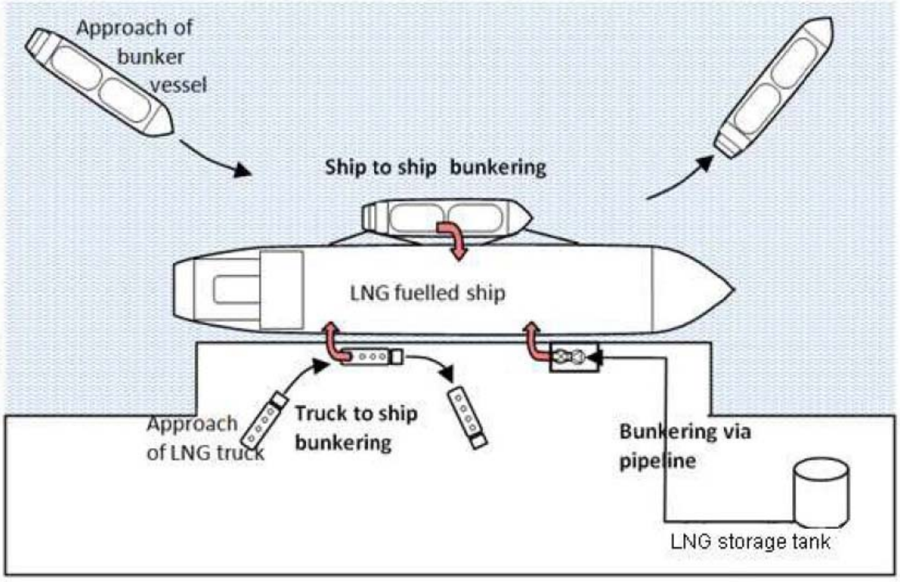
An overview of the supply chain of the LNG bunkering for deep-sea trading and IWTs is presented in the figure below.

Figure 25: Supply chain for LNG bunkering



The different bunkering options are visually presented in the figure below. The bunkering process is dependent on the technical specifications of each port, especially its size, depth and available refuelling equipment.

Figure 26: LNG bunkering options (Source: German Ministry of Transport and Digital Infrastructure)



The bunkering process may be:

- Ship-to-Ship (STS) for vessels with a bunker volume in excess of 100 m^3. The bunker vessel's capacity is 1,000 – 10,000 m^3;
- Truck-to-Ship (TTS) for vessels with a bunker volume below 200 m^3. The trucks are cryogenic-type and similar to the ones used to refuel LNG stations for NGVs.
- Terminal-to-Ship (TPS) for vessels of all bunker sizes. Close proximity to the terminal is required. Existing importing terminals could be utilised, given appropriate infrastructure developments.

All the above cases are applicable to deep-sea trading vessels. For IWT vessels, the TTS and TPS are considered more appropriate. Another solution for bunkering is via a small floating LNG storage unit. The process is similar to the STS and can be used in cases of large ships that cannot enter a port or for refuelling in the open sea.

Main stakeholders involved in the supply chain

LNG use in sea vessels is highly influenced by the stakeholders involved in the supply chain. The main stakeholders include the owner/operator of the LNG terminal where the bunkering is carried out, the supplier of LNG, the owner/operators of LNG bunkering barges and trucks and the end-user, either a cargo-handling vessel or a passenger vessel.

Particularly concerning IWT, an additional stakeholder in the supply chain could be the owners/operators of satellite LNG storages.

Economics

Ships are considered as investments with a lifespan of 20 to 30 years for deep-sea trading, and 50 years for IWT vessels. The large lifespan results in relatively low fleet turnover and thus slow introduction of new technologies. During the lifetime of vessels new directives emerge along with regulations and standards, all of which aim to reduce environmental pollution. To comply with these directives, ship owners have to make incremental and sometimes radical changes, leading to significant capital expenses.

Vessels

Table 11 presents indicative costs provided by IEA, for the conversion of different vessel types to burn LNG along with the respective on-board fuel storage capability. According to IEA, a newbuild vessel able to burn LNG would have an additional cost of 25%, compared to conventional vessels.

Table 11: Indicative conversion costs for LNG-fuelled ships (Source: IEA)

Type	Total Conversion Cost	Distillate (m^3)	LNG (m^3)
Tug boat	5.8 € million	75.7	136.8
Ferry	8.6 € million	60.6	109.4
Great Lakes Bulk Carrier	19 € million	550	1081

Regardless of the vessel type, the breakeven point depends on the price differential between LNG and oil products, in conjunction with the operating hours within SECAs. Payback periods on average are estimated to be 3-5 years for deep-sea trading vessels and around 5 years for IWT vessels.

Bunkering

A study by the Danish Maritime Authority (DMA) provides costs of marine LNG refuelling options. These are presented in the table below.

Table 12: Indicative costs for bunkering infrastructure (Source: DMA)

Cost (€ million)	*Thoughput (m^3/yr LNG)*	
	204,000	***343,000 + 20,000 m^3 tank***
CAPEX	69	137
of which cost of vessels	*32*	*60*
Annual OPEX	10	17

Apart from the economic component, the investment depends on technical and logistical factors:

- Location of bunkering facilities;
- Characteristics of new vessels and rate of conversion of existing ones;
- Port physical features;
- International and local safety and environmental regulations;
- National incentives to invest in new infrastructure

Current applications of use of gas in maritime transport

Deep-sea trading vessels operate around the globe and therefore are subject to international laws, regulations and standards. On the other hand, IWT vessels mainly operate inside a specific country. These vessels must therefore comply with the specific country's laws and regulations. The use of LNG in the water sector is currently very limited, and the country that is mostly recognised for operating LNG-powered IWT vessels is Norway.

In terms of technology providers, the largest engine manufacturers are Rolls Royce, Wartsila and MAN. Large vessel manufacturers do not exist in Europe as the vast majority of large vessels are manufactured in Asia. There is a limited interest by manufacturers for IWT vessels, as the market still remains small.

The widespread adoption of LNG in maritime transport does not rely solely on ship owners to convert their vessels to utilise LNG. Providers of LNG bunkering facilities need the development of an efficient and reliable network of refuelling stations in order to service the projected increase of LNG global demand. Steps forward have been made by terminal operators to accommodate the need of LNG bunkering, as currently the vast majority of terminals only import LNG from carrier vessels greater than 150,000 m^3. For example, the ports of Rotterdam, Zeebrugge and Antwerp are developing infrastructure (i.e. jetties, mooring and storage facilities) to accommodate smaller vessels to refuel directly from the terminal as well as refuelling stations for cryogenic trucks.

The map below shows the LNG import terminals that currently have or are planning to develop bunkering facilities in the EU, as well as the LNG loading terminals in Norway (including the small-scale liquefaction plants).

Figure 27: LNG bunkering facilities in the EU and Norway (Source: Gas Infrastructure Europe, Gasnor)

The EU AFI Directive aims at increasing the availability of bunkering services at an EU-wide level, to facilitate the refuelling of ships with LNG. The timeline set by the Directive for the development of bunkering facilities foresees the implementation of LNG refuelling point at maritime ports up to the end of 2025 and at inland ports up to the end of 2030. This Directive also requires the definition of common technical standards for the bunkering facilities. Although the deadlines of the AFI Directive are not in line with the requirements of the IMO regulations and Directive 2012/33/EU, its provisions are perceived as a positive step by all the stakeholders interviewed.

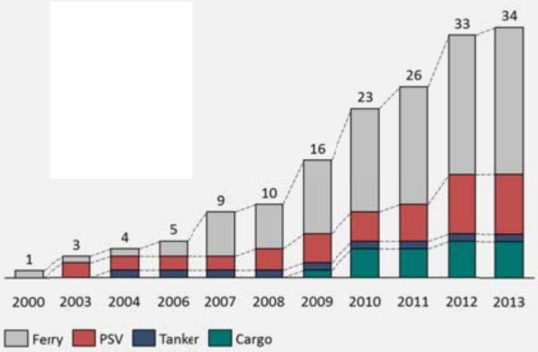
There are also initiatives emerging, to promote the use of LNG in IWTs. One such project is the development of the waterway axis Rhine/Meuse/Danube, funded by the TEN-T network, which includes the construction of LNG bunkering infrastructure in main inland ports as well as the retrofitting of vessels.

To further analyse the current applications of LNG in water transport, in the scope of this study, two markets were examined in detail; Norway and USA. Case studies for these two markets are presented below. Particularly for Norway, the case study presents the market developments for the use of LNG is ships, as well as for the supply of LNG using virtual pipelines.

Case Study: LNG in waterways and operation of LNG Virtual Pipelines in Norway

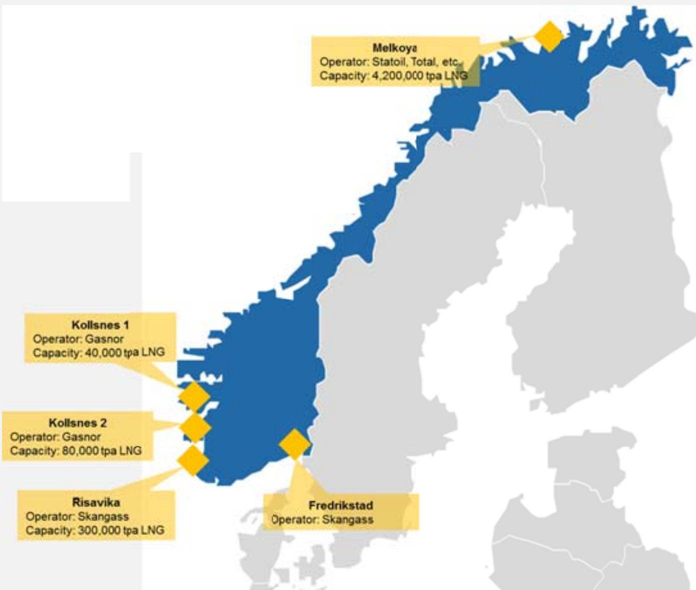
Norway is a world leader in the use of LNG for waterways. The first ferry using LNG was built in 2000 and the fleet has been growing ever since. As of mid-2013, there were 34 LNG-fuelled ships flying the Norwegian flag (Figure 28), while additional new-builds were expected in 2014. The ships include ferries, platform supply vessels (PSV) and cargo vessels, with deadweight tonnage ranging from 150 to 6200.

Figure 28: LNG-fuelled ships in Norway until mid-2013 (Source: Norwegian Marine Authority)



The Norwegian Government has supported the application of small scale LNG in waterways, by using LNG in public ferries and providing incentives, such as the NOx fund, that allows enterprises to reinvest in low NOx technologies instead of paying an emission tax. The Norwegian regulations on LNG-fuelled ships include provisions concerning the safety and specifications for the construction and operation of passenger and cargo ships.

Figure 29: Liquefaction plants in Norway (Source: Gasnor)



Currently there are 6 liquefaction plants in operation in Norway; one large terminal (Melkoya) used to export LNG to international markets and 5 small scale ones, used for LNG supplies in the local market and neighbouring countries (Figure 29). The terminals are connected to the country's gas fields of the North Sea. Satellite LNG storages are also available in the country.

The most common method currently applied in Norway for the bunkering of LNG is the use of LNG trucks on the quay terminal, directly loading the ships. Alternatives include the use of on-shore LNG storages at the liquefaction plants or satellite plants.

Apart from the application of small scale LNG in the water transport sector, due to the lack of sufficient gas transmission infrastructure, LNG virtual pipelines are also used to supply industries, large commercial companies and local distribution networks. LNG is transported using LNG trucks, small scale LNG vessels or combinations of both, depending on the location of the final consumers. There are currently 4 LNG vessels, 2 owned by Gasnor and 2 by Skangass, operating in Norway, with capacities ranging from 1,100 m^3 of LNG (the smallest LNG vessel available) to 15,000 m^3 of LNG. In addition, over 35 LNG trucks are used for the road transport of LNG.

LNG virtual pipelines are also used to export gas to neighbouring countries. An example of a virtual pipeline transporting LNG from Risavika to Nynäshamn in Sweden, from where it is further transported with LNG trucks is presented in the figure below.

Figure 30: LNG virtual pipeline Norway – Sweden

Case Study: Use of gas in waterways in North America

In North America, there are more than 54,000 km of navigable waters that connect 38 States across the inland. These are considered an alternative and more cost-efficient mean of transporting goods across States, as operators are able to achieve higher economies of scale in comparison to road transportation. The US Department of Transportation has initiated the "America's Marine Highway Program" in order to increase the navigable waterways' usage and reduce road congestion and air pollution. At the moment, all IWT vessels use traditional fuels for their propulsion. But as the deployment of more IWT vessels is expected in the coming years, the introduction of LNG as fuel will become an attractive solution to minimise operating expenses and pollution.

The move towards the adoption of LNG began with the agreement of Interlake Steamship Co. with Shell Petroleum in 2013, for the latter to become the exclusive supplier of LNG for future converted IWT vessels. The company's goal is to conclude the first conversion by the spring of 2015. Other companies have also announced plans for covering existing vessels to LNG and ordering LNG-only new-builds, such as Tote Inc., Washington State Ferries and British Columbia Ferries.

The major barrier towards the widespread adoption of LNG in IWT transport is the non-existent refuelling infrastructure. Prior to the exploitation of shale gas, the US gas market was heavily dependent on LNG imports. Following the boost of indigenous production, the LNG import terminals are largely underutilised and could be used as refuelling terminals for LNG-fuelled vessels. Additional LNG terminals, mainly liquefaction plants for gas export, are being planned, and can be used as refuelling facilities as well.

Figure 31: Existing (blue) and approved (green) LNG fuelling terminals (source: DNV)

Due to the size of LNG tankers these terminals are not expected to be able to accommodate the smaller IWT vessels for bunkering. Moreover, their location could not support IWT vessels that only follow routes towards the country's inland. Therefore, these vessels would need to be refuelled by new stations, barges or trucks. The stations' refuelling could be accommodated with LNG trucks or small LNG carriers.

Although the application of LNG for water transport in the USA is still in development, the IMO, the United States Coast Guard and the American Bureau of Shipping have been proactive in establishing regulations, codes and standards for gas-fuelled vessels, bunker vessel operators and bunkering facilities' operators.

Factors affecting development

The widespread use of LNG in water transport is dependent on technical, market and regulatory factors. The most important factors that have been identified from the literature review and the interviews with stakeholders involved in the sector are the following:

- Owners/Operators: Taking into account the significant capital expenses, either to convert an existing or purchase a new LNG-fuelled vessel, and the lack of bunkering network, owners/operators are often reluctant to make the investment decision.
- Ship builders and engine manufacturers: These are influenced by the decisions of ship owners/operators. In order to offer products they have to invest in R&D, an action which is capital intensive.
- Infrastructure providers: The significantly high investment costs hinder the development of bunkering facilities in the absence of concrete proof that LNG vessels will be widely adopted in the future. The EC policy for the promotion of gas as fuel for ships and the AFI Directive requiring the availability of bunkering facilities at ports will facilitate the application of LNG-fuelled vessels in the EU. However, in the case of deep-sea ships, bunkering facilities are required at a global scale.
- Regulations: The transition towards the use of LNG requires the establishment of local and international regulations defining the operation of new vessels and bunkering facilities. For instance, a regulation for refuelling with LNG during cargo handling or passenger boarding does not exist. Moreover, safety regulations for STS bunkering are lacking.
- Standards: As deep-sea vessels travel worldwide, internationally harmonised standards for both vessels and refuelling equipment are required. The same is required for IWT vessels at least at regional level.
- Technical: Engine technology for burning LNG is still evolving. The potential increase of LNG usage will require vessels to install larger fuel storage tanks, thus increasing weight and reducing cargo capacity. This has a higher impact on IWT vessels due to their smaller size and weight.

The IMO plays the foremost role in lifting the aforementioned barriers, and influencing ship owners and infrastructure providers, by establishing initiatives, directives and regulations. The EU and national bodies may also provide initiatives and an appropriate framework to promote the use of LNG in marine transport.

3.4 New concepts of energy storage

3.4.1 Power-to-Gas

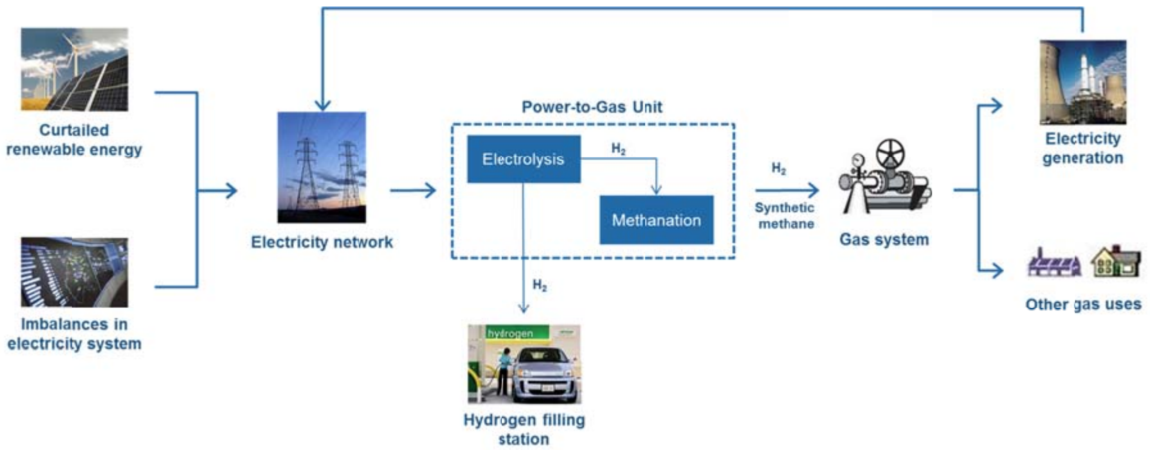
Overview

The increasing integration of renewable energy sources in the European power systems, particularly intermittent wind and solar energy, is resulting in excess amounts of non dispatchable renewable energy at times of low demand or when the networks are already at full capacity. In addition, the application of energy efficiency measures and the overall reduction of electricity consumption are leading to a reduction in the utilisation of base load capacity. Technologies for storing electricity are being developed to face these challenges and allow storage of curtailed energy for later use.

Power-to-Gas (P2G) is an electricity storage technology that links the electricity and gas infrastructure. Electricity (according to the stakeholders interviewed mostly curtailed renewables energy and/or excess electricity from system imbalances) is used in a process of electrolysis to produce hydrogen, which can in turn produce synthetic methane. The output of a P2G unit, either hydrogen or synthetic gas, is injected into the existing natural gas network for use in the gas sector (electricity generation, industrial processes, heating, transport, etc.). There are also applications in which hydrogen is directly used as fuel in vehicles; those are not covered in the scope of this study.

An overview of the P2G process is presented in the figure below.

Figure 32: Overview of the Power-to-Gas concept



Description of the technology applied

The P2G technology is currently at a pilot phase of development, with several demonstration projects being implemented, mainly in Germany. Some of the projects currently in operation are connected to the electricity grid, while others are directly linked to wind farms. According to the stakeholders interviewed, the future commercial application of P2G foresees exploitation of the curtailed renewable energy and also its use as a balancing tool by the electricity TSOs, as it can quickly absorb any excess power.

The technology providers involved in the development of P2G do not expect significant modifications in the currently applied technology, during the commercial roll-out of P2G. Large scale application, however, is expected to lead to a reduction of the required investment costs.

The first step of the P2G technology is the conversion of electricity into hydrogen, by means of water electrolysis. Through this process, water is broken down into its component parts, hydrogen and oxygen. The majority of the energy is then bound on the hydrogen. The main benefit of this method is that hydrogen, unlike electricity, can be stored as well as transported in large quantities and for long periods.

The efficiency of the process is variable but is usually between 50 – 80% and is heavily dependent on the method used. The three electrolysis methods that have been examined in the P2G process include:

- The alkaline water electrolysis using a liquid basic electrolyte;
- The acid or polymer electrolyte membrane electrolysis (PEM electrolysis) using a solid polymer electrolyte;
- The high-temperature steam electrolysis using a solid oxide electrolyte.

The basic indicators of the alkaline water and the PEM electrolyses related to the P2G process are presented in the table below.

Table 13: Indicators of alkaline water and PEM electrolyses (Source: dena)

	Alkaline water electrolysis	PEM electrolysis
Efficiency (Gross Calorific Value)	67 – 82%	44 – 86%
Specific energy consumption	4 – 5 kWh/Nm^3 H_2	4 – 8 kWh/Nm^3 H_2
Investment cost	800 – 1500 €/kW	2000 – 6000 €/kW

The electrolysis methods used in the P2G process allow for quick start-up and shut down on the units. With Alkaline electrolysers P2G has a deployment time from stand-by mode of 5 minutes and cold start time of less than 10 minutes. PEM electrolysers have even faster shut down and start up times, and capability for black-start.

The interviewed P2G technology providers consider that the most efficient electrolysis method for P2G is PEM, for the following reasons:

- PEM electrolysis has a very quick responsiveness to power load fluctuations. This makes this method suitable for use to quickly absorb curtailed energy and resolve any excess electricity imbalances in the power system;
- The method has more potential for cost reduction compared to the alkaline electrolysis in large scale applications;
- PEM electrolysis has a low carbon footprint, as its products are only high quality hydrogen, oxygen and heat.

The electrolysis process requires approximately 1.5 lt of water per Nm^3 of hydrogen, taking account of water losses. In this respect there is no need for large water resources dedicated to the P2G unit.

Following the production of hydrogen, different pathways are possible:

a. Direct conversion into heat or electricity;
b. Storage into pressure accumulators and conversion back into electrical energy when required;
c. Injection directly into the gas system (up to the hydrogen volumes that the technical specifications of the transmission or distribution system allows);
d. Formation of synthetic methane through a methanation process, which is then injected in the gas system (with virtually no limitations).

The production of synthetic methane from hydrogen (pathway d above) takes place by mixing the hydrogen produced with carbon dioxide at high pressure and high temperature, using the Sabatier reaction[6]. Two methanation processes are currently being applied, biological and chemical methanation. The former has the advantages of requiring lower capital investments and resulting in higher efficiency factors. The methanation process requires a source of carbon dioxide, located close to the P2G unit. The methane gas produced in this way is similar to natural gas and can be fed into

[6] Sabatier reaction: $CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O$ + energy, $\Delta H = -165.0$ kJ/mol

the existing gas network. The excess heat produced in the methanation can additionally be used for heating. Although there are currently pilot projects applying methanation, according to ITM Power, the technology readiness level is still low.

The P2G units currently in operation have an electrical capacity of up to 2 MW. According to Hydrogenics and ITM Power, the future large scale application of the technology will be achieved either with units of 60 – 80 MW, or with modular units of stacked units of 1 – 5 MW.

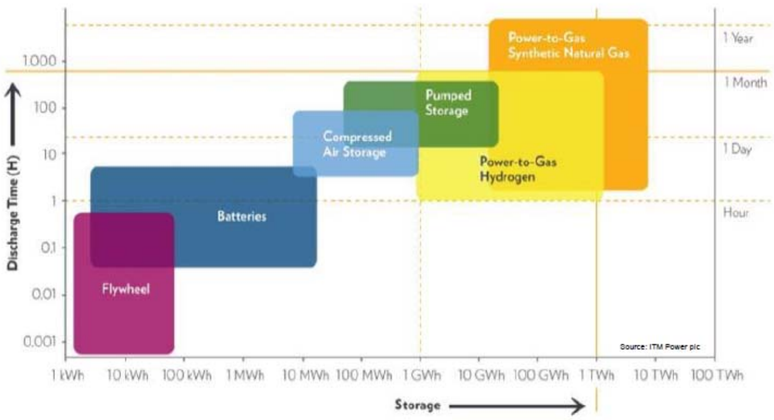
Alternative technologies for electricity storage

Power-to-Gas is distinctive from power storage technologies by the characteristic that hydrogen or synthetic methane is being produced as an intermediate product. This can subsequently be processed as gas or reconverted into electricity. In case of conversion into power, there are two options: hydrogen from electrolysis is stored and is reconverted by a fuel cell, or hydrogen/methane is accommodated in the gas infrastructure and reconverted into power by conventional gas-fired power plants. Apart from P2G, the most developed energy storage options include:

- Pumped hydro storage: Pumped storage is the most common electricity storage medium currently used. Water is pumped to a high storage reservoir during off-peak hours, which is then used for hydroelectric generation during peak hours. Pumped storage has an efficiency of 70 – 85% of the energy consumed.
- Flywheel: Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a very high speed and storing the energy in the form of kinetic energy.
- Batteries: Batteries store electricity through a reversible electrochemical reaction. Types of batteries include Pb-acid, nickel based, sodium sulphur, lithium ion, zink bromium and flow batteries. Existing batteries are characterised by high costs and limited duration.
- Compressed air storage: This storage method includes using off-peak or renewably generated electricity to compress air, which is usually stored in natural formations with appropriate technical characteristics. When electricity demand is high, the compressed air is heated with natural gas and flows through turbo expanders to generate electricity.

A comparison of the electricity storage technologies, carried out by the P2G technology provider ITM Power, shows that P2G has the advantage of achieving larger storage capacity for a longer period of time (Figure 33).

Figure 33: Comparison of alternative storage technologies (Source: ITM Power)



Advantages of the P2G technology

The following advantages of Power-to-Gas have been presented in the literature and during the interviews with stakeholders involved in the development of the technology:

- Storing time: The production of hydrogen and its storage or injection in the gas system enables to store energy longer than any other medium.
- Location flexibility: Compared with other large scale storage systems, e.g. pumped storage or compressed air storage, P2G can be connected to the electricity grid without geographical constraints, provided that a gas network is available in the area. Additionally, the land required by a P2G unit is limited, due to its small size and scalability.
- Better balancing of the system: P2G can quickly absorb any excess electricity, improving the system's ability to balance out energy deficits caused by intermittent renewable resources or low load needs.
- Potential coupling of carbon dioxide by-products with methanation: Carbon dioxide produced by other generation methods can be captured using Carbon Capture and Storage techniques or other similar technologies to supply the carbon dioxide needed to generate methane in the P2G cycle.
- Indigenous source for the gas systems: The hydrogen or synthetic methane injected in the gas system is an indigenous source of gas, thus increasing the security of gas supply.
- Possibility of exploitation of the by-products of the electrolysis and methanation: Apart from the main outputs of hydrogen and synthetic gas, the by-products of the processes, oxygen and heat, can also be exploited.
- Enablement of carbon neutral transport: Because Power-to-Gas enables the storage, transportation and distribution of renewable energy as hydrogen or methane it also offers new opportunities for the usage of wind and solar energy in the transport sector. For example, the German car manufacturer Audi is piloting the Power-to-Gas process through its "e-gas project". As part of the project, Audi cars with hydrogen-oxygen fuel cells will be fuelled by hydrogen produced from wind turbines and vehicles powered by natural gas will be fuelled by the methane gas produced by Audi's "e-gas" methane producing installation.

Main stakeholders involved in the supply chain

There are two main approaches foreseen for the future full deployment of P2G; units can either be connected to the electricity grid and utilise curtailed energy from the whole system or linked with a direct line to a RES plant. The exact roles, interactions and synergies in the supply chain of P2G are still not clearly defined. Regardless of the approach applied, the main stakeholders involved (in some cases coinciding) in the supply chain of a P2G application include:

- The supplier of electricity;
- The technology provider for the P2G unit;
- The owner and operator of the P2G unit;
- The gas supplier procuring the produced hydrogen or synthetic methane;
- The operator of the gas transmission or distribution system in which the produced hydrogen or synthetic methane is injected.

The structure of the electricity market, and particularly the role of RES producers, is expected to affect the supply chain of P2G. For example the stakeholder in charge of system balancing (e.g. the TSO or the RES producers) would have an incentive to develop P2G units as a demand response measure, if the large scale applications of the technology prove to be economically effective.

Economics

The current lack of large scale P2G applications and relevant business cases does not allow a clear overview of the technology's economics. According to stakeholders interviewed, the costs of a large scale unit of P2G are expected to be at least 25% lower than those of the demonstration projects, due to the learning curve achieved and the mass production of equipment.

The operating expenses of a P2G unit depend on whether it is connected to the electricity grid, or directly linked to specific RES units. In the former case, the cost of electricity is the largest operating expense of the overall process. Other costs, such as catalysts, water supply and maintenance are significantly lower.

Current applications of Power-to-Gas

So far, interest for the development of P2G projects has been expressed mainly in the EU, as a result of the massive development of RES in the European power system. The technology is currently at a demonstration phase. Several demonstration projects, with limited hydrogen production capacities, are currently operational in Germany, which is spearheading the application of the technology. Some similar projects are also being under development outside the EU as well, particularly in USA and Canada.

Case Study: Application of Power-to-Gas in Northern Europe

The Power-to-Gas technology is new, with the applications to date being demonstration projects. There are currently around 15 pilot and demonstration projects operational in Germany, while additional small projects are being developed in both Germany and Denmark.

One of the largest P2G projects to date, on industrial scale, was commissioned by E.ON in Falkenhagen in eastern Germany in late August 2013. The unit uses wind power to run an electrolysis process and injects the produced hydrogen in the regional natural gas transmission system. The unit, has a capacity of 2 MW (i.e. the power consumption of the electrolyser is 2 MW) and can produce 360 m^3/hr of hydrogen.

E.ON built and is operating the P2G unit in partnership with Swissgas AG, which will procure some of the unit's hydrogen output. The unit was built in Falkenhagen because the region has a high output of wind power, the necessary power and gas infrastructure is already in place, and E.ON has a control centre there.

A P2G demonstration project is also under development in Denmark. Electrochaea is implementing the "Biocat" project at the wastewater treatment plant Avedøre in Copenhagen. The "BioCat" installation will use hydrogen made from excess wind power to convert biogas from sewage sludge into cleaner methane gas. The size of the project will be 1 MW. Gas production is expected to begin by mid-2015.

Even though development of P2G is still at a demonstration stage, the Bundesnetzagentur has proceeded with an update of the provisions of the gas regulatory framework, so as to facilitate the injection of hydrogen and synthetic methane to the gas system. Specifically, the definition of biogas has been adjusted in the Energy Act, so as to include hydrogen and synthetic methane. This has an impact on the Gas Network Access Ordinance, particularly in relation to the rules for access to the gas system, the connection of the P2G unit to the system and the availability of the entry capacity to the system.

Interest on the P2G technology from various stakeholders in the energy landscape has led to the establishment of cooperation platforms, in which stakeholders such as technology providers, electricity producers, gas suppliers, gas transmission system operators, examine the prospects and promote P2G. Two such platforms are the North Sea Power to Gas Platform (exploring the possibilities for Power-to-Gas in the North Sea) and the Power to Gas Strategy Platform (focusing on the German applications of P2G).

Factors affecting development of the technology

The development and commercial deployment of the P2G technology is dependent on technical, market and regulatory factors. The most important factors that have been identified from the literature review and the interviews with stakeholders involved in the sector are the following:

- Maturity of the technology: The readiness level of the technology will affect the timing for the development of large scale applications. The electrolysis process is considered mature. On the other hand, the methanation process, which could address limitations of hydrogen applications, such as difficulties in storing large quantities and the low energy content of the fuel, is still not at a fully mature level.
- Competing technologies: The P2G technology will have to compete with other energy storage technologies, which are also at an advanced stage of development, such as batteries, or are already commercially applied, such as pumped storage.
- Cost of electricity: The price of electricity can be the largest operating expense of the P2G process, if electricity is procured from the market to operate the unit (this is the operating modality of some demonstration units currently in operation). Any taxes and levies imposed on the electricity price would result in an increase of costs and largely reduce the economic attractiveness of the technology.
- Limitations of hydrogen injection: Each gas transmission or distribution system has limitations in the share of hydrogen mix in the gas volumes, for reasons of safety and quality (hydrogen has considerably lower energy content than gas). This limits the output of hydrogen by the P2G unit to the allowable levels of the specific gas system to which it is connected.
- Incentives: According to the stakeholders interviewed, the large scale application of the P2G technology requires financial incentives, such as the inclusion of the technology in a feed-in-tariff scheme, or the issuing of green certificates.

- Location: P2G units connected to the electricity grid have to be placed at appropriate locations that ensure connection to the electricity and natural gas grids as well as availability of water resources. Units connected with direct lines to specific RES units are constrained to the location of the renewables generation. Furthermore, the methanation process requires a local source of carbon dioxide. The exploitation of the produced heat at a local level, e.g. using a district heating system, would increase the economic effectiveness of the project.
- Clarity of regulatory framework: The regulations, rules and procedures for the injection of hydrogen or synthetic methane in the gas system have to be specified. The regulatory issues are discussed in detail in Chapter 5.

3.4.2 Natural gas Hydrates

Hydrocarbon hydrates (or clathrates, as they are often referred to in the literature) are solid crystalline compounds in which gas molecules are encaged inside the lattices of ice crystals. Their composition is thus $M \times N_H\ H_2O$, where N_H is the hydration number, indicating the number of molecules of water (ice) per hydrocarbon (M) molecule.

Vast amounts of hydrocarbons are trapped in hydrate deposits, the majority of which contain methane in overwhelming abundance. Such deposits exist where the thermodynamic conditions allow hydrate formation, and are concentrated in two distinctly different types of geologic formations where the necessary low temperatures and high pressures exist, in permafrost and in deep ocean sediments. Current estimates of the global reserves of hydrocarbon gas (primarily methane) hydrates range between 10^6 to 10^9 bcm. The magnitude of this resource (which, even by the most conservative estimates may surpass by a factor of 2 the energy content of the total fuel fossil reserves recoverable by conventional methods) could make hydrate reservoirs a substantial future energy resource. While current economic realities do not favour gas production from the hydrate accumulations, there is ongoing research on this matter. The production of natural gas (methane) from naturally occurring hydrates is outside the scope of this study.

This study examines instead the use of hydrates as a medium for the storage and transportation of natural gas. The original idea, presented in 1938, was to transform natural gas to hydrates, under suitable temperature and pressure, and keep it in storage, in order to meet peak gas demand. Subsequent interest encompassed production of hydrates, rather than LNG, for transportation by sea vessels. The main benefit that supported this idea – and the relevant research – over the more established storage of gas in liquid form (LNG), is the fact that methane hydrates appear to be stable at a considerably higher temperature than LNG (-20^{o}C, versus -162^{o}C for LNG at atmospheric pressure, while higher temperatures are also possible at increased pressure). As a result, the terminal would require a smaller refrigeration plant and substantially less energy for freezing. This would also avert the problems occurring with boil-off of LNG. A moderate amount of research was conducted in this regards in the 1990s and the early 2000s.

The main shortcoming in the use of hydrates as a storage medium, in place of LNG, is the higher volume and higher weight required to store the same quantity of methane. This is so, because methane hydrates crystallise mostly in the so-called I structure. This structure has a hydration number ranging from 5.77 to 7.41, with an average of 6, and N_H=5.75 corresponding to complete hydration (i.e. when all positions in the lattices destined for methane molecules are occupied). This means that 1 m^3 of methane hydrate contains (and can produce) at best about 170 m^3 of methane. This compression ratio of 170:1 is much lower compression ratio than LNG's (about 600:1). There has been research on achieving different crystallisation structures with smaller hydration number, i.e. a higher proportion of methane in the hydrate. Such structures have been achieved in laboratory experiments, but scaling up, even to pilot applications, appears to be problematic.

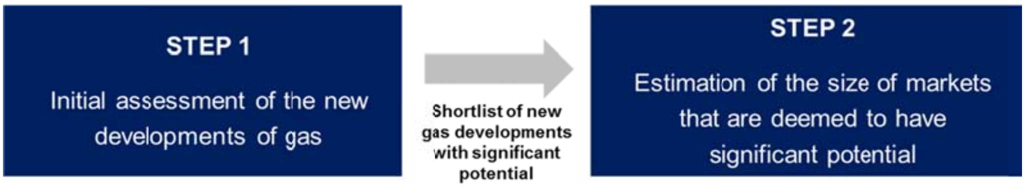
This disadvantage of hydrates is even more important when transportation of gas is considered. The content of methane in a hydrate is at best 13.3% w/w. This means that from every 7.5 tons of hydrate transported only 1 ton is methane gas, the rest being water. This obviously is not an economical option, compared to LNG, which yields, upon gasification, 100% natural gas.

4. GROWTH PROSPECTS FOR NEW GAS SUPPLY CHAIN DEVELOPMENTS

4.1 Assessment methodology

To assess the prospects for growth of the new developments in the gas supply chain, a two-step process was applied (Figure 34).

Figure 34: Overview of assessment methodology



In Step 1, an initial assessment of each new development was performed. The aim of this assessment was to perform a qualitative analysis to identify the developments that have an immediate or short-term growth potential, those with a medium-term potential, or those whose application is considered long-term, marginal or uncertain.

In Step 2 only the new developments with a potential for growth over the short and medium term were examined. High level projections were carried out, estimating the market size for each development in 2025. It should be noted that the purpose of these projections is to provide an order of magnitude for the potential future demand of the examined developments, and not to perform in depth forecasts.

4.2 Initial assessment

4.2.1 Approach

The initial assessment was performed using multi-criteria analysis (MCA) to examine the new developments under four criteria (Table 14). The specific MCA approach applied is the Weighted Sum Method, which for each new development included multiplying the value score for each criterion by the relevant weight, and then adding all weighted scores together to one overall final rating. Different weights were assigned to each of the four criteria, to reflect qualitatively their comparative importance in the assessment. The table provides the description and weights of the criteria.

Table 14: Criteria examined for the initial assessment

Criterion	*Description*	*Weight*
Current state of maturity	Examines the level of maturity of the new development (e.g. commercial, pilot or research) and its current applications	40%
Cost competitiveness characteristics	Examines whether the new development is competitive against other fuels or other technologies that address the same market	30%
Infrastructure require-ments to implement	Examines whether the new development is dependent on other infrastructure and to what extent this infrastructure is available	15%
Environmental & safety implications	Examines whether the development may lead to strong environmental implications and whether new safety requirements and regulations have to be imposed.	15%

4.2.2 Rating of new developments in the gas supply chain

The scoring of the examined new developments on the above criteria was carried out qualitatively, using a scale from 0 to 4. To assign scores, the conclusions drawn from the literature review and the interviews with stakeholders were taken into consideration. Table 15 presents the scoring for each development against all criteria, along with a justification of the scores given. Table 18 summarises the scores per criterion and calculates the overall score for each new development, on the basis of the weights assigned. To offset the impact of the somewhat arbitrary assignment of weights, a second score was calculated (last column of Table) with all weights being equal (25% each).

Table 15: Initial assessment - Scoring of new developments per criterion

	Current state		Cost competitiveness		Infrastructure		Environmental &	
	Rating	*Justification*	*Rating*	*Justification*	*Rating*	*Justification*	*Rating*	*Justification*
Virtual Pipelines								
CNG Virtual Pipelines	3	There are CNG virtual pipelines in operation worldwide (including in Bulgaria and Italy)	3	Low gas price makes CNG competitive to other fuels, but dependent on the distance of final consumption from the loading point.	3	Compression stations and trucks are required for the development of the virtual pipelines. The wide coverage of the EU gas grid allows a widespread application of the technology.	2	Safety regulations are required especially for the road transport of CNG. Environmental performance is superior to the use of oil products by the targeted consumers.
LNG Virtual Pipelines	3	There are LNG virtual pipelines in operation worldwide (including in Spain and Portugal).	2	Low LNG prices make the technology competitive to other fuels, but is dependent on the distance of final consumption from the loading point. The requirement for storage and regas facility on the client's premises reduce price competitiveness.	2	Existing LNG terminals can be used as loading facilities with modifications, reducing costs. Expensive LNG trucks and/or vessels are required.	2	Safety regulations are required especially for the road transport of LNG. Environmental performance is superior to the use of oil products by the targeted consumers.
Land Transport								
NGVs - LDVs	3	There are already many applications of NGVs worldwide and in the EU (e.g. Italy) .	2	There is currently a price differencial with the alternative fuels. However, incentives and national policies are required to cover part of the capital expenses. There is strong competition from electric vehicles.	2	A number of stations are already available in the EU. However the network must be expanded considerably for large scale use of NGVs is to occur.	3	Technical specifications and safety regulations are already in place for NGVs. Environmental performance is superior to the use of gasoline but less good than that of electric vehicles.
NGVs - HDVs	2	LNG is already used as a fuel for HDVs worldwide (although penetration is much smaller than for LDVs). There are some technical problems, especially for heavy trucks.	4	Gas-powered HDVs present a clear price advantage. Incentives and national policies may be required to cover part of the capital expenses.	1	LNG virtual pipelines and a sufficiently dense network of filling stations are required.	4	Technical specifications and safety regulations are already in place for NGVs. Environmental performance is superior to the use of diesel.

	Current state		Cost competitiveness		Infrastructure		Environmental &	
	Rating	*Justification*	*Rating*	*Justification*	*Rating*	*Justification*	*Rating*	*Justification*
Rail Transport								
Gas for rail transport	0	No applications to date. Pilot projects are being planned for the next couple of years in USA.	2	Price differencial with diesel can make LNG competitive, although significant retrofit and infrastrucure costs are required.	0	LNG storages at rail stations and virtual pipelines supplying them are required.	1	Harmonization of rules and regulations between countries along the rail route is required.
Water Transport								
LNG-fuelled vessels	3	There are already applications of small LNG-fuelled ships. For deep-sea ships, although the applications are still limited, the technology is mature (e.g. LNG carrying ships already use LNG as fuel).	2	The price differential and emmission limits, especially for ECA areas, presents cost advantages. Nevertheless, high initial capital costs are faced.	1	LNG storages at ports and virtual pipelines supplying them are required.	2	LNG apperas to be the best solution that responds to the strict emission standards to be imposed. Harmonization of rules and regulations between countries worldwide is required.
New concepts of energy storage								
Power-to-Gas	2	Several pilot projects are being implemented, mainly in Germany. Still more pilot applications are required for a staged commercial development until 2022.	2	In principle the technology exploits excess energy to domestically produce synthetic gas, which could be competitive to imported gas. However, as the technology is still in pilot stage, exact costs are still to be determined.	1	Wind farms with large excess energy are required. Due to the small size of the P2G plants a large number is required for sufficient production of gas.	3	There are no environmental concerns for the use of hydrogen/methane. The rules for entry into the system have to be specified, while gas quality and safety constraints affect how much hydrogen can be injected in the gas system.
Gas hydrates	0	Still at research level, with commercial development not expected in the short and medium term.	1	Cost for commercial application still not fully defined. Other types of storage (e.g. LNG) are technologically mature and at lower costs.	1	The size of the infrastructure required is not fully defined. Plants will probably have to be directly connected to the gas grid.	0	Safety rules are required for gas hydrates as these are highly flammable.

As seen in the Table, the resulting final scores are very close to the ones calculated using the originally assigned weights and certainly the categorisation of the developments into short-, medium- and long-term prospects, which is the aim and final outcome of this assessment, does not change when the weights are altered.

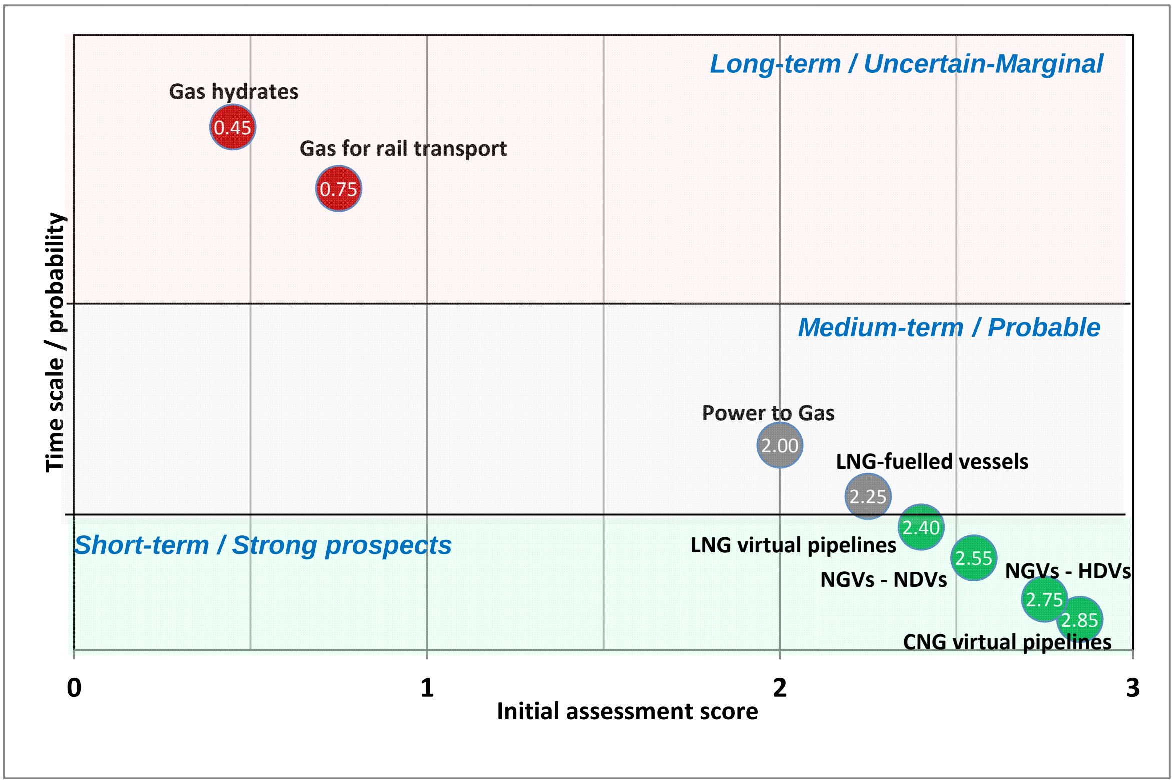
Table 16: Initial assessment – Scoring of new developments

	Current state	Cost competi-tiveness	Infrastructure requirements	Environmental & safety implications	Total score	
Weight	*40%*	*30%*	*15%*	*15%*	*Defined weights*	*Equal weights*
Virtual Pipelines						
CNG Virtual Pipelines	3	3	3	2	**2.85**	**2.75**
LNG Virtual Pipelines	3	2	2	2	**2.40**	**2.25**
Land Transport						
NGVs - LDVs	3	2	2	3	**2.55**	**2.50**
NGVs - HDVs	2	4	1	4	**2.75**	**2.75**
Gas for rail transport	0	2	0	1	**0.75**	**0.75**
Water Transport						
LNG-fuelled vessels	3	2	1	2	**2.25**	**2.00**
New concepts of gas storage						
Power-to-Gas	2	2	1	3	**2.00**	**2.00**
Gas hydrates	0	1	1	0	**0.45**	**0.50**

4.2.3 Results of Step 1

The results of the initial assessment are summarised in Figure 35 below, along with the corresponding classification of the new developments as regards growth potential and time scale.

Figure 35: Results of Step 1



Consequently, the new developments examined further in Step 2 were the following:

- CNG virtual pipelines;
- LNG virtual pipelines;
- Land transport – LDVs;
- Land transport – HDVs;
- Water transport – deep sea trading vessels and inland waterways;
- Power-to-Gas technology.

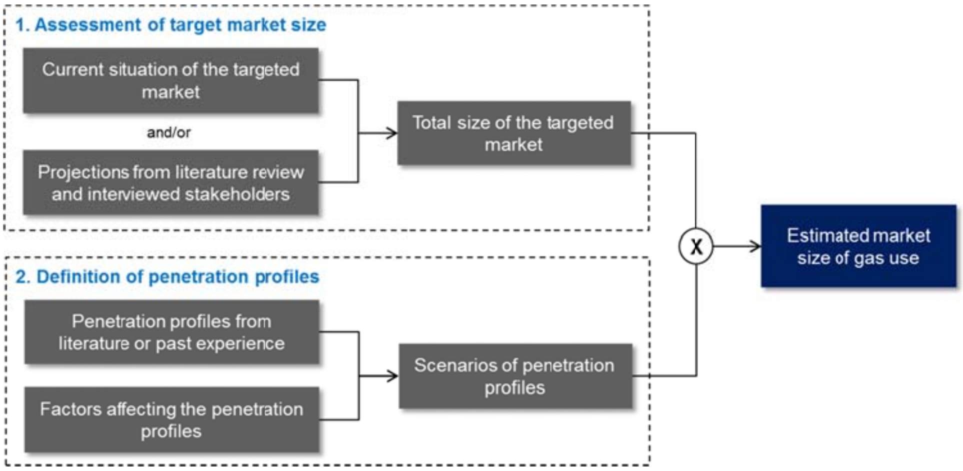
4.3 Estimation of the market size of new developments with significant potential

4.3.1 Introduction

The overall approach used to estimate the potential future market size for each of the new developments in the gas supply chain includes (Figure 36):

1. Assessing the total size of the targeted market, i.e. the total energy demand of the market to which the new development is applied;
2. Defining the expected penetration of the new development in the targeted market, taking into consideration the main factors affecting its growth;
3. Multiplying the outputs of points 1 and 2, to calculate the estimated market size for the new development in question.

Figure 36: Overall approach for estimation of market size



This approach was tailored to each new development, due to the significant differences in the characteristics of the targeted market, the readiness level of the technology and the availability of data. The tailored approach applied in each case is presented in the relevant sections below.

The projections for the market size are carried out for 2025. That year was selected because it is the year of reference for ACER's "Energy Regulation: A bridge to 2025" paper.

For each new development in the gas supply chain, three growth scenarios were assessed: a base case, a fast-growth and a slow-growth scenario. These involved different assumptions on the penetration profiles and, in some cases, different growth potential of the targeted market.

4.3.2 Virtual pipelines[7]

Key factors taken into consideration

The key factors and drivers that affect the development of CNG and LNG virtual pipelines and have been taken into consideration directly or indirectly in the assessment of their growth prospects are presented below:

- Price differential between natural gas and competing fuels plays an instrumental role in the penetration of virtual pipelines in a region's energy mix. Usually the final consumers use dual-fuel applications, which leads to a continuous fuel-to-fuel competition;
- Direct or indirect tax incentives promoting the use of natural gas will increase its competitiveness with alternative fuels;
- Large scale applications of virtual pipelines are usually used to supply remote regions and end-users that are not connected to the transmission system;
- Distance affects the cost effectiveness of the virtual pipeline as the truck fuel is one of the largest operating expenses. Consumers at a large distance from the loading facility cannot be targeted;
- CNG virtual pipelines usually target smaller consumers compared to LNG virtual pipelines, due to the economies of scale of the latter. In general CNG is used to supply small towns and individual households, whereas LNG can supply larger local distribution networks;
- Harmonisation of the safety rules and technical specifications for CNG containers and for LNG trucks are required to facilitate cross-border trade;
- Utilisation of existing LNG terminals as loading facilities decreases the capital expenses and makes the LNG virtual pipelines more cost efficient;
- Supply of the LNG filling facilities is carried out through virtual pipelines.

Applied approach

The approach applied to estimate the market size for CNG and LNG virtual pipelines included the following steps (in some of these steps different assumptions were applied for CNG and LNG):

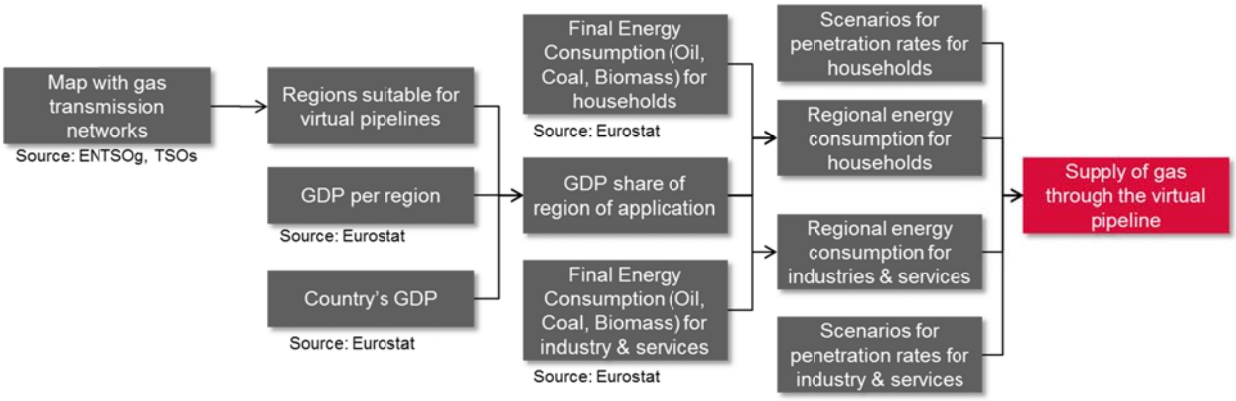
1. Identification of regions in the EU, which are suitable for the development of virtual pipelines of significant size. Using the maps from ENTSOG and national TSOs, an approximation to the areas without coverage of a gas transmission system was made. It is noted that any small transmission systems not included in these maps were not taken into consideration in this exercise. There are differences in the regions identified, for each of the scenarios examined.
2. Estimation of the identified regions' GDP. The GDP of each identified region was sourced on a NUTS 2[8] code level, from Eurostat. If the GDP data covered a broader area than the one identified, only a share of the NUTS 2 GDP was used.

[7] As the approaches applied for CNG and LNG virtual pipelines are similar, these are presented together, with the differences between the two pathways pointed out.
[8] Nomenclature of Territorial Units for Statistics

3. Calculation of the identified regions' final energy consumption, for fuels that are competitive to natural gas (oil, coal and biomass) for the industrial, services and residential sectors. The final energy consumption of a specific region was estimated as the share of the national final energy consumption, corresponding to the share of the region's GDP over the national GDP[9].
4. Application of penetration rates on the identified regions' final energy consumption. The penetration rates for the industrial and services sectors were differentiated from those of the household sector. Additionally, different rates were used for the penetration in households of regions with large climatological differences (three sets of rates for north, central and south EU were applied).

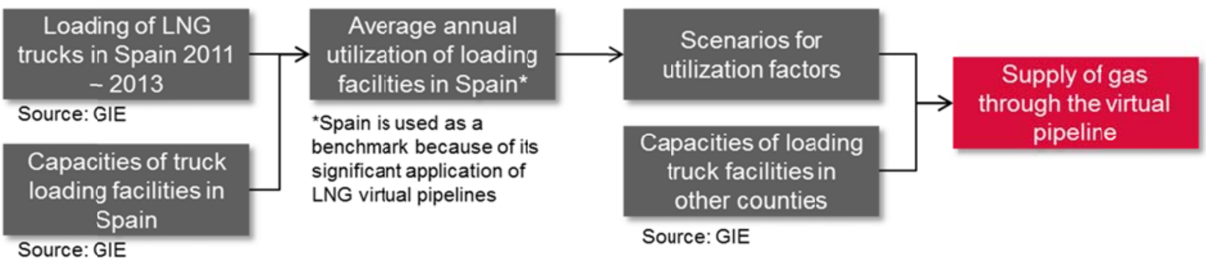
An overview of the approach is presented in the figure below.

Figure 37: Approach for CNG and LNG virtual pipelines



There are cases of countries with LNG terminals and very wide network coverage (Belgium, France, Italy, Netherlands, Portugal, Spain and UK), for which the approach described above would not allow the identification of large regions with potential for virtual pipelines. For these specific markets, an alternative approach is applied for LNG virtual pipelines (presented in Figure 38), based on the current LNG operation in Spain, which is the most mature market of such services in the EU. For the case of CNG virtual pipelines it is assumed that any supplies to final consumers would be very limited and therefore not examined in this high level estimation.

Figure 38: Approach for penetration of LNG virtual pipelines in markets with wide network coverage



[9] The nature of the economic activities of each region is important for the level of energy consumption and penetration of natural gas. As is the scope of this study a high level estimation of the market potential is carried out, a unified approach based on GDP is applied for all EU regions, and the breakdown of the economic activities for each region is not examined in detail.

After the procedure described above was applied, to calculate the market size for the supply consumers of the industrial, services and residential sectors, the supply of CNG and LNG filling stations using virtual pipelines was taken into consideration. The results of Chapter 4.3.2, for the projections of the use of gas in land transport were used as follows:

- For LNG filling stations, all supplies come from virtual pipelines. All the gas volumes estimated for the use of LNG in transport are added to the calculated market size;
- For CNG filling stations, it is assumed that only a small part will be located away from the gas system and will have to be supplied with virtual pipelines. Only 5% of the gas volumes estimated for the use of CNG in transport are added to the calculated market size.

Key assumptions

The key assumptions were the following:

- The virtual pipelines will be developed in the coming couple of years, allowing a sufficient time for maturity of the supplied markets until 2025, and the development of local distribution networks where required;
- Energy consumption is distributed within the countries in accordance with GDP distribution;
- No development of virtual pipelines in areas supplied with piped gas is examined (as such supplies are considered very limited and of little impact to the final result). Markets with dense gas networks will not receive any gas supplies, unless in the case of existing LNG terminals with truck loading facilities;
- The expansion plans presented in the ENTSOG's map (supplemented with maps of TSOs) are those taken into consideration when identifying the regions suitable for virtual pipelines;
- No implications in the cross-border transportation of CNG and LNG are considered;
- Any gas-fired power plants will be supplied through the network; targeted consumers of the virtual pipelines will be industrial, commercial and residential;
- No competition between CNG and LNG virtual pipelines is examined;
- LNG virtual pipelines are cost effective for a radius of 500 km from the loading facility. The respective range of CNG virtual pipelines is considered at 300 km;
- All LNG filling stations are considered to be supplied by LNG virtual pipelines.
- It is assumed that CNG virtual pipelines are used to supply a small fraction (5%) of the CNG filling stations, as most of them are either connected to the grid or are supplied through LNG virtual pipelines (L-CNG).

The main differences in the approaches used for CNG and LNG virtual pipelines are the following:

- A different range from the loading facilities is applied for CNG and LNG, as described in the assumptions above. It is assumed that CNG pipelines will not supply any islands, unless a pipeline is available on the island.
- CNG virtual pipelines can only target a small part of residential consumers (10% is assumed to be targeted for penetration). LNG pipelines can target any type of consumers.

- It is assumed that CNG virtual pipelines will not supply any markets which have a widely developed network and LNG virtual pipelines already in place (e.g. Spain, Portugal).

Scenarios examined

There are two groups of scenarios which are combined to perform the analysis; a group concerning the market penetration rates of the virtual pipelines (Table 17), and a group related to the infrastructure available for the development particularly of LNG virtual pipelines (Table 18).

As regards the penetration scenarios:

- The penetration rates of the base scenario are based on the EU experience for gas markets that have been operational for approximately 10 years.
- A lower penetration is used in the case of households, as the market penetration typically lags that of the other sectors. Additionally, different penetrations are applied for households in regions with large climatological differences.
- In the low scenario, the load factor of the truck loading facilities in Spain for the period 2011 – 2013 is applied, for France, Italy, Portugal, Spain and UK. In the base and high scenarios a moderate and high growth of the utilisation of the facilities is considered.
- In the cases of Belgium and Netherlands, due to the very wide network coverage, lower load factors are considered for the truck loading facilities.

Table 17: Market penetration scenarios (CNG & LNG virtual pipelines)

Market penetration scenarios	*Low*	*Base*	*High*
Penetration (industries & services)	20%	25%	30%
Penetration (households) – South	10%	15%	20%
Penetration (households) – Central	12%	18%	23%
Penetration (households) - North	15%	20%	25%
Load factor of truck loading to serve France, Italy, Portugal, Spain, UK	15%	20%	25%
Load factor of truck loading to serve Belgium and Netherlands	10%	15%	20%

Table 18: Infrastructure scenarios (for LNG virtual pipelines)

Infrastructure Scenarios	*Low*	*Base*	*High*
Existing and planned truck loading facilities at LNG terminals (source: GIE)	✓	✓	✓
Development of truck loading facilities at all LNG terminals	✓	✓	
Utilisation of existing small LNG storages (source: GIE)	✓	✓	
Development of any infrastructure required (e.g. LNG storages or liquefaction plans)			✓

Results of the analysis

The regions examined for each scenario of the CNG and LNG virtual pipelines and the detailed results per region are presented in Annex II.

The results of the analysis for the estimation of the market size of the CNG and LNG virtual pipelines in 2025 are presented in the tables below.

Table 19: Market size of CNG virtual pipelines for the 3 scenarios

	Low	*Base*	*High*
Gas supply to regions not connected to the gas system (bcm)	2.23	2.80	3.44
Supply of off-grid CNG filling stations (bcm)*	0.34	0.96	2.39
Total (bcm)	**2.57**	**3.76**	**5.83**

* Assuming 5% of the CNG demand for NGVs

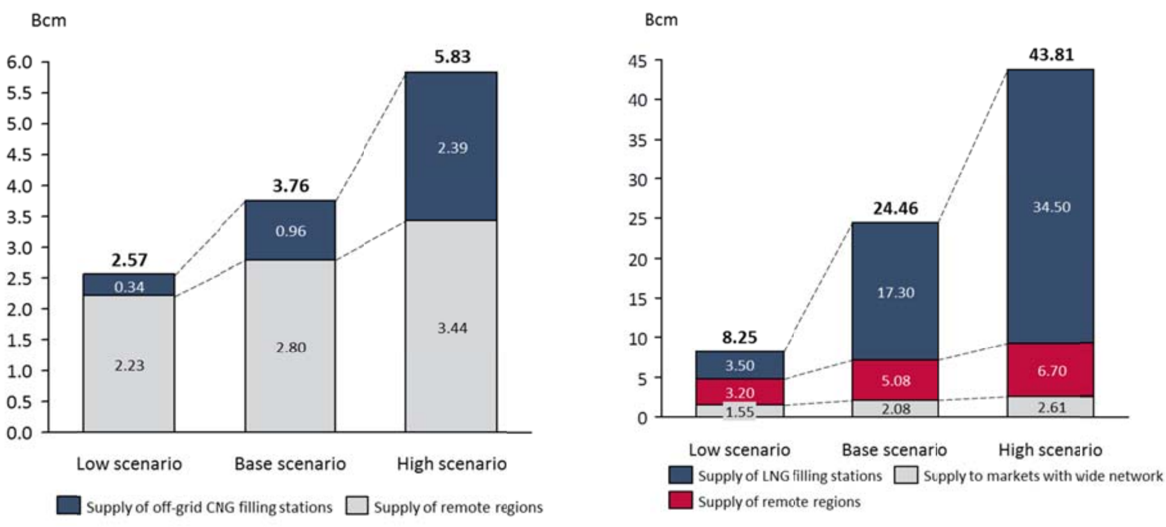
Table 20: Market size of LNG virtual pipelines for the 3 scenarios

	Low	*Base*	*High*
Gas supply to regions not connected to the gas system (bcm)	3.20	5.08	6.70
Gas supply to markets with a wide gas network, operating LNG truck loading facilities (BE, FR, IT, NL, PT, ES, UK) (bcm)	1.55	2.08	2.61
Supply of LNG filling stations (bcm)	3.5	17.3	34.5
Total (bcm)	**8.25**	**24.46**	**43.81**

According to GIE, the use of LNG virtual pipelines for the supply of filling stations and final consumers in the EU was around 1 bcm in 2013, so a significant growth is expected.

The results of the market size estimation show that a large share of the gas supply through virtual pipelines, particularly in the case of LNG, is linked to the use of natural gas in the transport sector.

Figure 39: Estimated market size for CNG and LNG virtual pipelines



CNG Virtual Pipelines **LNG Virtual Pipelines**

4.3.3 Land transport[10]

Key factors taken into consideration

The key factors and drivers that affect the use of natural gas in the land transport sector, and were taken into consideration directly or indirectly in the assessment of the application's prospects, are presented below:

- The introduction of stricter regulations by the EU concerning pollution and tailpipe emissions and the plans to minimise dependency on oil boosts the development of a market for alternative fuels. NGVs compete with other technologies, such as electric, hydrogen fuelled and LPG fuelled cars. The penetration of each technology is dependent on the fuel price, convenience to the drivers (e.g. availability of wide network of filling stations), incentives, and promotion from OEMs.
- The widespread adoption of CNG and LNG as a fuel in the transport sector is highly dependent on the creation of a sufficient network of filling stations (CNG and LNG). At the moment, a limited number of stations exist in EU countries, while plans for expansion are in place. The AFI Directive aims at the development of the required network of stations throughout the EU.
- The development of a market of CNG and LNG in the transport sector is highly driven by EU and country policies. For example financial incentives (subsidies) and favourable taxation for natural gas could provide a competitive advantage to gas against alternative fuels.
- Harmonisation of the technical standards for filling stations and for NGVs is required to facilitate the pan-European use of CNG and LNG. The AFI Directive seeks to establish harmonised standards in all EU Member States.
- The availability of NGV models and promotion of natural gas as fuel by the OEMs would boost the interest of the public.

Growth expectation by the industry

The literature examined includes projections for the future demand of natural gas for cars and LDVs in the medium term. The market shares expected in the year 2025, according to the Oxford Institute of Energy Studies, are shown in the following table.

Table 21: Estimates for growth of NGVs in 2025 (Source: Oxford Institute for Energy Studies)

Scenario	*Cars*		*Buses*		*Large Trucks*	
	% of market	*bcm*	*% of market*	*bcm*	*% of market*	*bcm*
Low	1%	9	10%	3	2%	2.1
Medium	2%	15	20%	5	10%	9.8
High	5%	33	50%	12	20%	19.5

NGVA Europe's estimates presented as "conservative", aim at a market share of 7% for all NGVs (CNG and LNG) in 2025, reaching 10% in 2030.

[10] The same approach, with different key assumptions and data is applied for all vehicles examined

The main drivers for the penetration of CNG in the sector include a favourable and sustainable EU-wide taxation regime, fiscal and subsidy schemes encouraging the adoption of NGVs, the expansion of the filling stations' network and the willingness to improve air quality in urban areas, which will promote the usage of CNG buses and other urban service vehicles.

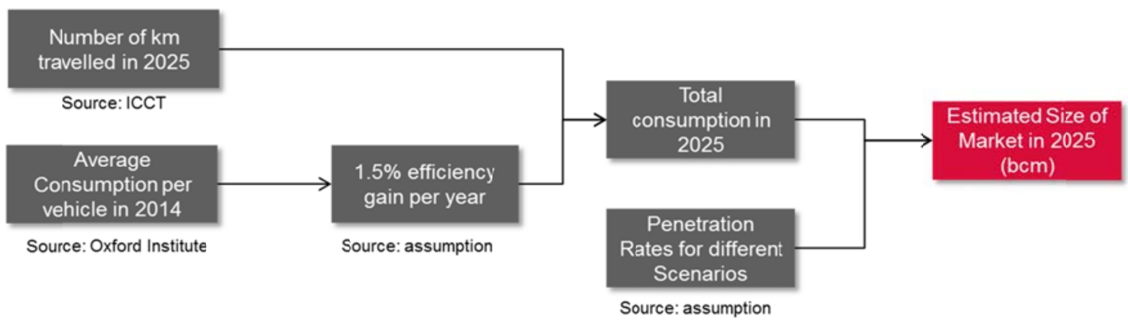
Applied approach

The potential market size for three types of vehicles was examined, cars & LDVs, buses and HDVs, using the same approach, which included the following steps:

1. Estimation of the number of kilometres that vehicles are expected to travel in the year 2025. Projections provided by the International Council on Clean Transport (ICCT) were used.
2. The average consumption per vehicle was estimated for 2014 (data from Oxford Institute of Energy Studies) and an efficiency factor was applied for expected developments in internal combustion engine technology.
3. The outputs of points 1 and 2 were used to calculate the total potential consumption of the vehicle fleet for the year 2025 (target market).
4. The estimated penetration of NGVs in the target market was applied to calculate the market size for 2025, expressed in terms of fuel consumption (bcm).

An overview of the approach is presented in the figure below.

Figure 40: Approach for gas use in transport



Key assumptions

Different assumptions were applied for each examined vehicle type. These are summarised in the table below.

Table 22: Assumptions per vehicle type

Type of vehicle	*Assumptions*
LDVs	- Current (2014) average consumption is assumed to be 8.5 lt of gasoline equivalent per 100 km (corresponding to 0.0875 Nm^3 gas/100 km), assuming the following: o Density of gasoline: 0.74 kg/lt o Calorific Value of gasoline: 47.3 MJ/kg o Calorific Value of natural gas: 34 MJ/Nm^3 (Russian gas) - Average consumption in 2025 will decrease, due to efficiency improvements. Assuming an annual efficiency gain of 1%, the average consumption will be 0.078 Nm^3/km.
Buses	- The average consumption of a bus is assumed to be the same as that of a light truck, i.e. about 0.18 Nm3/km in 2015.
HDVs	- The ICCT statistics lumps in one vehicle category different types and sizes of trucks. The medium

	and heavy duty vehicles are examined in this category - 10% of the trucks can be classified as heavy trucks (Oxford study). Given that, on average, heavy trucks travel many more km than light ones, 25% of the total number of kilometres is assumed to correspond to heavy trucks, and the remaining ones of light trucks, vans, etc. - Current (2014) average consumption for a heavy truck is assumed to be 27 kg of LNG per 100 km (Oxford study corroborated by other evidence). This corresponds to about 0.38 Nm^3 of gas per kilometre. - The average consumption of a light truck is assumed to be 60% of that of a heavy truck. - The above assumptions lead to an average current consumption of 0.265 Nm^3/km. - Average consumption in 2025 will decrease, due to efficiency improvements. Assuming an annual efficiency gain of 2% (Oxford study), an average consumption of 0.21 Nm^3/km is obtained.

Scenarios examined

The scenarios for development of the market assumed different penetration rates on the basis of the factors presented in the table below.

Table 23: Factors assessed to define penetration rates

Factors	*Low*	*Base*	*High*
Economic growth	Low growth / Recession	Medium economic growth	High growth
Availability of financing	Restricted	Reasonable	Financing readily available at low cost
Fuel prices (all fuels)	Low	Medium	High
Taxation of natural gas as a motor fuel	Increased taxation on gas agreed EU-wide or significant increases by key Member States	EU-wide taxation regime unclear. Some states increase taxes.	Long-term commitment by EC to low taxes
Ratio of gas / oil prices	Medium	Medium/Low (gas price decoupled from oil)	Low (gas price decoupled from oil)
Policy measures & incentives applied*	No incentives	Limited incentives	Strong incentives

*Note: Incentives may include indicatively: Fiscal incentives (tax cuts for NGVs); financial incentives (low-cost financing of buying NGVs, financial support to manufacturers' R&D, financial support for projects promoting NGVs, including information campaigns, etc.); "administrative" incentives, such as privileges for drivers of NGVs (driving of fast lanes, entering city centre, etc.).

Table 24: Penetration rates assumed for each vehicle type per scenario

Vehicle type	*Low*	*Base*	*High*
Cars & LDVs	1.0%	3.0%	7.5%
Buses	10.0%	20.0%	50.0%
HDVs	2.0%	10.0%	20.0%

Results of the analysis

The main data used to perform the analysis are presented in Table 25. The final results for each type of vehicle are presented in Table 26 and Table 27.

Table 25: Data used for each vehicle type

Vehicle type	No of Vehicles (2025) million*	No of total km/year (2025) million*	Average consumption (m^3/km) per vehicle
Cars & LDVs	284.6	3,522,000	0.078
Buses	1.1	35,000	0.182
HDVs	43.0	811,000	0.213

*Data from ICCT

Table 26: Estimated number of NGVs for each vehicle type per scenario

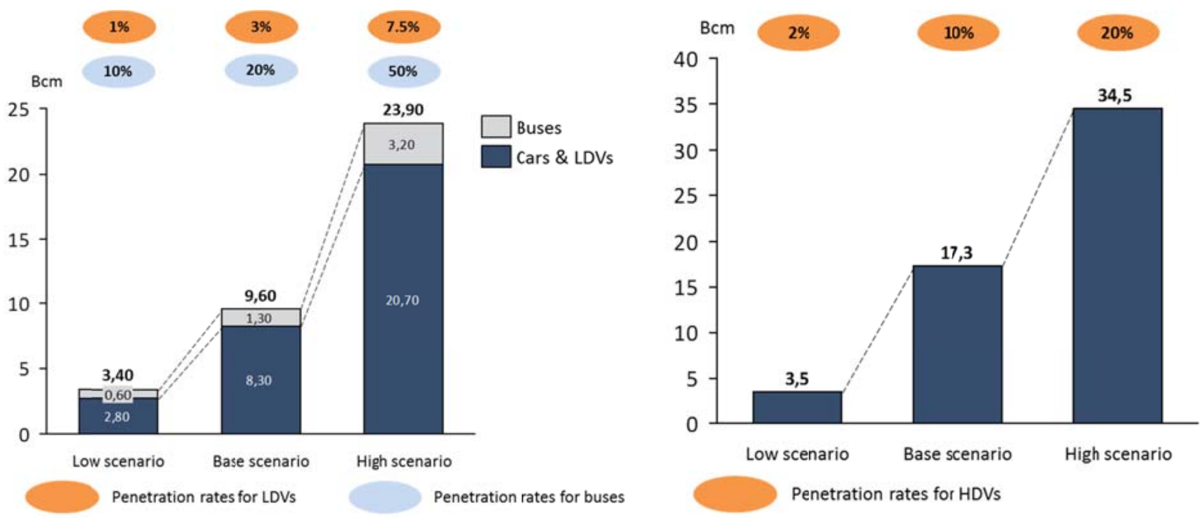
Vehicle type	***Low***	***Base***	***High***
Cars & LDVs (‘million)	2.8	8.5	21.3
Buses (‘million)	0.1	0.2	0.6
HDVs (‘million)	0.9	4.3	8.6

Table 27: Estimated market size for each vehicle type per scenario

Vehicle type	***Low***	***Base***	***High***
Cars & LDVs (bcm)	2.8	8.3	20.7
Buses (bcm)	0.6	1.3	3.2
HDVs (bcm)	3.5	17.3	34.5

The wide range between the high and low scenarios for the estimated market sizes of both LDVs and HDVs shows the potential for gas demand in the transport sector and also the uncertainty for the future development of this gas use, particularly as a result of the lack of infrastructure and uncertain EU-wide tax regime.

Figure 41: Estimated market size for CNG and LNG in road transport



CNG in road transport (LDVs and buses) **LNG in road transport (HDVs)**

4.3.4 Water transport

Key factors taken into consideration

A common estimate has been derived for deep sea vessels and inland waterways. The key factors and drivers that affect the use of natural gas in the water transport sector, and were taken into consideration directly or indirectly in the assessment of the development prospects are presented below:

- The introduction of worldwide regulations by the IMO and their adoption by the EU for reducing the pollution of maritime transport, by setting limits to SOx levels of exhaust gases, leads to the application of low or zero sulphur applications in ships, particularly in ECA regions. LNG is considered as an alternative fuel by the ship industry, as it complies with these regulations, but it has to compete with other alternatives, such as the use of MGO and the installation of scrubbers.
- The price differentials HFO vs. LNG and MGO vs. LNG play an important role in the decision of the shipping industry whether to switch to gas.
- Refuelling infrastructure will be required, including both LNG bunkering facilities in ports and LNG bunkering barges, to achieve widespread adoption of LNG. The size and location of stations will be determined by the bunkering requirements of deep-sea and inland waterway vessels. The AFI Directive addresses the development of the required infrastructure to facilitate bunkering in EU waters. However, particularly in the case of deep sea vessels, infrastructure is required at a worldwide level.
- Adoption of LNG as fuel will require the further development of dual-fuel vessel engines and common technical specifications for refuelling.

Growth expectation by the industry

Presently, there are a very limited number of vessels that utilise LNG as bunker fuel. There are also a limited number of LNG terminals that offer bunkering facilities. Even though the price of LNG is currently competitive to that of HFO and occasionally lower (Figure 24) ship owners are reluctant to change due to the high investment costs required to upgrade their vessels to burn LNG. Another factor hindering change is the lack of a network of LNG bunkering facilities close to SECAs. Ship owners expect that the SECAs will take effect on time; however the 2020 worldwide SOx limitations might get postponed.

Fuel accounts for the vast majority of a vessel's daily OPEX and given the current lower price of LNG (more than half of MGO), stakeholders expressed their desire to utilise LNG, as long as sufficient LNG bunkering infrastructure is in place.

According to the Danish Maritime Authority (DMA), there are currently 14,000 vessels entering the European ECA, which consume about 12 mtpa. Assuming a fleet growth rate of 2 %, about 17 mtpa can be expected to be used within the SECA in 2030. Given the lifespan of vessels and urgency to meet the new IMO regulations, the DMA expects the demand from both retrofits and newbuilds to increase. It also expects the annual LNG demand to reach 5 bcm (8.5 million m^3 of LNG) in 2020 and 8.5 bcm (14 million m^3 LNG) in 2030.

As regards IWT vessels, the Oxford Institute for Energy Studies, assuming a penetration of 10% for NLG, expects the annual consumption of LNG to increase to 6.2 bcm in 2025.

Several stakeholders have undertaken projections for the use of natural gas for international marine transportation. The following table summarises the projections for global demand of gas.

Table 28: Projections for gas demand for international marine transportation (Source: Oxford Institute for Energy Studies)

Forecast (bcm)	*2015*	*2020*	*2025*	*2030*
IEA NPS				5 (2035)
Lloyds	0-1	0-3		6 -52
Shell		7-18	22-90	
DNV		11-45		
DMA		5		8.5
Total SA	0	15		45

Applied approach

The applied approach used data from literature on the number of ships in EU waters and worldwide projections on the LNG consumption is ships, to estimate the market size:

1. The number of vessels entering EU waters was defined using EC data (statistical yearbook 2013) for 2011;
2. DNV data were used to define the projected global LNG demand in shipping in 2020, for different scenarios concerning the price of LNG;
3. The outputs of points 1 and 2 are used to calculate the market size for the use of natural gas in the water sector. It is noted that, due to limitation in the available data, for the case of water transport 2020 is used as year of reference.

The following key assumptions were taken into consideration in the calculations:

- The projected LNG worldwide consumption in 2020 is the same as in DNV's report. Prices of LNG were determined as a proportion of HFO prices;
- According to the EC data, the EU fleet accounted for 31% of world fleet in 2011. It is assumed that the same proportion will exist in 2020.

The scenarios examined were a selection of the scenarios assessed by DNV in their projections (Table 29).

Table 29: Scenarios for use of gas in water transport (based on DNV data)

	Low	*Base*	*High*
LNG World Consumption (bcm)	11.29	19.68	44.84
Scenario description	Price of LNG assumed to be 110% of HFO	Price of LNG assumed to be 70% of HFO	Price of LNG assumed to be 30% of HFO

Results of the analysis

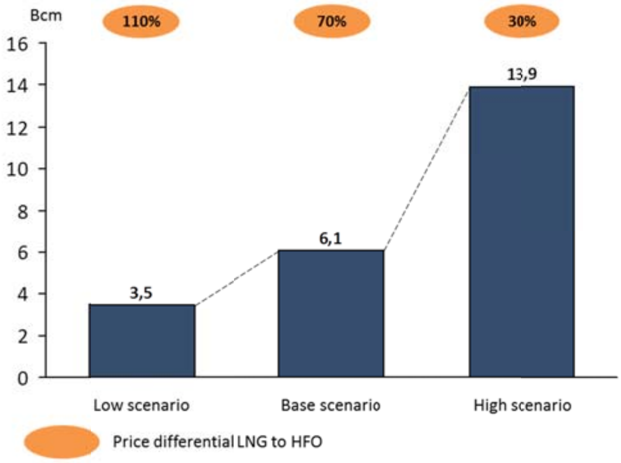
The estimated market size for the use of gas in the water sector is presented in the table below.

Table 30: Market size for use of gas in water transport

	Low	*Base*	*High*
Market size (bcm)	3.5	6.1	13.9

The use of LNG as a fuel in deep sea vessels and inland waterways depends to a large extent on the price differential with HFO, as this would determine whether LNG is used only in regulated zones or in other areas as well. This can be seen in the market size results, which are sensitive to the scenarios of LNG price levels.

Figure 42: Market size for use of gas in the water sector



4.3.5 Power-to-Gas

Key factors taken into consideration

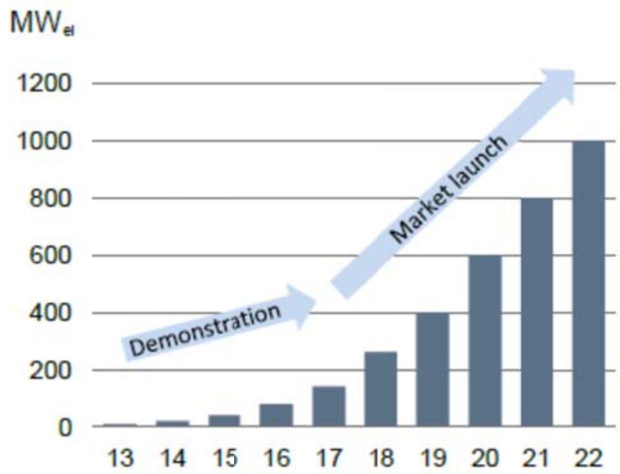
The key factors and drivers that affect the integration of the Power-to-Gas technology in the electricity and gas grid, and were taken into consideration directly or indirectly in the assessment of its development prospects, are presented below:

- The level of integration of RES in the power system and the subsequent need for electricity storage is the key driver for the deployment of P2G units;
- Potential utilisation of other energy storage media, such as pumped hydro storage and batteries can affect the excess energy available for P2G;
- Incentives provided to the investors of the P2G technology and levies imposed on the used electricity price strongly affect the future development of P2G applications;
- Gas quality constraints and safety issues at the gas transmission or distribution system may limit the amount of hydrogen injected in the system;
- The electrolysis method applied for the production of hydrogen affects the input of electricity required and consequently the efficiency of the unit.

Growth expectation by the industry

Germany, as the European leader in Power-to-Gas application so far, sees favourable prospects for this technology. According to the stakeholders of the Power to Gas Strategy Platform (led by the German Energy Agency, dena), which is involved with the development of the technology in Germany, P2G units with aggregate electrical capacity of 1,000 MW are required to achieve a commercial market launch by 2022 (Figure 43).

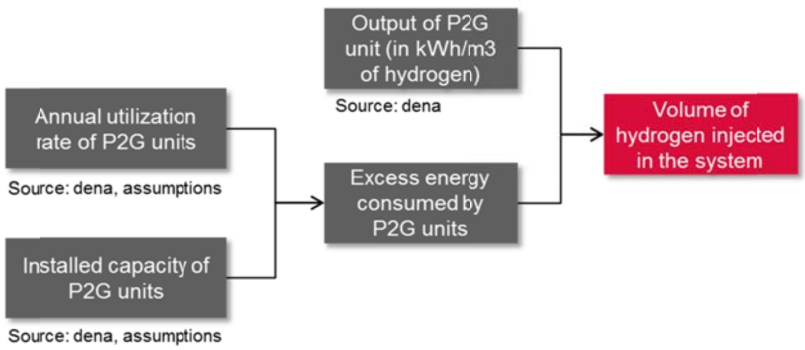
Figure 43: Development of P2G market in Germany up to 2022 (Source: Power-to-Gas Strategy Platform)



Applied approach

The basis of the estimates for the market size of P2G in 2025 were the estimations of dena and the Power-to-Gas Strategy Platform, according to which a capacity of 1,000 MW will be available in Germany by 2022. The scenarios examined assumed the implementation of P2G units in Germany and in other countries with large integration of renewables, and also an annual utilisation rate of the P2G units. The approach applied is presented in the figure below.

Figure 44: Approach for Power-to-Gas



Key assumptions

The key assumptions were the following:

- Installed P2G units in Germany in 2025 will have an aggregate capacity of 1,200 MW (20% increase of the installed capacity foreseen by dena in 2022);
- Other countries, in which future installation of P2G is assumed, are those that are expected to have a high estimated share of RES in the energy mix and high wind curtailment needs in 2025, according to JRC. These countries are considered to have increased needs for energy storage capacity and therefore may be interested in developing P2G units. Namely the countries examined (different sets of countries examined in each scenario) are Denmark, Ireland, Greece, Portugal, Spain, UK;

- Starting from the German P2G installed capacity for market launch (1,000 MW) as a reference, the capacity of P2G units of each of the above countries is considered to be proportional to the wind capacity of the respective country;
- All P2G units are assumed to be connected to the electricity grid. Most of the energy storage requirements are expected to be covered with utilisation of pumped hydro storages and interconnections with other countries, while P2G will have a supporting role;
- It is assumed that there are no quality limitations for the injection of hydrogen to the system;
- The P2G units are assumed to use PEM electrolysis (in accordance with the views of the interviewed stakeholders), with electricity input of 4 kWh/Nm^3 of hydrogen required. No future increase in the efficiency of hydrogen production is taken into consideration.

Scenarios examined

There are two groups of scenarios which are combined to perform the analysis; a group related to the countries in which the P2G technology will be applied in 2025, presented in Table 31, and a group regarding the assumed load factor (utilisation rate) of P2G units, presented in Table 32.

Table 31: Scenarios for countries applying the P2G technology

Country	*Assumed P2G installed capacity in 2025 (MW)*	*Low*	*Base*	*High*
Denmark	130	✓	✓	✓
Germany	1,200	✓	✓	✓
Greece	175			✓
Ireland	90			✓
Portugal	150			✓
Spain	770		✓	✓
UK	600		✓	✓

Table 32: Scenarios for load factors of P2G

Country	*Low*	*Base*	*High*
Load factor of P2G unit	10%	15%	20%

The penetration rates indirectly take into account research on the future needs of energy storage in EU countries, such as the EC-funded project “stoRE”[11].

Results of the analysis

The estimated electricity input and hydrogen output of the P2G units are presented in Table 33 and Table 34 below.

[11] http://www.store-project.eu/en_GB/documents

Table 33: Estimated electricity input for the P2G units

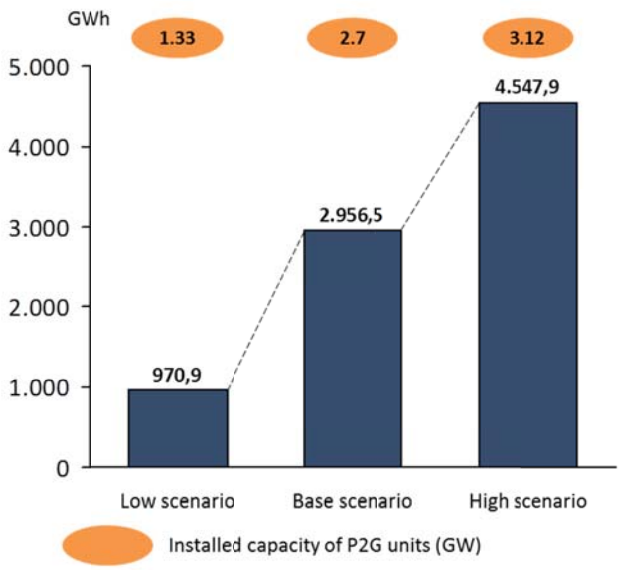
Country	*Low*	*Base*	*High*
Denmark (MWh)	113,880	170,820	227,760
Germany (MWh)	1,051,200	1,576,800	2,102,400
Greece (MWh)	-	-	306,600
Ireland (MWh)	-	-	157,680
Portugal (MWh)	-	-	262,800
Spain (MWh)	-	1,011,780	1,349,040
UK (MWh)	-	788,400	1,051,200

Table 34: Estimated hydrogen output from the P2G units (market size)

Country	*Low*	*Base*	*High*
Denmark (GWh)	94.9	142.4	189.8
Germany (GWh)	876.0	1.314.0	1.752.0
Greece (GWh)	-	-	255.5
Ireland (GWh)	-	-	131.4
Portugal (GWh)	-	-	219.0
Spain (GWh)	-	843.2	1.124.2
UK (GWh)	-	657.0	876.0
Total (GWh)	970.9	2.956.5	4.547.9

The estimation of the potential for development of Power-to-Gas up to 2025 shows that its market size will remain limited, even at the high scenario. It should be taken into consideration, however, that the reference year examined is only 3 years after the expected full market launch of the technology, which is foreseen in 2022. A large scale development of P2G units, together with an increased penetration of renewables in the energy mix, could lead to much higher market sizes from 2030 onwards.

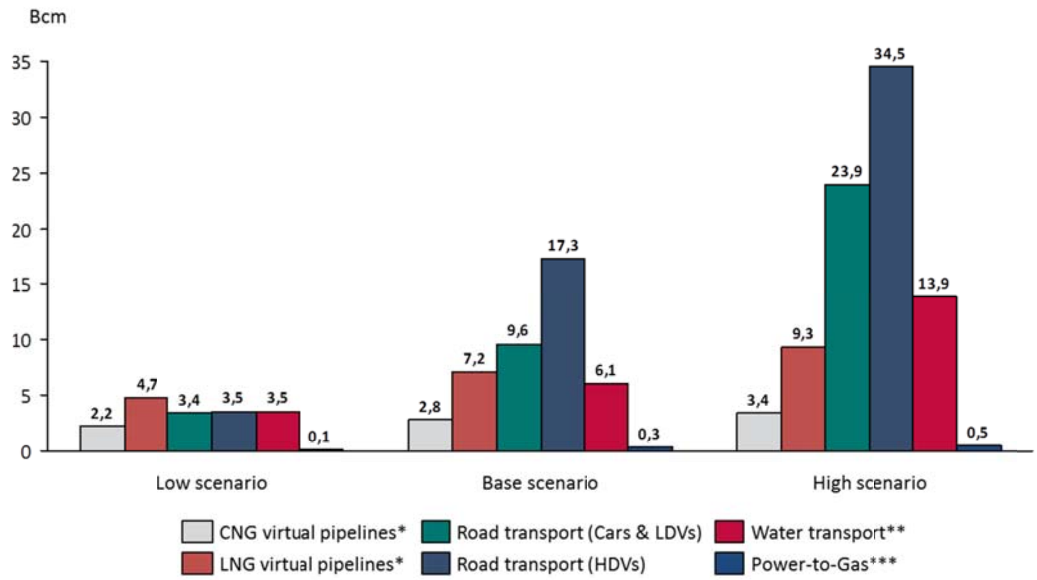
Figure 45: Estimated market size for Power-to-Gas



4.4 Conclusions

The figure below summarises the estimated market sizes in 2025 for all new developments in the gas supply chain that were examined.

Figure 46: Market sizes for all examined new gas supply chain developments in 2025



* Virtual pipelines: Supply of CNG and LNG filling stations not included in the values
**Water transport: Data used are projections for 2020
*** Power-to-Gas: Hydrogen output converted to natural gas equivalent, using GCV of Russian gas

The use of gas in the transport sector is considered to have the largest growth potential, given the large fleet of vehicles and vessels that could switch to natural gas.

Brief comments on the prospects for development of each use for gas are provided below.

<u>Virtual Pipelines</u>

Virtual pipelines are expected to have a short-term prospect of development. There are already many applications of non-piped CNG and LNG supply worldwide and in the EU, while gas transported with virtual pipelines can be competitive with alternative fuels.

As most of the large gas consumption centres in the EU are already connected to the transmission system and receiving piped gas, it can be expected that the large-scale applications of virtual pipelines will mostly target smaller final consumers or non-gasified regions with relatively low demand. This leads to a limited market size for virtual pipelines supplying final consumers[12], in comparison to piped gas, and to their application in specific regions in the EU.

The further development of virtual pipelines has strong synergies with the use of gas in the transport sector:

- CNG virtual pipelines can supply filling stations located away from the gas grid, allowing the expansion of the network station. At the same time, large CNG filling stations can operate

[12] Not including the case of virtual pipelines supplying filling stations.

as compression and loading terminals for virtual pipelines, increasing the cost effectiveness of both applications.

- The supply of the LNG filling stations and satellite bunkering facilities is carried out through LNG virtual pipelines. The widespread use of LNG-fuelled HDVs and vessels would boost the application of virtual pipelines, while the development of the required truck loading infrastructure would develop economies of scale that reduce the gas transportation costs for the supply of all other final consumers.

Land transport – cars, LDVs, HDVs

The main driver for use of gas in land transport is economic. The market is currently driven by the low prices of gas, compared to oil products, with a price differential that is enhanced by very low taxes on gas. The strong support expressed by the AFI Directive (which, however, lacks a priori mandatory targets) and the impending development of international standards for CNG and LNG filling stations have removed some important non-economic barriers. The NGV market (in both LDVs and HDVs) is poised to grow fast if the key stakeholders (vehicle owners, infrastructure developers/gas suppliers and vehicle manufacturers) receive an unequivocal signal from the European Commission that it is seriously interested in promoting gas in transport and that it will support this policy with sustained low taxation on gas and with appropriately targeted incentives and measures by the Member States.

Land transport - rail

The use of gas in the EU's rail sector is expected to be marginal. Although there are ongoing applications for the use of LNG in locomotives in Russia and the United States, most of which in the pilot stage, the market characteristics in those countries favour the use of gas in the sector; they have abundant quantities of cheap gas and a high market concentration in the rail sector. In the EU the use of LNG in rail is hindered by the limited market (a large number of locomotives are electricity-powered) and the large number of players that would have to cooperate and coordinate for the large scale development of the application. Small scale applications at a local level may take place, but a large scale deployment is not expected at least in the medium-term.

Water transport

Use of gas (LNG) as a marine fuel is driven almost exclusively by the progressively stricter environmental regulations, imposed by both the IMO in ECA zones and the EU along the member states' coasts. The gas bunkering market is expected to grow significantly in the coming decade, as natural gas appears to be the ideal solution: it is environmentally friendly (zero sulphur emissions) and much cheaper than MGO, while the solution of HFO scrubbers cannot be a long-term one. What remains is the development of adequate infrastructure for gas bunkering at LNG terminals and in key European ports, a matter that is dealt with by the AFI Directive. The availability of appropriate financing for both the infrastructure and the retrofitting of existing ships will be important for catalysing market growth.

Power-to-Gas

The Power-to-Gas technology is expected to have a medium-term prospect. This is also the perception of stakeholders involved with the technology, such as the Power-to-Gas Strategy Platform that expects the commercial launch of the technology in 2022.

A large commercial deployment of P2G units depends to a large extent on the technology's competitiveness compared with other electricity storage technologies and its resulting position in the merit order of energy storages. The EU policies for further integration of renewables in the energy mix and the resulting increase of excess electricity could boost the development of P2G, especially post 2025, when P2G commercial applications can be expected to reached an adequate level of maturity.

Gas hydrates

Gas hydrates as a means of storage and transport of gas are considered to have a long-term and marginal prospect for development, and therefore the respective market size was not assessed. The technology is still at a research level, with its commercial development not expected in the next decade. In addition, there are already mature technologies (mainly LNG storage and virtual pipelines) addressing successfully the same market needs as gas hydrates, i.e. storage and transport of gas. Consequently, the targeted market for hydrates is expected to be non-existent or at best marginal at least in the short and medium term.

5. BARRIERS, ISSUES TO BE ADDRESSED AND RECOMMENDATIONS

5.1 Overview

In this Chapter the potential barriers to the development of the new developments in the gas supply chain are discussed. Only the developments that are considered to have short and medium term prospects, as identified in Chapter 4, are being examined in the following sections.

The focus of the analysis is the regulatory barriers and issues to be addressed, as this is a main topic of this study. Recommendations on some of the identified regulatory issues are proposed. Other important barriers that may hinder the growth of each new development use are also presented. The relevant information was sourced from the literature review, the input provided by stakeholders during the interviews and the Consultant's own expertise.

The examined barriers cover issues related to:

- market regulations;
- technology;
- technical specifications, health & safety regulations;
- economics;
- financial issues;
- infrastructure; and
- consumer behaviour.

As regards market regulations, the study examines each activity of the supply chains of the new developments and identifies whether, according to the regulatory framework in force (defined mainly by the Directive 2009/73/EC – "the Directive") the activity is clearly defined as regulated, is clearly unregulated or the regulatory regime is unclear. The study also identifies some regulatory barriers arising from the nature of the market operations, associated with the new developments. This analysis seeks is to support ACER and the NRAs in comprehending the barriers and issues related with the new developments, so that they can address them and take appropriate regulatory action if and where required, to assure proper market operation in the EU.

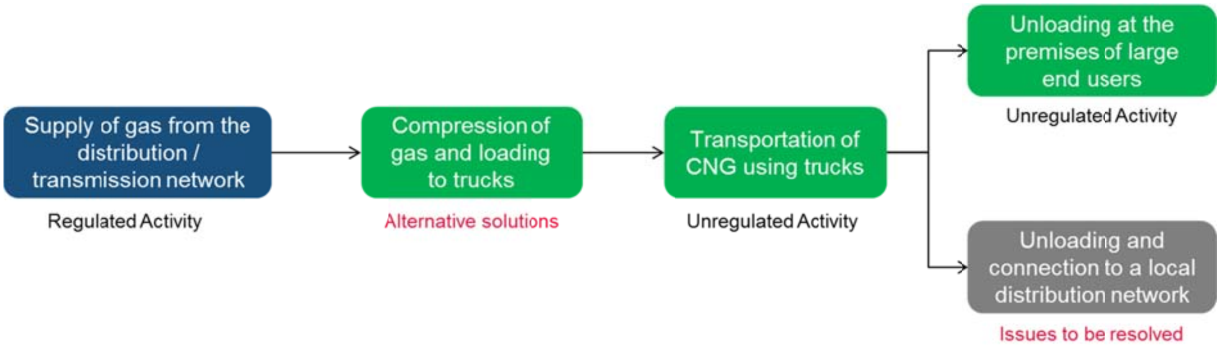
5.2 CNG virtual pipelines

5.2.1 Regulatory issues, barriers and recommendations for CNG virtual pipelines

Regulatory issues related to the operation of CNG virtual pipelines

An overview of the main activities included in the supply chain of a CNG virtual pipeline is presented in Figure 47. As shown, most of these activities can be clearly considered as regulated or unregulated.

Figure 47: Activities of a CNG virtual pipeline*



*Blue: regulated, Green: unregulated, Grey: to be clarified

The regulatory considerations and potential issues to be addressed, related to each of the activities of a CNG virtual pipeline and its overall operation, are discussed below.

<u>Supply from the network</u>

The CNG loading terminal is an exit point of the transmission or distribution system to which it is connected. Therefore, the operators of the CNG terminal (or CNG suppliers if these are different entities) receive gas in accordance with the network operation codes, like all network users.

<u>Operation of the CNG terminal (compression and loading)</u>

In principle the operation of the compression station and loading of CNG trucks at a CNG terminal is an unregulated activity in privately-owned facilities. This is the case for two examined applications of virtual pipelines (Italy and Bulgaria). The unregulated operation can be justified by the potential development of competition with other CNG terminals (as the capital investment required is not very large) and with CNG filling stations that can provide small or even large volumes of CNG.

An alternative option would be to install a public compression station operated by the TSO/DSO with third party access to all interested users at regulated tariffs. This can be an important tool for opening the market to competition, especially with small providers, as several market players would be able to supply CNG on the same terms.

<u>Transportation of CNG</u>

The transportation of CNG using trucks is not a regulated activity. According to the Directive, only the transmission and distribution activities in relation to the transport of natural gas through networks of pipelines, with a view to its delivery to customers, are regulated.

<u>Unloading at the premises of an end-user</u>

The unloading and storing of CNG in containers at the site of a final consumer (either owned by the final consumer or sub-let by the CNG supplier), supplying gas for their own use, is not subject to any regulations.

<u>Operations at the local distribution network</u>

The use of CNG canisters to inject gas to a local distribution network is an alternative way of supplying the network, in case connection to a transmission system is not available. In accordance with the Directive, the local distribution networks should provide third party access to all suppliers, apart from the cases where an exception to TPA is provided, e.g. for closed distribution systems according to Art. 28.

However, although TPA is required, there are practical problems in operating a network with more than one CNG suppliers, especially related to the dispatching of gas from CNG canisters of several suppliers. Although this is an issue of technical and not regulatory nature, the smooth operation of the network by the DSO could be hindered.

A network code with clear and detailed rules for dispatching CNG by several suppliers should be established by the DSO. The code should also define the technical specifications of the canisters connected to the distribution system, to avoid any unjustified refusal of access to CNG suppliers due to the specifications of their CNG virtual pipelines.

Licensing

The activities of CNG supply to final consumers using virtual pipelines should be treated in the national regulatory framework as an activity of natural gas supply. In this respect, in countries where gas supply requires a license from the NRA, CNG suppliers should obtain such a licence. The Directive does not explicitly include the case of CNG in the definition of supply. This may delay the process of licencing of the activity in some countries and thus hinder the market entry of prospective CNG suppliers.

In regards to the operation of a CNG terminal, as the activity is considered unregulated, no licence for its operation is required.

Gas-to-gas competition

In cases of transmission or distribution systems where non-piped gas can be competitive to piped gas supplies (e.g. cases of expensive distribution networks with limited final consumers), situations of competition between non-piped gas and piped gas may emerge. In some countries (e.g. Spain) the current regulatory framework does not allow non-piped gas to piped-gas competition and obliges end-users to be supplied through a network if they are close to it. In such cases, the development of virtual pipelines may be disincentivised.

Cross-border issues

According to the stakeholders interviewed, no regulatory issues or barriers have been noted for cross-border trade using virtual pipelines.

Potential regulatory barriers related to the operation of CNG virtual pipelines

Taking into consideration the issues discussed above, the following regulatory barriers can be identified, which may hinder the development of CNG virtual pipelines:

- In cases where the national regulatory framework foresees a licence for gas supplies, the lack of licensing provisions particularly for CNG supplies, either in a special licence or in a licence including both piped and non-piped activities, may delay or even obstruct the development of the CNG virtual pipeline. The lack of such provisions may lead to uncertainties as to when and whether a supplier will be able to receive a licence to perform such activities.

- Provisions not allowing gas-to-gas competition between piped and non-piped supplies can hinder the development of virtual pipelines. Interested parties may be reluctant to invest in the implementation of virtual pipelines, especially infrastructure, if after they have developed a significant market of non-piped gas supply, there is a risk of the construction of a transmission and/or distribution network to which connection is obligatory for all consumers.
- The technical difficulties of supplying a local distribution network with CNG canisters of various suppliers may lead to distortion of competition.

Recommendations

To tackle with the regulatory barriers to the development of virtual pipelines, the following recommendations should be taken into consideration:

- In the absence of a specific definition of supply of CNG in the EU regulatory framework, it is recommended that ACER and the NRAs ensure that CNG supplies are treated in the market under the same terms as piped gas. If a licencing process for gas supplies is required, this should also include licencing of non-piped CNG.
- The issue of gas-to-gas (CNG to piped gas) competition has to be assessed at national level, depending on the national policy for promoting non-piped gas and for developing gas networks. In this respect, the issue should be addressed, if required, by the pertinent National Authorities.
- The operators of local distribution networks supplied with CNG virtual pipelines should develop network codes that provide clear and detailed rules for the dispatching of CNG by several suppliers.

5.2.2 Other issues and barriers for the development of virtual pipelines

Apart from the regulatory issues and barriers discussed above, there are other potential barriers that may hinder the development of CNG virtual pipelines.

<u>Technical Specifications and Health & Safety Regulations</u>

- Any national restrictions in the allowed weight of shipments transported with trucks would reduce the effective gas volumes that are supplied per truck trip. In cases of cross-border transportation of CNG, the supplier must adhere to the restrictions of every country crossed. This has an impact in the cost effectiveness of the virtual pipeline, particularly if large distances have to be travelled.
- The lack of national regulations allowing the transportation of CNG with trucks may result in restrictions in the transportation of gas, particularly by local communities.
- The lack of safety regulations regarding the loading and unloading terminals may delay the permitting process of a virtual pipeline.

<u>Technology</u>

CNG virtual pipelines have been in operation for several years and the technologies applied are mature. Thus no technological barriers have been identified.

Economics

- In general the transportation costs of a CNG virtual pipeline are higher than a mature gas network. As a result, non-piped gas supplies are not competitive to piped gas and the large scale applications are limited to areas with no pipeline coverage.
- The limitation of the CNG supplies to 150 – 300 km from the loading terminal, for economic reasons, reduces the accessibility of the virtual pipelines to targeted final users. Cross-border trade using CNG virtual pipelines is also limited only to loading facilities that are located near the borders.

Infrastructure

- The lack of CNG vessels hinders the transportation of CNG to islands. This is currently possible only with open-type ferries, which are very limiting to the gas volumes that can be transported.
- Due to the small volumes of gas transported by each CNG truck, the logistics of the CNG virtual pipelines are increased, in comparison to LNG ones. The supply of large final consumers or networks requires the availability of a significant number of trucks, increasing the cost of the application.

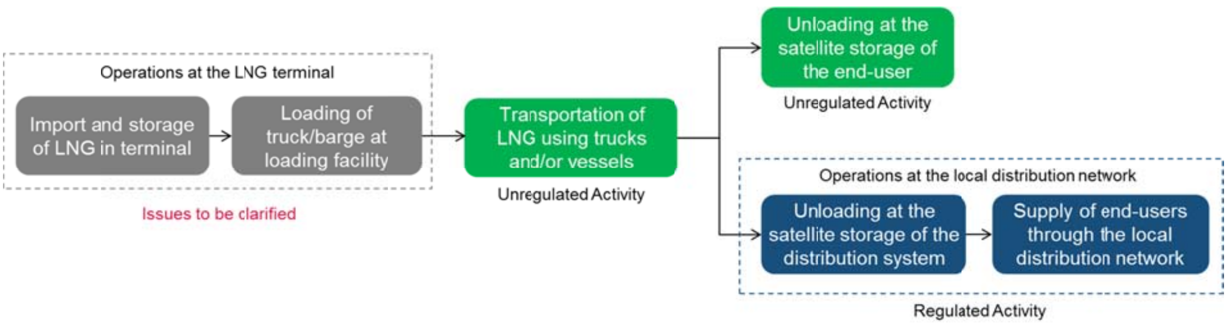
5.3 LNG virtual pipelines[13]

5.3.1 Regulatory issues, barriers and recommendations for LNG virtual pipelines

Regulatory issues related to the operation of LNG virtual pipelines

An overview of the main activities included in the supply chain of an LNG virtual pipeline is presented in Figure 48. As shown in the figure, some of these activities can be clearly considered as regulated or unregulated, while for others the regime is unclear, and is dependent on the type and operation of the infrastructure involved.

Figure 48: Activities of an LNG virtual pipeline*



*Blue: regulated, Green: unregulated, Grey: to be clarified

The regulatory considerations and potential issues to be addressed, related to each of the activities of an LNG virtual pipeline and its overall operation, are discussed below.

[13] There are similarities and overlaps in the identified barriers for the CNG and LNG virtual pipelines. However, these are mentioned separately for each gas use, to avoid confusion by the reader.

Operations at the LNG terminal (LNG storage)

There are alternative set-ups for the supply of LNG virtual pipelines, including loading facilities that utilise LNG storages of regasification terminals, facilities connected to dedicated LNG storages or satellite LNG storages, etc. Careful consideration is required to determine in which cases the operations of the loading facilities and the related LNG storages should be regulated.

The term “LNG Facility” as defined in the Directive, covers only the activities related to the regasification of gas. The LNG storages of virtual pipelines fall under the definition of “Storage Facilities” of the Directive, i.e. “[…] facility used for the stocking of natural gas and owned and/or operated by a natural gas undertaking, including the part of LNG facilities used for storage […]”. According to Art. 15 and 33 of the Directive, for Storage Facilities that are technically and/or economically necessary for providing efficient access to the system for the supply of customers, the storage system operator has to be at least legally and operationally unbundled from supply functions, while negotiated or regulated third-party access should be provided.

Furthermore, for such Storage Facilities, Art. 15, 17, 19, 20 and 22 of Regulation 715/2009 set legally binding standards for third-party access services, capacity allocation and congestion management, and transparency concerning storage facilities. For any other Storage Facilities, only the provisions of Art. 19(4) that concern transparency in storage capacity and use are applied.

Currently NRAs in the EU member states apply different approaches as to which LNG facilities (used in the supply chain of virtual pipelines) are regulated. This lack of a consistent EU-wide approach, may distort competition, for example between a bundled undertaking and an unbundled supplier, using LNG facilities at different countries and competing for the supply of the same final consumer through virtual pipelines. This is an issue that has potential cross-border impact and may have to be addressed with a common EU-wide approach coordinated by ACER.

Operations at the LNG terminal (Loading facilities)

In case the LNG storage that supplies the truck or barge loading terminal is open to third party access, the TPA should also be provided to the loading terminal (otherwise TPA to the storage facility for the purposes of the virtual pipeline would not make sense).

In case TPA is provided, a code of operation of the facility is required (covering issues such as capacity allocation mechanism, rules for secondary market, operating rules, management procedures, truck approval procedures, LNG specifications, testing and measurements procedures, congestion management at the terminal, handling of emergencies), a standard agreement between the operator of the facility and that of the LNG trucks/barges, and regulated tariffs for the service.

Transportation of LNG

As in the case of CNG virtual pipelines, the transportation of LNG using trucks or barges in the frame of a virtual pipeline is not a regulated activity. According to the Directive, only the transmission and distribution activities in relation to the transport of natural gas through networks of pipelines, with a view to its delivery to customers, are regulated.

Unloading at a satellite storage of an end-user

A satellite LNG storage installed at the site of a final consumer (either owned by the final consumer or sub-let by the LNG supplier), supplying gas for their own use, is not subject to any regulations.

Operations at the local distribution network

Satellite LNG storages that are supplying local distribution networks not connected to the transmission system may:

- either be owned and operated by LNG suppliers (each supplier having their own storage connected to the distribution system); or
- be part of the distribution system and operated by the DSO.

The first option is not expected to be widely applied, as it may raise technical and operational issues for the distribution system.

Where the satellite LNG storages are part of the DSO's assets, their operation should be regulated and subject to the same provisions as the distribution system. TPA should normally be granted to LNG suppliers. In case the distribution network can be classified as a closed distribution network, according to Art. 28 of the Directive, an exception to TPA is provided. The network code of the DSO should include provisions for the procedure of LNG unloading to the storage facility (capacity allocation, operating rules, truck approval process, etc.).

Licensing

In the Directive, the definition of "supply" includes the sale or resale of LNG to customers. The activities of LNG supplies to final consumers using virtual pipelines should be treated in the national regulatory framework as an activity of natural gas supply. In this respect, in countries where gas supply requires a license from the NRA, LNG suppliers have to obtain such a licence.

A licence for the operator of the LNG storage and the LNG loading terminal is required if the activity is regulated.

Gas-to-gas competition

In cases of transmission or distribution systems where non-piped gas can be competitive to piped gas supplies (e.g. cases of expensive distribution networks with limited final consumers), situations of gas-to-gas competition may emerge. In some countries (e.g. Spain) the regulatory framework does not allow gas-to-gas competition and obliges end-users to be supplied through a network if they are close to it. In such cases, the development of virtual pipelines may be disincentivised.

Regulations for the LNG storage

Regulations related to the storing of gas or LNG at the storage facilities of a country may distort the operation of a virtual pipeline. For example, according to stakeholders interviewed, in France the maximum period that a supplier may store gas at an LNG terminal is one month. This is a sufficient period for LNG to be regasified and injected in the system, but may hinder the supply of small volumes of LNG to final consumers, as the LNG supplier would have to import small shipments of LNG each month instead of receiving a large shipment and exploiting the economies of scale. In the case of Spain there is no time limitation for storing LNG.

This may lead to a distortion of cross-border competition as suppliers importing LNG in different markets may have to purchase LNG at significantly different prices, due to different operating rules at the LNG facilities.

Apart from cases in which limitations to the storing period of LNG result from technical issues, an EU-wide approach coordinated by ACER may have to be considered.

Addressing cases of emergency

An issue related to LNG storages and truck loading facilities is how these are used for security of supply reasons in cases of emergency and supply disruption. The virtual pipelines could be included in the emergency plans foreseen in Regulation 994/2010.

Cross-border issues

According to the stakeholders interviewed, no regulatory issues or barriers have been noted for cross-border trade using virtual pipelines.

Potential regulatory barriers related to the operation of LNG virtual pipelines

Taking into consideration the issues discussed above, the following regulatory barriers can be identified, which may hinder the development of LNG virtual pipelines:

- The lack of a consistent approach by all NRAs for the application of the provisions concerning the operation of the LNG storage and loading facilities may lead to cases of competition distortion, if LNG suppliers perform cross-border trade.
- In cases where the national regulatory framework foresees a licence for gas supplies, the lack of licensing provisions particularly for LNG supplies, either in a special licence or in a licence including both piped and non-piped activities, may delay or even obstruct the development of the LNG virtual pipeline.
- Provisions not allowing gas-to-gas competition between piped and non-piped supplies can hinder the development of virtual pipelines. Interested parties may be reluctant to invest in the implementation of virtual pipelines, especially infrastructure, if after they have developed a significant market of non-piped gas supply, there is a risk of the construction of a transmission and/or distribution network to which connection is obligatory for all consumers.
- Regulations limiting the period of time for which LNG could be stored can distort the operation of small LNG suppliers, as they would have to import LNG at high prices, without taking advantage of any economies of scale.

Recommendations

To tackle the regulatory barriers to the development of virtual pipelines, the following recommendations should be taken into consideration:

- ACER and the NRAs should examine if the adoption of an EU-wide approach for the regulation of the operation of LNG storage and loading terminals for virtual pipelines would be required to ensure fair competition in cross-border trade of LNG supplies. A potential approach for distinguishing regulated from unregulated activities is the following:

- LNG import Terminals not classified as LNG Facilities (i.e. non regasification capability) with LNG storage infrastructure, built and functioning exclusively as LNG loading facilities, are not regulated infrastructure, except for the transparency issues (Gas Regulation art.19(4)).
- Storage capacity of an "LNG Facility" classified as a "Storage Facility" which serves exclusively as an LNG loading facility for truck/barge loading, is not a regulated infrastructure, with the exception for transparency issues. In that case nevertheless considerations arise concerning the operational, organisational, accounts unbundling and cost allocation of the LNG loading service operating within an LNG Facility.
- Storage capacity of an "LNG Facility" classified as a "Storage Facility" which serves as an LNG loading facility for truck/vessel loading, and at the same time is connected to the regasification station and can supply grid connected customers is classified as a "Storage capacity" and is regulated under the Directive and the Regulation.

- NRAs should ensure that LNG supplies are treated in the market under the same terms as piped gas. If a licence for gas supplies is required, this should also include the case of non-piped LNG.
- The issue of gas-to-gas (LNG to piped gas) competition has to be assessed at national level, depending on the national policy for promoting non-piped gas and for developing gas networks. In this respect, the issue should be addressed, if required, by the pertinent National Authorities.
- ACER and the NRAs should consider whether EU-wide rules for storing LNG at terminals, as part of the supply chain of virtual pipelines, would be required (provided that the technical specifications of the LNG terminals allow it), to provide a level playing field for all LNG suppliers across the EU.

5.3.2 Other issues and barriers for the development of virtual pipelines

Apart from the regulatory issues and barriers discussed above, there are other potential barriers that may hinder the development of LNG virtual pipelines.

Technical Specifications and Health & Safety Regulations

- Any national restrictions in the allowed weight of shipments transported with trucks would reduce the effective gas volumes that are supplied per truck trip. In cases of cross-border transportation of LNG, the supplier must adhere to the restrictions of every country crossed. This has an impact in the cost effectiveness of the virtual pipeline, particularly if large distances have to be travelled.
- The lack of national regulations allowing the transportation of LNG with trucks or barges may result in restrictions in the transportation of gas, particularly by local communities.
- The lack of safety regulations regarding the loading terminals and satellite storages may delay the permitting process of a virtual pipeline.

<u>Technology</u>

LNG virtual pipelines have been in operation for many years and the technologies applied are mature. Thus no technological barriers have been identified.

<u>Economics</u>

- In general the transportation costs of an LNG virtual pipeline are higher than a mature gas network. As a result, non-piped gas supplies are not competitive to piped gas and the large scale applications are limited to areas with no pipeline coverage. The economies of scale resulting from the increased utilisation of a virtual pipeline (e.g. with the supply of LNG filling stations), could decrease the transportation costs and potentially make the LNG supplies competitive.

<u>Infrastructure</u>

- The lack of LNG terminals with truck/barge loading facilities within a cost effective radius of the targeted final consumers does not allow the development of virtual pipelines. As the costs for the development of such facilities is significant, currently loading terminals are installed at operational LNG terminals, to exploit the economies of scale. There are cases in which the development of LNG loading facilities are financially or technically difficult and would require large investments that increase the cost of the virtual pipeline and make gas supplies less competitive compared to alternative fuels.

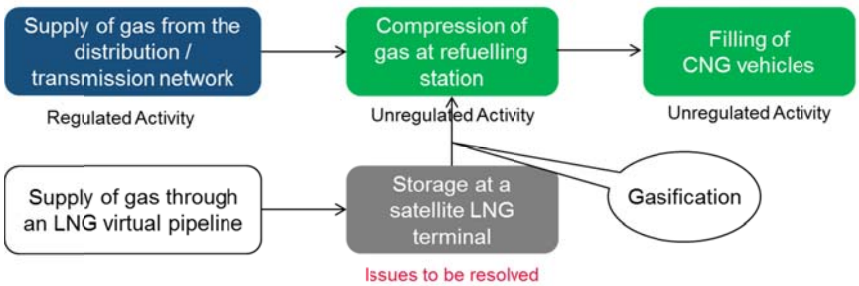
5.4 Land transport

5.4.1 Regulatory issues, barriers and recommendations for use of gas in road transport

Regulatory issues

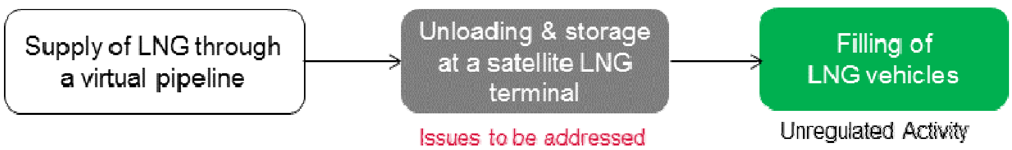
The main activities foreseen in the supply chain of use of gas in road transport are depicted in Figure 49 and Figure 50 for CNG and LNG respectively.

Figure 49: Activities in a motor CNG supply chain*



*Blue: regulated, Green: unregulated, Grey: to be clarified, White: Discussed under LNG VP operations

Figure 50: Activities in a motor LNG supply chain*



* Green: unregulated, Grey: to be clarified, White: Discussed under LNG VP operations

The regulatory considerations and potential issues to be addressed, related to each of the activities shown in the above figures, are discussed below.

Supply from the transmission/distribution network (CNG only)

The CNG loading point (which is the filling station) is an exit point of the transmission or distribution system to which it is connected. Therefore, its operators and/or its CNG suppliers need to conclude a connection agreement with the Network Operator and abide by the Network Code. When a filling station is connected to the network the provisions of the Network Code for new connections of exit points will apply. These provisions will determine, among others, whether the relevant infrastructure becomes part of the DSO's regulated asset base or is considered partly or fully a private investment.

The transmission/distribution activity is regulated and a regulated tariff is charged by the system operator for the transmission and/or distribution of the gas. For the supply of the CNG filling station with natural gas via the distribution network the regime for supply and shipping gas to eligible customers applies.

Supply of LNG through a virtual pipeline (L-CNG and LNG stations)

The supply through an LNG virtual pipeline (VP) involves terminal operations, including the storage of LNG at an LNG terminal, the loading of trucks and the road transportation of LNG through the trucks to the satellite terminal. The regulatory issues related with these activities are examined in detail in the preceding discussion of LNG VPs.

Unloading and storage to a satellite LNG terminal (L-CNG and LNG)

The satellite terminal consists of a tank for LNG storage, a regasification facility and, in the case of L-CNG stations, includes also a compressor of the gas to 200-250 bar. The satellite terminal is located on the premise of a filling station, which supplies LNG and possibly also CNG. The station can be either a public one, serving all incoming vehicles, or a private one, with access restricted to specific vehicles only (e.g. vehicles belonging to a certain truck or bus or company).

In either case, in principle the LNG storage is considered a private, unregulated activity. The tank's size is usually in the order of 60 m^3, and cannot be considered essential facility, as its cost is such that it allows duplication by other operators without restricting competition.

Compression of gas at the filling station (CNG only)

The operation of the compression station is an unregulated activity at a privately-owned facility.

Operation of CNG filling station – Filling of CNG vehicles

According to the Directive, the sale of natural gas to wholesale or final customers is an activity of supply and, as such, requires a supply licence in some Member States. Applying a strict interpretation of this term, even the owner/operator of a filling station who sells fuel to final customers exercises the activity of gas supply. In general, however, no such status – and consequently no such license – is foreseen in the EU Member States. In some countries (e.g. UK, Germany) the licensable supply activity relates exclusively to supply to premises through pipes, whilst in others (e.g. Greece) the Licensing Code explicitly excludes gas filling stations from the obligation to obtain a gas supply license. Such class exemptions from supply licensing is reasonable because: (a) the stations supply non-grid connected customers; (b) gas resale from an eligible customer to another eligible customer is allowed and is not a licensable activity; (c) the filling station already provides open access to customers, gas retail prices are not regulated, and intra-station competition exists anyway as the CNG filling stations face both gas to gas competition and competition by oil products (petrol, diesel, LPG); and (d) CNG fuelling devices for CNG NGVs are already available for use at the premises (home, office) of the NGV owners, provided they are connected to the gas network.

Thus, in practice, CNG filling stations are considered end users and, as such, belong in the category of eligible customers.

Operation of LNG filling station – Filling of LNG vehicles

The situation with LNG stations is similar to that of CNG. Thus, LNG filling stations should also be granted a class exemption for the supply of LNG to final customers, which in this case are the LNG fuelled vehicles.

Regulatory barriers and recommendations related to CNG and LNG used in road transport

No actual regulatory barriers have been noted in regard to the use of CNG or LNG in road transport. It is remarked, however, that the existing infrastructure (especially that for LNG) is still underdeveloped in Europe. As the market develops, the NRAs should ensure that the supply of gas to the filling stations is included in their market monitoring practices, to ensure that fair competition among gas suppliers exists.

It might also be meaningful to confirm "officially" that both CNG and LNG filling stations are to be considered end users rather than gas suppliers and that no gas supply license is required.

5.4.2 Other issues and barriers to the use of gas in road transport

Apart from the regulatory issues and barriers discussed above, there are other (non-regulatory) barriers and potential barriers that may hinder the use of gas in road transport and the development of the relevant markets.

Specifications, Health & Safety Regulations

- There are no EU/international specifications yet regarding CNG & LNG filling stations. The different specifications that may exist in different countries can in some cases not allow NGVs from a country to refuel in another one. This issue is being addressed by the Alternative Fuels Infrastructure (AFI) Directive, which will establish EU-wide or international specifications. An international standard is being developed for CNG & LNG stations (ISO TC252).
- The development of workshops for retrofitting NGVs and the operation of filling stations cannot be implemented unless relevant provisions are included in the legislation (e.g. technical specifications, rules for Health & Safety)

Technology

- Although natural gas combustion in vehicle engines has been developed and widely applied in many vehicle types, there are few NGV new models. In particular:

  - CNG: A limited number of Original Equipment Manufacturers offer NGVs in the market. Although retrofitting of existing vehicles is possible, end-users may be reluctant to switch fuels, for reasons such as valid warranty of equipment and scarcity of local workshops.
  - LNG: A very limited number of LNG-fuelled models are available in the market, while retrofitting of existing trucks is very expensive. Heavy trucks of over 450CV are not available in Europe yet, as they are still facing technical difficulties (sensitivity to gas quality, difficulty to certify by Euro-VI, coupled with high R&D costs).
- Investment by the industry in improved diesel engines, so as to meet Euro-VI standards, has weakened interest in NGVs, driven by environmental standards.

Economic considerations

- Retrofitting of vehicles to burn natural gas requires an initial investment. Moreover, dual-fuel vehicles are more expensive than their single-fuel counterparts. The initial investment has to be recovered by the fuel price differential.
- Taxation: Lack of clarity, compounded by the EC proposal for revision of the fuel taxation Directive, leads to uncertainty as to the future price of gas and makes end-users reluctant to invest in NGVs.

Infrastructure

- Lack/scarcity of refuelling infrastructure:
  - For CNG a sufficiently dense network is required to increase confidence in NGVs creating a sense of comfort among vehicle owners
  - For LNG, filling stations must be placed on main road corridors, to ensure the fuel availability for trucks driving long distances and/or crossing the EU
- The AFI Directive requires the Member States to ensure the development of adequate CNG/LNG infrastructure. However, the AFI Directive does not impose obligatory targets. As the facilities will be built by the private sector (presumably with incentives by the Member States), there is still uncertainty in the mobilisation of sufficient investments in all EU countries.

Behavioural issues

- Public awareness: The public in many countries remains misinformed on the safety and the performance of natural gas as a fuel, often confusing it with LPG
- Different measurement unit: The pricing of CNG in kilograms, instead of litres as all other fuels, does not allow direct comparison of prices and often leads to misconception by end-users on the economic advantages of the CNG compared to other fuels.

Cross-border issues

No regulatory cross-border barriers have been noted. Only different standards between countries (to be harmonised soon) can hinder cross-border operation.

5.5 Water transport

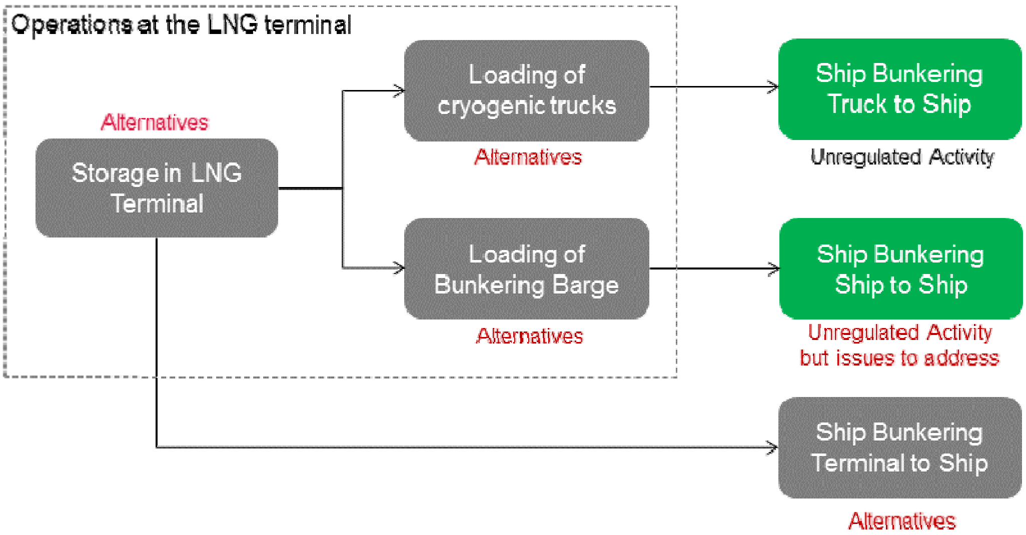
5.5.1 Regulatory issues, barriers and recommendations for use of gas in water transport

Regulatory issues

The main activities foreseen in the supply chain of use of gas as a fuel in water transport are shown in Figure 51. The regulatory considerations and potential issues to be addressed, related to the activities shown in the figure, are discussed below.

It is noted that the activities enclosed within the rectangle with the dashed line are operations that take place at the terminal, often termed also "terminaling". These involve access to an LNG terminal storage, loading of trucks and loading of bunkering barges. Those activities and their regulatory regime, which is not clear from the Directive, are discussed in detail in the preceding section dealing with LNG Virtual Pipelines. Thus, the discussion is limited here to the activities that are outside the dashed rectangle.

Figure 51: Activities relating to use of gas as a fuel in water transport (bunkering)*



* Green: unregulated, Grey: to be clarified

Truck to Ship Bunkering

Loading of a ship by trucks, which have been previously loaded through a terminal operation, is not covered in any way by the provisions of the Directive and is thus an unregulated activity.

Ship to Ship Bunkering (STS)

The same principle as for bunkering via trucks should normally hold for bunkering via another ship (barge). This bunkering (the operation of loading LNG from one ship to the other) is a free unregulated activity. There may be issues to address, however, depending on where the bunkering takes place. If this takes place in a port or in the open sea, it is clearly outside the scope of the Directive.

The complication arises when STS takes place when both vessels are docking at the same time, within the frame of an LNG facility. There is still no doubt that the activity is unregulated, as it does not access a storage facility in any way. The complexity is that the unregulated LNG STS service makes shared use of the piers with the regulated LNG Facility service. The coexistence of these different services gives rise to two requirements:

- Firstly, operating rules for access to the piers need to be applied, ensuring that the provision of the STS service does not have a negative impact on the access conditions for the regulated services offered by the LNG Facility. In particular the scheduling of trans-shipment slots should not negatively affect the conditions of access to the regulated LNG Facility service. In the event of a conflict between rescheduling requests for trans-shipment and off-loading slots, the regulated services take priority, in order not to harm the predictability of the terminal's send-out profile. For this purpose, the LNG Facility operator must submit to the NRA for review and prior approval the operations management detailed rules in line with these principles.
- Secondly, organisational and accounting measures should be implemented to ensure the transparency of the allocation of the respective costs of the different services and in particular to ensure the allocation of costs generated by the STS service to the users of that service. To avoid any form of discrimination, cross-subsidisation or distortion of competition the LNG Facility operator must abide by the accounting unbundling rules of the Directive (Art. 30 & 31) between the regulated LNG activity and the unregulated STS activity, and cost allocation must be based on rules set by the NRA. Other things being equal, these cost allocations will lead to a reduction in the level of the revenue requirement to be covered by the regulated tariff for the LNG Facility service.

Terminal to Ship Bunkering (TTS)

Bunkering directly from the terminal is also a terminal operation, whose regulatory regime is similar to that for truck loading or barge loading. In principle this regime depends on whether the bunkering operation makes use of storage capacity of an "LNG Facility" classified as "Storage Facility" according to the Directive. There are three possibilities:

a. The bunkering process uses LNG import terminals not classified as LNG Facilities (i.e. with no regasification capability) with LNG storage infrastructure, built and functioning exclusively as LNG reloading facilities, either for STS re-loading or re-loading from the storage tanks to trucks/vessels. This is not regulated infrastructure, and thus the activity is not regulated except for transparency issues (Gas Regulation Art. 19(4)).
b. The bunkering process accesses storage capacity of an "LNG Facility" classified as "Storage Facility", which serves exclusively as an LNG reloading facility for truck/vessel loading. This is not regulated infrastructure, with the exception for transparency, as it is not technically and/or economically necessary for providing efficient access to the system for the supply of customers. In that case similar considerations arise (operational, organisational, accounts unbundling, cost allocation) as in the case of the STS loading service operating within an LNG Facility.
c. The bunkering process accesses storage capacity of an "LNG Facility" classified as "Storage Facility" which serves as an LNG re-loading facility for truck/vessel loading, i.e. is connected to truck/vessel re-loading station, and at the same time is connected to the regasification

station and can supply grid connected customers. This is classified as "Storage capacity" and is regulated under the Directive and the Regulation. In that case, the bunkering is regulated and a regulated tariff has to be charged. There must also be appropriate separation of accounts of the different regulated activities.

Regulatory barriers and recommendations related to use of LNG in water transport

- In current practice, different NRAs currently apply different approaches as to whether loading of trucks or barges or directly a ship through access to an LNG storage is a regulated or unregulated activity. This may distort competition between terminals lying in different countries. ACER might desire to establish a common regulatory approach based on clear rules.
- If the loading service provided by the LNG terminal is unregulated, there should be a separation between the use of the assets for this activity (and possibly other unregulated activities) and the use of the assets for the regulated activities of the LNG terminal and the respective value has to be removed from the RAB. This is a regulatory matter to be addressed.
- The vessel loading activities should be included in the emergency plan of the LNG terminal operator.

5.5.2 Other issues and barriers to the use of LNG in water transport

Apart from the regulatory issues and barriers discussed above, there are other (non-regulatory) barriers that may hinder the use of gas in water transport and the development of the relevant market.

Specifications, Health & Safety Regulations

- Harmonised specifications are required to enable the bunkering of ships (particularly pumps and hoses to load the ship).
- There is no international regulation enabling the simultaneous cargo handing/passenger loading and bunkering with LNG. The lack of such a regulation results in loss of time that may be significant.

Technology

- Current technology enables the retrofitting of existing ships as well as newbuild dual-fuel ships. However, in some types of ships (e.g. container ships) retrofitting reduces space available for cargo.

Economics

- Fuel price levels are currently such that they favour use of HFO where there are no environmental restrictions. LNG or MGO or HFO with scrubbers are expected to be used in sulphur restricted zones.
- Retrofitting of ships to burn natural gas requires an initial investment. Moreover, dual-fuel ships are also more expensive than their single-fuel counterparts. The initial investment has

to be recovered by the price differential of LNG vs. MGO or compared to the use of scrubbers with HFO.

Financial

- Many ship-owners are unable or reluctant to invest in LNG ships without appropriate financing options.

Infrastructure

- Existing LNG terminals need to be equipped with bunkering facilities including reloading equipment, berthing for small ships and/or truck loading.
- Apart from bunkering in LGN terminals, particularly for inland waterways a network of satellite LNG storages is required.
- The AFI Directive requires the Member States to ensure the development of adequate LNG bunkering infrastructure. However, development of that infrastructure may start as much as two years from the publication the AFI Directive and may take a considerable time to be completed. On the other hand, vessels need to apply the necessary measures much earlier, to comply with stricter environmental regulations (in ECAs and eventually along the EU coast). This time lag between the need for action and the likely development of infrastructure may lead the industry to implementing solutions other than converting to LNG (e.g. scrubbers, low-sulphur HFO).

5.6 Power-to-Gas

5.6.1 Regulatory issues for Power-to-Gas

As there are currently no large scale applications of P2G, and the PEM electrolysis method is in pre-commercial phase development, the most important barriers identified for large scale short term exploitation of the P2G technology are related to technical and financial issues. Actual regulatory issues can be determined after the technical and economic characteristics for commercial deployment of the technology become validated.

Considerations for P2G related to the electricity sector

The basis for commercial exploitation of the P2G technology is the occurrence of excess capacity from intermittent RES (wind and PVs), which otherwise would have been curtailed.

It is of importance to determine whether a P2G facility, being a flexible, dispatchable load that may also offer auxiliary services, may be considered and remunerated from the electricity market as a facility that offers Demand Side Response (DSR) service, in particular considering that the hydrogen produced may not be in whole or in part used subsequently as a source of electricity (e.g. it may be used as fuel in transport, feedstock for industrial processes, or for heating).

Prices of electricity are directly affected by the renewable energy curtailment, which sets the equilibrium price in firm oversupply situations. The curtailment rules constitute an important element of the RES support scheme applied. Depending on the curtailment penalty level the power market adapts to the degree of flexibility implied by the curtailment rules. Under high curtailment penalties substantial investments in storage occur, depending also on the capability for international exchanges. As a consequence the appropriate design of all system components that affect market flexibility is very important for long-run system adaptation that enables higher RES share.

In this context, the commercial development of P2G as an energy storage solution has to be carried out in line with the considerations on the long term development of the EU electricity market and the increasing share of renewables in it.

Considerations for P2G related to the gas sector

Some regulatory issues that were identified during the interviews with stakeholders and are related to the gas sector are the following:

- For a large scale commercial deployment of P2G to be achieved, there should be clear provisions for the injection of its outputs (hydrogen and/or synthetic gas) into the gas system, especially if P2G uses renewable energy (as is the case for biogas). Such provisions include non-discriminatory access to the gas system, provided such access is permanently compatible with the relevant technical rules and safety standards. In Germany provisions for hydrogen and synthetic gas have already been included in the network code, particularly in relation to the rules for access to the system, the connection of the P2G unit to the system and the availability of the entry capacity.
- In P2G units hydrogen or synthetic gas are indigenously produced and injected in the gas system. The role of the operator of a P2G unit in the gas market (e.g. gas producer or gas supplier) should be clarified.
- The P2G pilot applications that are currently operational in Germany are perceived as final consumers of the electricity market and therefore have to pay the levies foreseen in the end-user electricity prices. According to stakeholders interviewed, these levies result in a 70% increase of the unit's electricity costs, making its operation uneconomical. The technology providers argue that P2G is not a final electricity consumer, but an intermediary point of the supply chain and therefore should not pay any end-user levies. In any case, at present the economical operation of the P2G applications seems to require a special regime regarding electricity prices.
- According to the technology providers interviewed, incentives are required to promote cross-border trade of produced hydrogen or synthetic gas, as this would also facilitate the development of P2G. One such incentive would be the development of a mechanism (certificates of origin) for validating that the gas has been produced from renewable resources or from excess electricity production that could not be curtailed, when this is indeed the case.

5.6.2 Other issues and barriers for the development of Power-to-Gas

Other potential issues and barriers that may hinder the development of P2G applications are discussed below.

Technical Specifications and Health & Safety Regulations

- The share of hydrogen that can be injected into the gas system is limited for security and gas quality reasons. This constraint limits the output of the P2G unit and consequently its cost effectiveness. The level of hydrogen depends on the system characteristics and the proximity of the entry point to infrastructure for which hydrogen would be a hazard (e.g. CNG filling stations). According to the technology providers interviewed, the currently allowed maximum fraction of hydrogen in the system (which, for example, in many parts of Germany is 2% and in some systems may be as low as 1%) is not representative of its actual technical limitations, and could increase to up to 20%, without the need for configuration changes to the end-user equipment and appliances.

Technology

- The lack of large scale applications and the fact that the P2G technology has not reached adequate maturity level, may create uncertainty to prospective investors and other stakeholders.
- The readiness level for the application of the methanation process is still low. As a result most pilot units are currently producing only hydrogen, although the production of synthetic methane would resolve any safety issues related to hydrogen.

Economics

- The business case for a large scale deployment of P2G is still uncertain, as so far only the economics of pilot units have been examined. This lack of information may discourage investors from participating in P2G projects.
- According to stakeholders interviewed, at this stage P2G applications can be economically viable only if incentives are provided, such as special electricity prices, feed-in-tariffs and green certificates.

5.7 Conclusions

The main regulatory issues that have been identified for the new developments in the gas supply chain are related to the market status of the stakeholders involved and to which of the activities that are part of the supply chain should be regulated. Some key points are the following:

- In the cases of LNG supplies (virtual pipelines and bunkering), a clear approach as to which are the regulated activities of LNG storage facilities and loading/bunkering facilities would facilitate the unimpeded operation of these uses for gas.
- The operation of CNG loading terminals for virtual pipelines should not be subject to TPA, as the terminals can be small scale infrastructure competing with each other. The issue of licencing for suppliers of CNG, where relevant, will have to be addressed to avoid potential delays in the development of the virtual pipeline.
- The LNG and CNG filling stations should not be considered as suppliers of gas, and consequently should not be subject to TPA or licencing procedures.
- For the case of Power-to-Gas the issues identified are related to the pilot units' operation and not large scale commercial application. Therefore, at this stage only future potential issues and not specific barriers can be identified.

The most important issues for each new development are summarised in Table 35 below.

Table 35: Summary of regulatory issues of the new developments in the gas supply chain

New development	*Main regulatory issues to be addressed*
CNG virtual pipelines	▪ Level playing field between CNG non-piped supplies and natural gas piped supplies ▪ Gas-to-gas competition between piped and non-piped gas ▪ Technical difficulties for the supply of a local distribution network with several CNG suppliers
LNG virtual pipelines	▪ Cases of TPA in the operation of LNG storages and loading terminals ▪ Level playing field between LNG non-piped supplies and natural gas piped supplies ▪ Gas-to-gas competition between piped and non-piped gas ▪ Regulations for the allowable storage period of LNG
CNG/LNG in land transport	▪ Confirming that operating CNG and LNG filling stations requires no license and these stations are considered end users of gas ▪ Clarifying whether or not - and other what conditions - a TPA or other regulatory regime should apply to satellite LNG terminals.
LNG in water transport	▪ Establishing common EU-wide rules, with clear criteria, to determine when a terminal activity is regulated and when not. ▪ Where unregulated activities utilise the same assets as regulated ones, an accounting separation is in order.
Power-to-Gas	▪ Provisions for the injection of hydrogen and synthetic gas produced by P2G units in the gas system ▪ Role of the P2G operator in the gas market ▪ Electricity pricing regime for P2G units

The analysis of the regulatory barriers concluded relevant recommendations towards ACER and the NRAs (Table 36).

Table 36: Summary of recommendations towards ACER and NRAs

New development	*Main recommendations*
CNG virtual pipelines	▪ The NRAs should ensure that CNG supplies are carried out with the same terms and conditions as natural gas. ▪ The distribution network codes should foresee supplies with CNG virtual pipelines and include clear provisions as to the connection of CNG shipments and dispatching of gas from CNG containers.
LNG virtual pipelines	▪ ACER and the NRAs should examine the appropriateness of establishing an EU-wide approach on the cases (if any) where LNG storage and loading facilities should be regulated, to ensure fair competition in LNG supplies at a European level. ▪ The NRAs should ensure that LNG supplies are carried out with the same terms and conditions as natural gas. ▪ ACER and the NRAs should examine the appropriateness of establishing an EU-wide approach on the rules for storing

	LNG at terminals for virtual pipelines, to ensure a level playing field for LNG suppliers at a European level.
CNG/LNG in land transport	▪ ACER is advised to coordinate with the NRAs to ensure that, for the purposes of gas market regulation, CNG and LNG filling stations are considered end customers rather than gas suppliers, and therefore they are not obliged to conform to the requirements imposed on gas suppliers. ▪ The NRAs should ensure to include the supply of gas to the filling stations in their market monitoring practices.
LNG in water transport	▪ ACER may undertake to coordinate the NRAs in establishing a common approach on discerning whether - and when - bunkering of a vessel with LNG is a regulated activity or not. This should cover all three methods of bunkering (STS, TTS, TPS). ▪ Where the loading service provided by the LNG terminal is unregulated, the NRAs should oversee to establish and enforce provisions accounting for the use of assets for both regulated and unregulated activities and relevant reductions to the operator's RAB, where appropriate. Moreover, the operating code should ensure that access to the regulated LNG facility services takes precedence and is not negatively affected by unregulated operations.
Power-to-Gas	▪ There is still no large scale application of P2G, and thus the dominant mode of its operation is still unclear. ACER and the NRAs may wish to proactively examine the impact of P2G in electricity balancing and particularly in DSR.

The regulatory issues may delay the growth of the new developments in the gas supply chain, but will not obstruct their application. There are however other non-regulatory barriers, with a strong impact to the prospects of development. Some major barriers are mentioned below:

- The uncertainty in taxation of natural gas leads to uncertainty regarding gas price and causes reluctance of stakeholders throughout the supply chain (gas suppliers, operators of filling stations, vehicle manufacturers, users) to invest in the development of NGVs.
- Due to the lack of bunkering infrastructure and the high costs for retrofitting, ship owners are reluctant to switch to LNG, even with the upcoming new regulations for SECAs.
- The P2G is a technology under development with no commercial business case available. This may discourage investors from participating in P2G projects.
- The limited volumes transported per shipment and the transport costs of the CNG virtual pipeline do not allow competition with piped gas. As a result, only small consumers, far from pipelines access, can be supplied.
- LNG virtual pipelines are highly dependent on the availability of infrastructure for LNG storage and loading of trucks/barges. Lack of such facilities within a cost-effective range will not allow the development of virtual pipelines.

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TABLE OF UNITS USED

Type	Units used
Bunker Fuel Price	€/MWh
Bunker Fuel emissions	tonnes/yr
LNG production	tpd
LNG Volume	m^3
LNG loading	m^3/hr
LNG storage cost	€/m^3
LNG volume rate	ktpa
LMG volume	bcm
Density of gasoline	kg/lt
Calorific value gasoline	MJ/kg
Calorific value natural gas	MJ/m^3
Consumption of MGO	mtpa
PEM Electrolysis input	kwh/Nm^3
P2G capacity	MW
P2G output	MWh

ANNEX I: LIST OF INTERVIEWED STAKEHOLDERS

Company Name	Interviewee	Type of interview	Main topics discussed
Natural Gas Vehicle Association	Matthias Maedge EU Affairs Manager	Phone	LNG & CNG Road Transport
Gas Infrastructure Europe	Thierry Deschuyteneer Executive Secretary	Face-to-Face	LNG & CNG Road Transport LNG Maritime Transport Virtual Pipelines
GEODE	Carmen Gimeno Secretary General	Face-to-Face	LNG & CNG Road Transport Virtual Pipelines
ENI	Flavio Mariani Methane for Vehicle Manager	Phone	LNG & CNG Road Transport Virtual Pipelines
IVECO	Jose Puis Perez Souto Product Engineering, Innovation & Advanced Eng.	Face-to-Face	Gas as an automotive vehicle (HDV and MDV)
FIAT Group Automobiles	Maurizio Pastine Institutional Relations	E-mail	CNG Road Transport
CNG Module Systems Ltd	Ognian Pavlov Manager of CNG modules Ltd	E-mail, Phone	CNG Road Transport Virtual Pipelines
Golden Union Shipping	George Gabriel Director	Face-to-Face	LNG Maritime Transport
Maran Gas Maritime Inc.	Stavros Hatzigrigoris, General Director Richard Gilmore, Director of Gas Fleet	Face-to-Face	LNG Maritime Transport
Public Gas Corporation of Greece	Theodoros Terzopoulos, Head, Gas Distribution Division Maria Schina, Antitrust Compliance Officer & Deputy Head of Reg. & Corporate Affairs Division Stefanos Economidis, Deputy Head, Strategic & Corporate Development Affairs	Face-to-Face	CNG Road Transport Virtual Pipelines
ENAGAS	Francisco de la Flor Garcia & Luis Ignacio Parada Regulatory Development Manager	Face-to-Face	LNG operations in Spain; regulatory framework
Vopak	Joop Jonkers Manager Business Development	Phone	LNG Road Transport LNG Maritime Transport Virtual Pipelines
Hydrogenics	Filip Smeets General Manager On-site Generation	Phone	Power-to-Gas
ITM Power	Phil Doran (for Germany and Europe)	Phone	Power-to-Gas
Gas Natural Fenosa	Javier Alonso Martinez Head of Technological Portfolio	Face-to-Face	New technologies for gas (incl. PtG)
Gas Natural Fenosa	Jose Ramon Freire Lopez Director, Mobility Solutions	Face-to-Face	Gas as an automotive fuel (mainly LNG)
Gas Natural	Oscar Arrazola Samper	Face-to-Face	Visit to LNG/L-CNG filling station

Fenosa	Vehicle Transport Projects		
Gasnam	Manuel Lage Secretary General	Face-to-Face	Gas as an automotive fuel
DG MOVE	Jose Fernandez Garcia Policy Officer Antonio Aizoun Policy Officer	Face-to-Face	CNG&LNG Road Transport LNG Maritime Transport
Fluxys	Hany Aouad Manager - Innovative Solutions	Face-to-Face	CNG&LNG Road Transport LNG Maritime Transport Virtual Pipelines Power-to-Gas
CNMC	Raul Yunta Huete Energy Direction	Face-to-Face	Regulation of CNG/LNG operations
Regulatory Authority for Energy of Greece	Katerina Sardi Aggeliki Mourtzikou	Face-to-Face	CNG Road Transport Virtual Pipelines

ANNEX II: MAPS & DATA USED FOR ESTIMATION OF THE MARKET SIZE OF VIRTUAL PIPELINES

Figure 52: Regions gwsupplied with CNG virtual pipelines – SE Europe

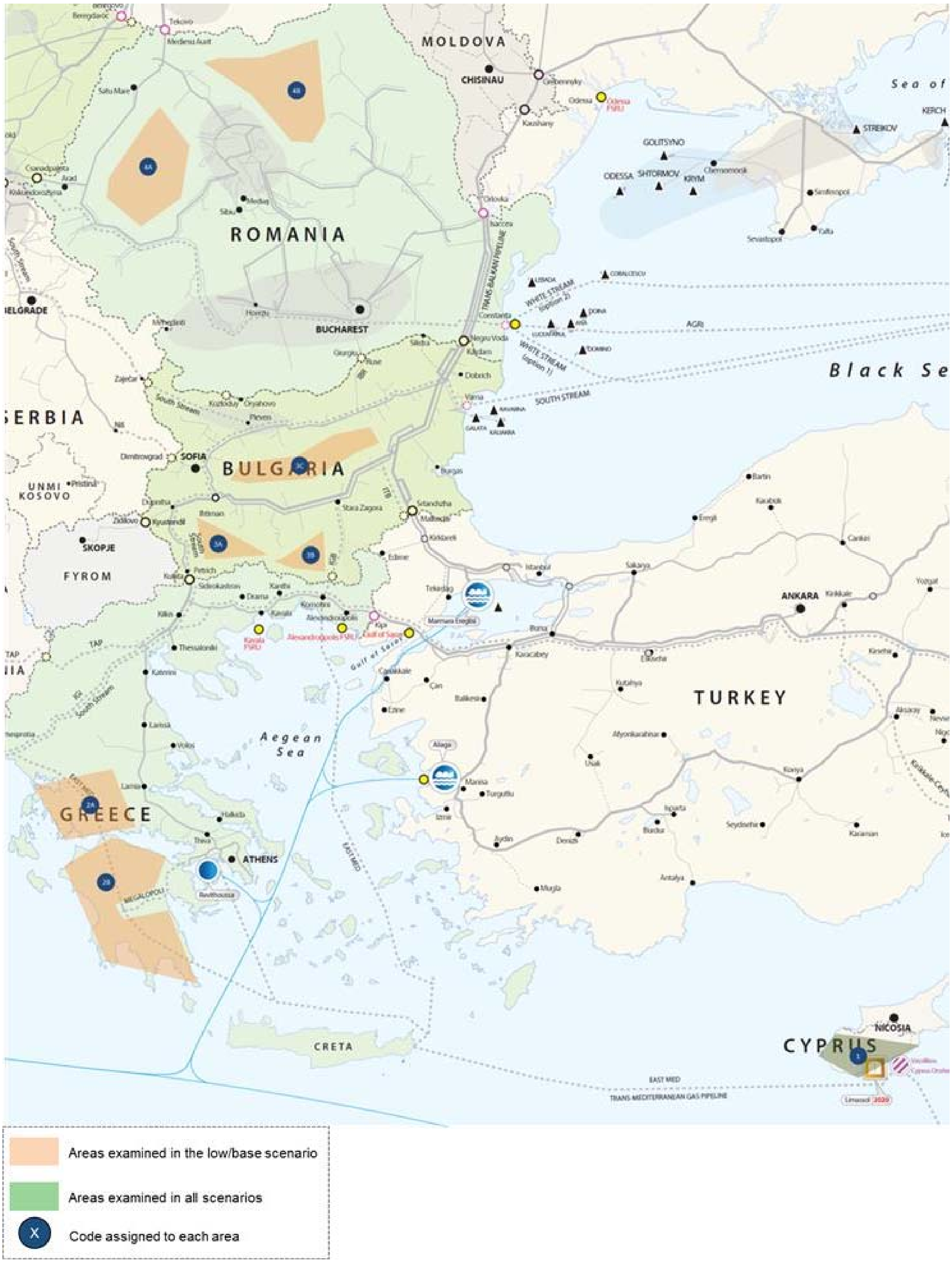


Figure 53: Regions supplied with CNG virtual pipelines – Central Europe

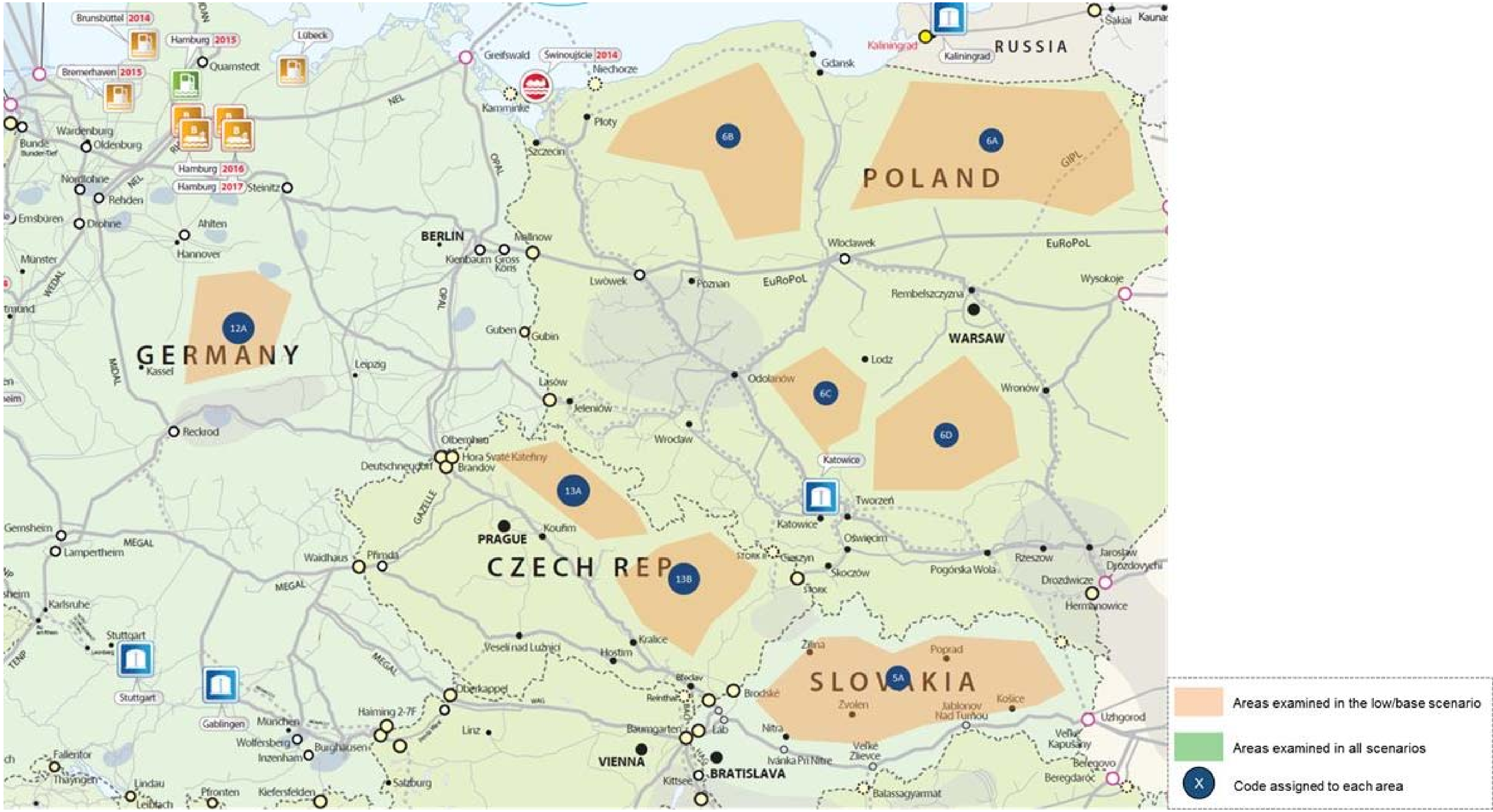
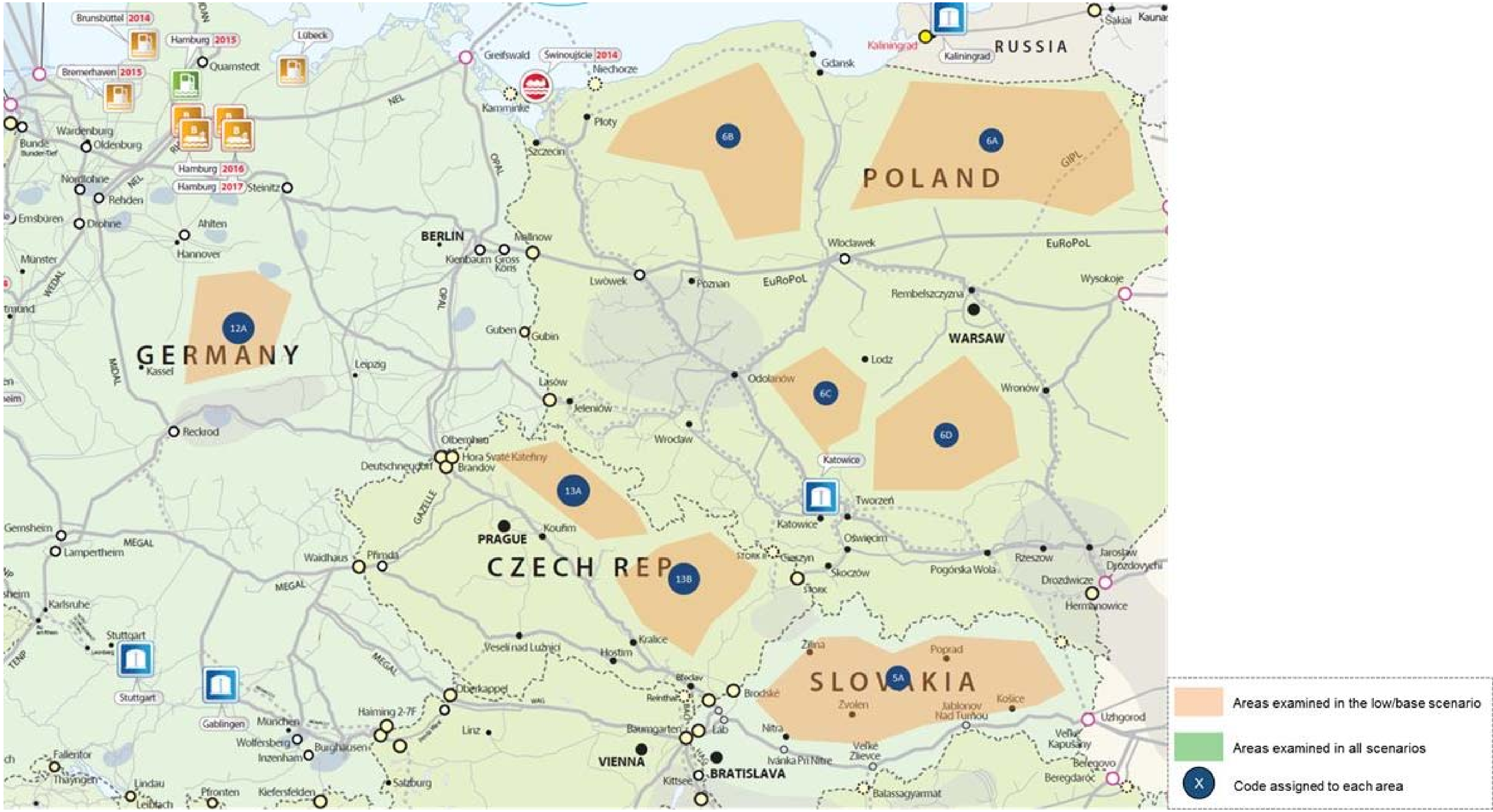


Figure 54: Regions supplied with CNG virtual pipelines – Baltic & Western Europe*

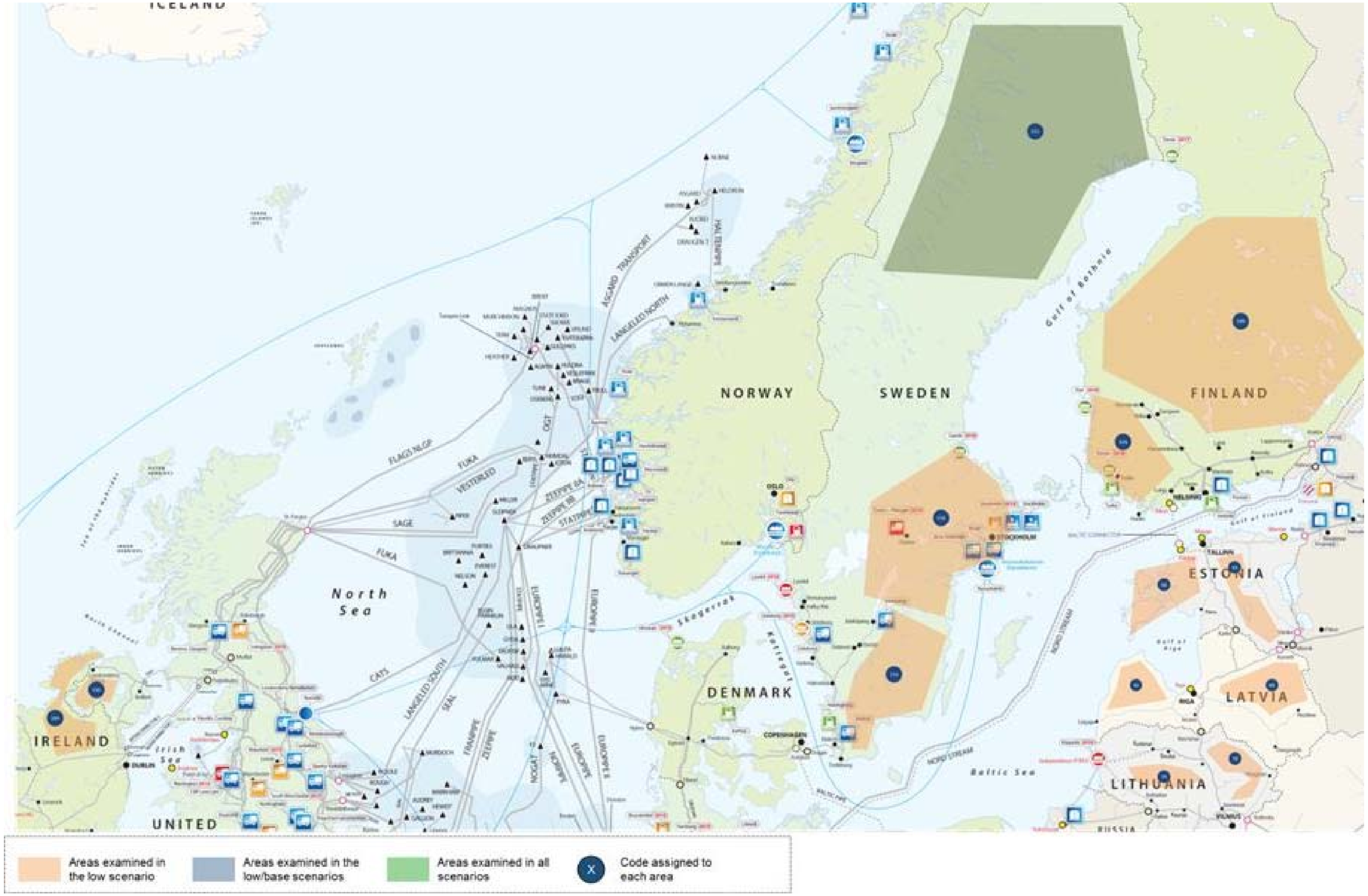


* The markets of IT, BE, NL, UK, FR, PT, LU, HU, DK, AT, HR are considered to be sufficiently covered by their transmission system, leaving no room for large deployment of CNG pipelines.

Figure 55: Regions supplied with LNG virtual pipelines – SE Europe

Figure 56: Regions supplied with LNG virtual pipelines – Central Europe

Figure 57: Regions supplied with LNG virtual pipelines – Baltic & Western Europe*



* The markets of IT, BE, NL, UK, FR, PT are being supplied or are planning to set up LNG loading facilities at their LNG terminals. A growth for the use of these facilities is assumed

Figure 58: CNG & LNG virtual pipelines – results per region (base case scenario)

			Scenario		CNG		LNG	
Map Code	**Country**	**Region**	**CNG**	**LNG**	**Consumption (ktoe)**	**Consumption (bcm)**	**Consumption (ktoe)**	**Consumption (bcm)**
1	Cyprus	CY00 - Kypros	High	High	0	0,00	0	0,00
2A	Greece	EL23 - Dytiki Ellada	All	Base, High	27	0,03	45	0,05
2B	Greece	EL25 - Peloponnisos	All	Base, High	15	0,02	25	0,03
2C	Greece	EL43 - Kriti	No supply	Base, High	0	0,00	48	0,06
2D	Greece	EL42 - Notio Aigaio	No supply	Base, High	0	0,00	33	0,04
2E	Greece	EL41 - Voreio Aigaio	No supply	Base, High	0	0,00	14	0,02
3A	Bulgaria	BG41 - Yugozapaden	All	High	10	0,01	0	0,00
3B	Bulgaria	BG42 - Yuzhen tsentralen	All	High	12	0,01	0	0,00
3C	Bulgaria	BG34 - Yugoiztochen	All	High	10	0,01	0	0,00
4A/4B	Romania	RO11 - Nord-Vest	All	High	39	0,05	0	0,00
4A	Romania	RO42 - Vest	All	High	21	0,03	0	0,00
4B	Romania	RO21 - Nord-Est	All	High	7	0,01	0	0,00
5A	Slovakia	SK02 - Západné Slovensko	All	Base, High	123	0,15	127	0,15
5A	Slovakia	SK03 - Stredné Slovensko	All	Base, High	74	0,09	76	0,09
5A	Slovakia	SK04 - Východné Slovensko	All	Base, High	76	0,09	79	0,09
6A	Poland	PL62 - Warminsko-Mazurskie	All	All	79	0,09	121	0,15
6A	Poland	PL34 - Podlaskie	All	All	65	0,08	99	0,12
6A	Poland	PL12 - Mazowieckie	All	All	65	0,08	99	0,12
6B	Poland	PL61 - Kujawsko-Pomorskie	All	All	65	0,08	99	0,12
6B	Poland	PL63 - Pomorskie	All	All	115	0,14	175	0,21
6B	Poland	PL42 - Zachodniopomorskie	All	All	55	0,07	84	0,10
6C	Poland	PL11 - Lódzkie	All	All	106	0,13	163	0,20
6D	Poland	PL33 - Swietokrzyskie	All	All	58	0,07	88	0,11
7A/7B	Lithuania	LT00 - Lietuva	All	All	33	0,04	70	0,08
8A/8B	Latvia	LV00 - Latvija	All	All	73	0,09	125	0,15
9A	Estonia	EE00 - Eesti	All	All	40	0,05	69	0,08

10A	Finland	FI19 - Länsi-Suomi	All	All	226	0,27	270	0,32
10A	Finland	FI1C - Etelä-Suomi	All	All	62	0,07	75	0,09
10B	Finland	FI1D - Pohjois- ja Itä-Suomi	All	All	326	0,39	390	0,47
11A	Sweden	SE21 - Småland med öarna	All	All	131	0,16	148	0,18
11B	Sweden	SE11 - Stockholm	No supply	All	0	0,00	591	0,71
11B	Sweden	SE12 - Östra Mellansverige	No supply	All	0	0,00	280	0,34
11B	Sweden	SE31 - Norra Mellansverige	No supply	All	0	0,00	144	0,17
11C	Sweden	SE33 - Övre Norrland	No supply	High	0	0,00	0	0,00
12A	Germany	DE91 - Braunschweig	All	All	46	0,06	72	0,09
12A	Germany	DE92 - Hannover	All	All	59	0,07	92	0,11
13A	Czech Republic	CZ05 - Severovýchod	All	Base, High	103	0,12	135	0,16
13B	Czech Republic	CZ07 - Stredni Morava	All	Base, High	74	0,09	98	0,12
13B	Czech Republic	CZ08 - Moravskoslezsko	All	Base, High	81	0,10	106	0,13
14A	France (Corsica)	FR83 - Corse	No supply	All	0	0,00	28	0,03
15A	Italy (Sardinia)	ITG2 - Sardegna	No supply	All	0	0,00	71	0,09
16A	Malta	MT00 - Malta	All	All	0	0,00	4	0,00
17A	Slovenia	SI01 - Vzhodna Slovenija	All	Base, High	5	0,01	9	0,01
18A	Ireland	IE01 - Border, Midland and Western	All	All	26	0,03	44	0,05
19A	UK (Northern Ireland)	UKN0 - Northern Ireland (UK)	All	All	25	0,03	32	0,04
				Total	**2,80**		**5,08**	

Figure 59: CNG & LNG virtual pipelines – results per region (low scenario)

			Scenario		CNG		LNG	
Map Code	**Country**	**Region**	**CNG**	**LNG**	**Consumption (ktoe)**	**Consumption (bcm)**	**Consumption (ktoe)**	**Consumption (bcm)**
1	Cyprus	CY00 - Kypros	High	High	0	0,00	0	0,00
2A	Greece	EL23 - Dytiki Ellada	All	Base, High	22	0,03	0	0,00
2B	Greece	EL25 - Peloponnisos	All	Base, High	12	0,01	0	0,00
2C	Greece	EL43 - Kriti	No supply	Base, High	0	0,00	0	0,00
2D	Greece	EL42 - Notio Aigaio	No supply	Base, High	0	0,00	0	0,00
2E	Greece	EL41 - Voreio Aigaio	No supply	Base, High	0	0,00	0	0,00
3A	Bulgaria	BG41 - Yugozapaden	All	High	8	0,01	0	0,00
3B	Bulgaria	BG42 - Yuzhen tsentralen	All	High	9	0,01	0	0,00
3C	Bulgaria	BG34 - Yugoiztochen	All	High	8	0,01	0	0,00
4A/4B	Romania	RO11 - Nord-Vest	All	High	31	0,04	0	0,00
4A	Romania	RO42 - Vest	All	High	17	0,02	0	0,00
4B	Romania	RO21 - Nord-Est	All	High	6	0,01	0	0,00
5A	Slovakia	SK02 - Západné Slovensko	All	Base, High	99	0,12	0	0,00
5A	Slovakia	SK03 - Stredné Slovensko	All	Base, High	59	0,07	0	0,00
5A	Slovakia	SK04 - Východné Slovensko	All	Base, High	61	0,07	0	0,00
6A	Poland	PL62 - Warminsko-Mazurskie	All	All	63	0,08	91	0,11
6A	Poland	PL34 - Podlaskie	All	All	52	0,06	75	0,09
6A	Poland	PL12 - Mazowieckie	All	All	52	0,06	74	0,09
6B	Poland	PL61 - Kujawsko-Pomorskie	All	All	52	0,06	74	0,09
6B	Poland	PL63 - Pomorskie	All	All	91	0,11	131	0,16
6B	Poland	PL42 - Zachodniopomorskie	All	All	43	0,05	63	0,08
6C	Poland	PL11 - Lódzkie	All	All	84	0,10	122	0,15
6D	Poland	PL33 - Swietokrzyskie	All	All	46	0,05	66	0,08
7A/7B	Lithuania	LT00 - Lietuva	All	All	26	0,03	54	0,07
8A/8B	Latvia	LV00 - Latvija	All	All	58	0,07	97	0,12
9A	Estonia	EE00 - Eesti	All	All	32	0,04	54	0,06

10A	Finland	FI19 - Länsi-Suomi	All	All	180	0,22	214	0,26
10A	Finland	FI1C - Etelä-Suomi	All	All	50	0,06	59	0,07
10B	Finland	FI1D - Pohjois- ja Itä-Suomi	All	All	260	0,31	308	0,37
11A	Sweden	SE21 - Småland med öarna	All	All	105	0,13	117	0,14
11B	Sweden	SE11 - Stockholm	No supply	All	0	0,00	469	0,56
11B	Sweden	SE12 - Östra Mellansverige	No supply	All	0	0,00	223	0,27
11B	Sweden	SE31 - Norra Mellansverige	No supply	All	0	0,00	115	0,14
11C	Sweden	SE33 - Övre Norrland	No supply	High	0	0,00	0	0,00
12A	Germany	DE91 - Braunschweig	All	All	36	0,04	54	0,06
12A	Germany	DE92 - Hannover	All	All	46	0,06	68	0,08
13A	Czech Republic	CZ05 - Severovýchod	All	Base, High	82	0,10	0	0,00
13B	Czech Republic	CZ07 - Strední Morava	All	Base, High	59	0,07	0	0,00
13B	Czech Republic	CZ08 - Moravskoslezsko	All	Base, High	64	0,08	0	0,00
14A	France (Corsica)	FR83 - Corse	No supply	All	0	0,00	21	0,03
15A	Italy (Sardinia)	ITG2 - Sardegna	No supply	All	0	0,00	54	0,07
16A	Malta	MT00 - Malta	All	All	0	0,00	3	0,00
17A	Slovenia	SI01 - Vzhodna Slovenija	All	Base, High	4	0,00	0	0,00
18A	Ireland	IE01 - Border, Midland and Western	All	All	21	0,02	34	0,04
19A	UK (Northern Ireland)	UKN0 - Northern Ireland (UK)	All	All	20	0,02	25	0,03
				Total	**2,23**		**3,20**	

Figure 60: CNG & LNG virtual pipelines – results per region (high scenario)

			Scenario		CNG		LNG	
Map Code	Country	Region	CNG	LNG	Consumption (ktoe)	Consumption (bcm)	Consumption (ktoe)	Consumption (bcm)
1	Cyprus	CY00 - Kypros	High	High	59	0,07	85	0,10
2A	Greece	EL23 - Dytiki Ellada	All	Base, High	33	0,04	56	0,07
2B	Greece	EL25 - Peloponnisos	All	Base, High	19	0,02	32	0,04
2C	Greece	EL43 - Kriti	No supply	Base, High	0	0,00	60	0,07
2D	Greece	EL42 - Notio Aigaio	No supply	Base, High	0	0,00	42	0,05
2E	Greece	EL41 - Voreio Aigaio	No supply	Base, High	0	0,00	18	0,02
3A	Bulgaria	BG41 - Yugozapaden	All	High	13	0,02	22	0,03
3B	Bulgaria	BG42 - Yuzhen tsentralen	All	High	14	0,02	25	0,03
3C	Bulgaria	BG34 - Yugoiztochen	All	High	12	0,01	21	0,03
4A/4B	Romania	RO11 - Nord-Vest	All	High	47	0,06	87	0,10
4A	Romania	RO42 - Vest	All	High	26	0,03	47	0,06
4B	Romania	RO21 - Nord-Est	All	High	9	0,01	16	0,02
5A	Slovakia	SK02 - Západné Slovensko	All	Base, High	148	0,18	153	0,18
5A	Slovakia	SK03 - Stredné Slovensko	All	Base, High	89	0,11	92	0,11
5A	Slovakia	SK04 - Východné Slovensko	All	Base, High	92	0,11	95	0,11
6A	Poland	PL62 - Warminsko-Mazurskie	All	All	95	0,11	149	0,18
6A	Poland	PL34 - Podlaskie	All	All	78	0,09	122	0,15
6A	Poland	PL12 - Mazowieckie	All	All	78	0,09	122	0,15
6B	Poland	PL61 - Kujawsko-Pomorskie	All	All	78	0,09	122	0,15
6B	Poland	PL63 - Pomorskie	All	All	138	0,17	216	0,26
6B	Poland	PL42 - Zachodniopomorskie	All	All	66	0,08	103	0,12
6C	Poland	PL11 - Lódzkie	All	All	128	0,15	200	0,24
6D	Poland	PL33 - Swietokrzyskie	All	All	69	0,08	108	0,13
7A/7B	Lithuania	LT00 - Lietuva	All	All	40	0,05	86	0,10
8A/8B	Latvia	LV00 - Latvija	All	All	87	0,10	153	0,18
9A	Estonia	EE00 - Eesti	All	All	48	0,06	85	0,10

10A	Finland	FI19 - Länsi-Suomi	All	All	271	0,33	327	0,39
10A	Finland	FI1C - Etelä-Suomi	All	All	75	0,09	90	0,11
10B	Finland	FI1D - Pohjois- ja Itä-Suomi	All	All	391	0,47	471	0,57
11A	Sweden	SE21 - Småland med öarna	All	All	157	0,19	178	0,21
11B	Sweden	SE11 - Stockholm	No supply	All	0	0,00	713	0,86
11B	Sweden	SE12 - Östra Mellansverige	No supply	All	0	0,00	338	0,41
11B	Sweden	SE31 - Norra Mellansverige	No supply	All	0	0,00	174	0,21
11C	Sweden	SE33 - Övre Norrland	No supply	High	0	0,00	127	0,15
12A	Germany	DE91 - Braunschweig	All	All	56	0,07	89	0,11
12A	Germany	DE92 - Hannover	All	All	71	0,08	113	0,14
13A	Czech Republic	CZ05 - Severovýchod	All	Base, High	124	0,15	165	0,20
13B	Czech Republic	CZ07 - Strední Morava	All	Base, High	89	0,11	119	0,14
13B	Czech Republic	CZ08 - Moravskoslezsko	All	Base, High	97	0,12	129	0,16
14A	France (Corsica)	FR83 - Corse	No supply	All	0	0,00	35	0,04
15A	Italy (Sardinia)	ITG2 - Sardegna	No supply	All	0	0,00	88	0,11
16A	Malta	MT00 - Malta	All	All	1	0,00	5	0,01
17A	Slovenia	SI01 - Vzhodna Slovenija	All	Base, High	6	0,01	11	0,01
18A	Ireland	IE01 - Border, Midland and Western	All	All	31	0,04	54	0,07
19A	UK (Northern Ireland)	UKN0 - Northern Ireland (UK)	All	All	30	0,04	39	0,05
				Total	**3,44**		**6,70**	

Figure 61: LNG virtual pipelines – Utilisation of truck loading facilities in markets with developed networks (base scenario)

	Capacity of loading facilities (m3/h)*	Assumptions	Utilzation factor	Consumption (Bcm)
Italy	100	Development of truck loading in Panigaglia	20%	0,11
Belgium	75	No new loading facility implemented	15%	0,06
Netherlands	100	No new loading facility implemented	15%	0,08
UK	300	Development of truck loading in Isle of Grain	20%	0,32
Spain	969	No new loading facility implemented	20%	1,02
France	300	No new loading facility implemented	20%	0,32
Portugal	175	No new loading facility implemented	20%	0,18
* Source: GIE and assumptions			Total	2,08

Figure 62: LNG virtual pipelines – Utilisation of truck loading facilities in markets with developed networks (high scenario)

	Capacity of loading facilities (m3/h)*	Assumptions	Utilzation factor	Consumption (Bcm)
Italy	100	Development of truck loading in Panigaglia	25%	0,13
Belgium	75	No new loading facility implemented	20%	0,08
Netherlands	100	No new loading facility implemented	20%	0,11
UK	300	Development of truck loading in Isle of Grain	25%	0,39
Spain	969	No new loading facility implemented	25%	1,27
France	300	No new loading facility implemented	25%	0,39
Portugal	175	No new loading facility implemented	25%	0,23
* Source: GIE and assumptions			Total	2,61

Figure 63: LNG virtual pipelines – Utilisation of truck loading facilities in markets with developed networks (low scenario)

	Capacity of loading facilities (m3/h)*	Assumptions	Utilzation factor	Consumption (Bcm)
Italy	100	Development of truck loading in Panigaglia	15%	0,08
Belgium	75	No new loading facility implemented	10%	0,04
Netherlands	100	No new loading facility implemented	10%	0,05
UK	300	Development of truck loading in Isle of Grain	15%	0,24
Spain	969	No new loading facility implemented	15%	0,76
France	300	No new loading facility implemented	15%	0,24
Portugal	175	No new loading facility implemented	15%	0,14
* Source: GIE and assumptions			Total	1,55

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