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CNG for commercialization of small volumes of associated gas

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EXECUTIVE SUMMARY

The study has analysed current Compressed Natural Gas (CNG) technology for its potential to monetise small volumes of this gas (1-15MMscf/d) and avoid or reduce the gas flaring.

Introduction

Compressed Natural Gas (CNG) is natural gas transported and stored in compressed form (pressurised to between 100 and 250 barg) in order to reduce the volume to be transported or stored by between 150 to 300 times that of gas at atmospheric pressure.

Historically, CNG has been used onshore for gas supply over short distances and in relatively small volumes. While the cost of delivered CNG depends on project specific conditions such as gas volume, in general CNG can be economically viable for volumes up to around 5 MMscf/d and distances up to 800 km.

Compressed Natural Gas (CNG) is mainly used as an alternative fuel for vehicles. Natural gas vehicles are very popular worldwide, particularly in countries such Pakistan, Argentina, India and China. Use of CNG as fuel for road vehicles has been driven by two main factors: rising gasoline prices and increased environmental concerns.

Use of CNG at a larger scale is not yet commercially viable but is being investigated by several companies as a potential economically viable alternative to Liquefied Natural Gas (LNG).

The CNG Chain

The CNG chain is composed of four elements: Production, Transportation, Receiving and Storage.

Production

CNG production consists of gas pre-treatment and compression. The pre-treatment process is simpler than in an LNG liquefaction plant and is generally set by the requirements of the end users. The main pre-treatment activities are:

- Removal of heavy hydrocarbons to avoid condensation when storing as CNG,
- removal of contaminates: hydrogen sulphide, carbon dioxide, etc., and
- dehydration.

The amount of compression required depends on the delivery pressure of the source gas reservoir and gas quality.

Transportation

CNG may be transported on-shore or off-shore (marine). There are a number of different options available for each alternative.

Marine CNG Transportation

Transportation cost is the most important factor in the CNG chain. The cost of CNG marine transport is directly proportional to the volume of gas and distance between the gas source and the consumers.

Since the early 1960's the marine transport of CNG has been investigated and analysed by various developers. The current marine CNG developers and their transportation concepts are as follows:

	CETech	**EnerSea Votrans™**	**Sea NG Corporation Coselle™**	**TransCanada CNG Technologies**	**Knutsen OAS Shipping**	**Trans Ocean Gas**
Type of Containment	Composite or X80 pipe steel ; composite (Iso container)	X80 steel cylinders	coiled X70 line pipe forming a carrousel (Coselle)	Composite reinforced steel Gas Transport Modules (GTM)	X80 steel cargo tank cylinders (CTC)	Composite HDPE and fibreglass cylinders (MEGC)
Development status	concept stage	advanced concept stage	advanced concept stage	concept stage	concept stage	Concept stage for MEGC container only
Transport capacity (MMscf)	85-319 (+ 60 to 120,000 m^3oil) 200 – 1,200 variable (container)	75 – 1,000 (ship) 10-100 (barge)	51 - 531 (ship) ?-80 (barge)	12 - 100	70 - 1,200	Variable as a function of the number of containers

On-shore CNG Transportation

On-shore CNG transportation is a proven technology that has been used for decades. The on-shore CNG transportation system consists of:

- gas compression and truck loading at the gas source location;
- truck offloading, heating, let-down and metering at the customer site.

Analysis of the cost of delivered CNG for a number of volumes and distances (see below) shows that, for production capacities higher than 5 MMscf/d, delivery of CNG by truck becomes difficult not only due to the substantial number of vehicles required (especially for longer distances), but also the significant extent of loading and offloading facilities required.

The CNG storage type used for transportation is the main difference between the various suppliers. The main characteristics are as follows:

	Tube type	Luxfer-GTM type III	Lincoln type IV	Galileo MAT
Container material	Steel – High strength steel	Aluminum inner wall wrapped with carbon fiberglass	Carbon fibre/epoxy composite	ISO 9809 steel cylinder
Trailer max capacity (MMscf)	up to 0.29	up to 0.44	up to 0.36	up to 0.25
Pressure (barg)	187-227	248	250	200-250
Corrosion resistance	-	?	++	-
Gas/container weight ratio (t/t)	0.24	0.41	0.79	0.2
Comparative cost	base case	++	++	+

Examples of CNG chain costs

The sizing and cost of the different elements of the chain depend on the specific characteristics of each project such as: gas volume and composition, distance to consumers, storage and infrastructure requirements, geographical location etc.

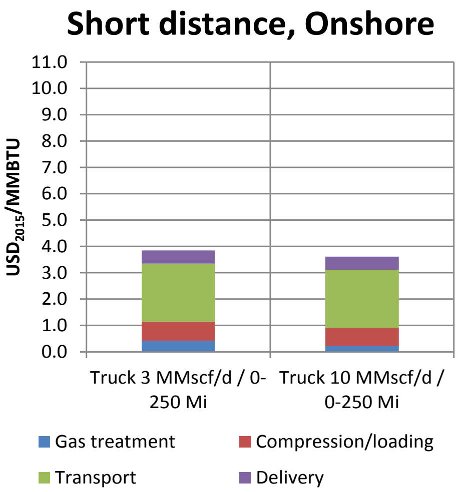
The unit cost (capital and operating) for four scenarios have been evaluated: Gas volumes of 3 and 10 MMscf/d, and short and long distances to customers. It must be noted that these cost estimates are only indicative as specific circumstances (e.g. a challenging physical environment, high labour costs in an overheated business environment such as the Bakken in N. Dakota), can affect the costs and hence economics significantly.

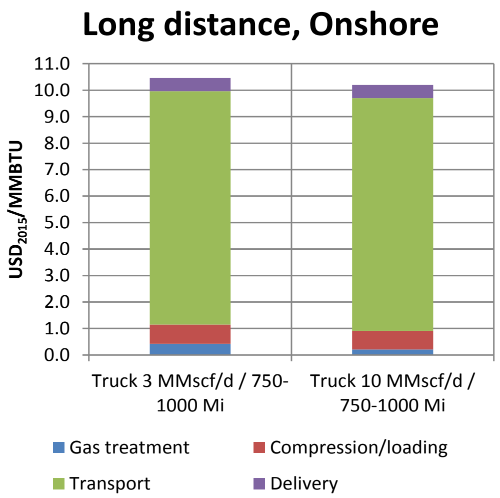
Transport method	**Long distance**		
	Capital & Operating cost, USD_{2015}/MMBTU		
Offshore	**Item**	**Marine 3 MMscf/d / 550-800 MN**	**Marine 10 MMscf/d / 550-800 MN**
	Gas treatment	0.42	0.21
	Compression/loading	0.73	0.70
	Transport	6.43	5.22
	Delivery	0.50	0.50
	Total	**8.08**	**6.63**

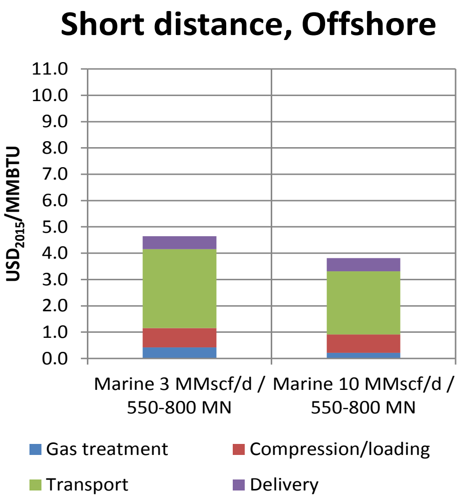
	Capital & Operating cost, USD_{2015}/MMBTU		
Onshore	**Item**	**Truck 3 MMscf/d / 750-1000 Mi**	**Truck 10 MMscf/d / 750-1000 Mi**
	Gas treatment	0.42	0.21
	Compression/loading	0.73	0.70
	Transport	8.81	8.79
	Delivery	0.50	0.50
	Total	**10.46**	**10.20**

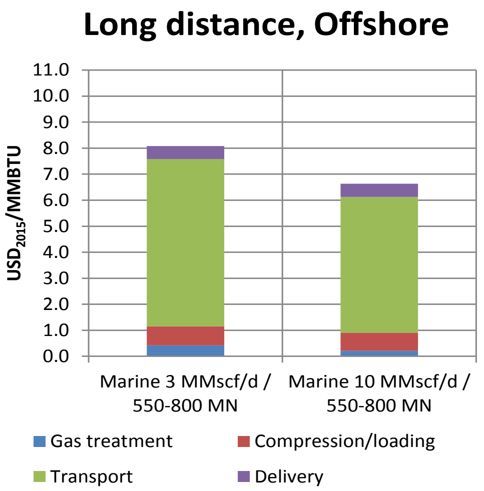
Transport method	Short distance		
	Capital & Operating cost, USD_{2015}/MMBTU		
Offshore	Item	Marine 3 MMscf/d / 55-150 MN	Marine 10 MMscf/d / 55-150 MN
	Gas treatment	0.42	0.21
	Compression/loading	0.73	0.70
	Transport	3.00	2.40
	Delivery	0.50	0.50
	Total	**4.65**	**3.81**

	Capital & Operating cost, USD_{2015}/MMBTU		
Onshore	Item	Truck 3 MMscf/d / 0-250 Mi	Truck 10 MMscf/d / 0-250 Mi
	Gas treatment	0.42	0.21
	Compression/loading	0.73	0.70
	Transport	2.20	2.20
	Delivery	0.50	0.50
	Total	**3.85**	**3.61**

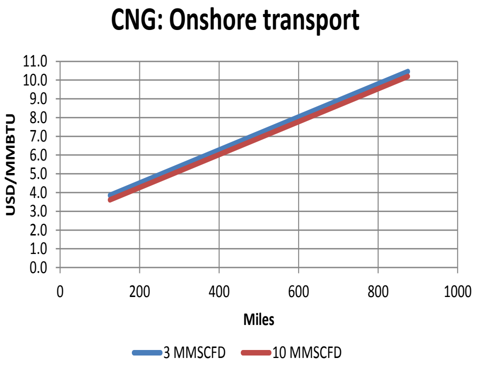


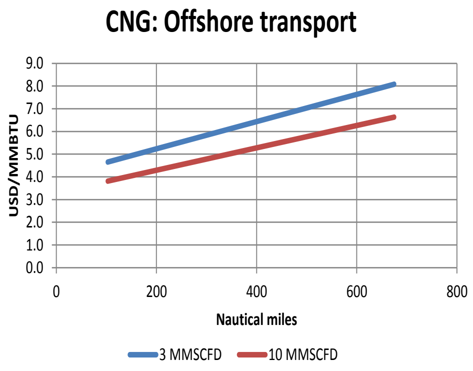






The above cost estimate examples can be summarized as follows:





CNG market overview

Onshore

There are currently almost 20 million road vehicles in the world in a wide range of countries using CNG as fuel. The ten countries with the largest CNG vehicle fleets (in millions) are:

Rank	Country	Registered fleet	Rank	Country	Registered fleet
1	Iran	3.50	6	India	1.50
2	Pakistan	2.79	7	Italy	0.82
3	Argentina	2.28	8	Colombia	0.46
4	Brazil	1.75	9	Uzbekistan	0.45
5	China	1.58	10	Thailand	0.42
World total = 18.09 million vehicles					

The fast growth of CNG as fuel for vehicles has been to a large extent driven by government subsidies and initiatives to promote conversion to CNG for environmental and economic reasons.

Other uses of CNG, such as for power generation; industrial consumers etc., are currently less developed mainly because the gas volumes required are often too high for truck distribution.

Offshore

The lack of proven commercial options for marine transportation of CNG is the main obstacle to faster business development in these areas.

Indonesia may become the first-mover in marine transportation of CNG. A 2,200m³ CNG carrier is currently being built to supply gas to a CNG storage facility in Lombok. The project is planned to start commercial operations in 2016.

Conclusions

CNG on-shore transportation is well established in a number of countries since the 1990s. Marine CNG transportation, however, is still under development and with no units yet in commercial operation.

While the cost of delivered CNG depends on project specific conditions such as gas volume and composition, in general:

- On-shore delivered CNG can be economically viable for volumes up to around 5 MMscf/d and distances up to around 500 miles (800 km).
- Marine CNG is not yet commercially proven but could be economically viable for large volumes and distances up to around 2000 nautical miles.

1. INTRODUCTION

Pressurising Natural Gas and sending it into pipeline network systems is the major means of transporting natural gas, especially for onshore purposes. Long distances pipelines together with compressor stations distributed along the pipeline route transport the gas from the producing area to consumers.

However, Compressed Natural Gas (CNG) used as an alternative fuel for vehicle is now popular worldwide and the twenty-first century has seen an important growth in onshore bulk transportation and infrastructure for delivery and distribution of natural gas at vehicle refuelling stations.

At the same time, several marine CNG transport technologies have been developed for short-distance transportation of small volumes of gas competing with less economical LNG solutions. However, despite marine CNG transportation options being promising, no project has yet been put into commercial operation.

This is expected to change in the coming years, influenced by emerging energy demand in countries with less developed infrastructure and with the growing sensitivity towards environmental impact of higher emission fuels.

Indeed, the development of economical CNG transportation could be part of the possible solutions for the recovery of associated gas as mentioned in the Global Gas Flaring Reduction (GGFR) program led by the World Bank.

The following sections focus on CNG solutions applicable for use with small volumes (1-15 MMscf/d) of associated gas in offshore and onshore conditions.

Before investigating the status of development by the various technology providers and their proposed technologies, it might be useful to first describe the issues linked to the handling and recovery of associated gas for the purpose of transporting it as CNG.

1.1. Abbreviations

ABS	American Bureau of Shipping
AG	Associated Gas
AIP	Awarded Approval in Principle
ANG	Adsorbed Natural Gas
APCNGI	Association Perusahaan CNG Indonesia
APL	Advanced production loading
ASME	American Society of Mechanical Engineers

ATB	Articulated tug-barge
barg	Gauge Pressure (bar)
Btu	British thermal unit
BV	Bureau Veritas
C	Celsius
CDM	Clean Development Mechanism
CETech	Compressed Energy Technology
CNG	Compressed Natural Gas
CO2	Carbon dioxide
CTC	Cargo Tank Cylinder
DNV	Det Norske Veritas
DOT	U.S. Department of Transportation
dwt	Dead weight tons
EYB	Energy Year Book
FPSO	Floating Production Storage and Offloading
FPU	Floating Production Unit
FRP	Fiber Reinforced Plastic
FSRU	Floating Storage Regasification Unit
GDP	Gross Domestic Product
GGFR	Global Gas Flaring Reduction
GPSS™	Gas Production Storage and Shuttle
GTM	Gas Transport Module
H2S	Hydrogen sulphide
HDIP	Hydrocarbon Development Institute of Pakistan
HDPE	High Density Polyethylene
IGC	International Gas Code

IMO	International Maritime Organization
IPL	Island Power Limited
kg	Kilogram
KRG	Kurdistan Regional Development
LASG	Lagos State Government
LNG	Liquefied Natural Gas
LPG	Liquefied petroleum gas
LPP	Length between perpendiculars
m	Meters
MEGC	Multi-Element Gas Container
MFS	Mobile Fuel Solution
mg	miligram
Mi	Miles
MJ	Mega Joule
mm	Milimeters
MN	Nautical Mile
MMscf/d	Million standard cubic feet per day
MOU	Memorandum of Understanding
MW	Mega Watt
NDRC	National Development and Reform Commission
NGC	North Gas Company
NGH	Natural Gas Hydrates
NGL	Natural Gas Liquid
NGV	Natural Gas Vehicle
NGVA	Natural Bio Gas Vehicle
NOC	North Oil Company

OSG	Overseas Shipholding Group
PG&E	Pacific Gas and Electric Co.
PLN (PGN)	Perusahaan Listrik Negara
PLNG	Pressurized Liquefied Natural Gas
PNG	Pressurized Natural Gas
ppmv	Parts per million per volume
PPP	Public Private Partnership
PRP	Pressure Regulating Plant
PUF	Polyurethane foam
QRA	Quantified Risk Assesment
SPDC	Shell Petroleum Development Company
STL	Submerged Turret Loading
t/h	Ton per hour
TCI	TransCNG International
TDG	Transport of Dangerous Goods
TOG	Trans Ocean Gas
TPED	Transportable Pressure Equipment Directive
UN	United Nations
VOTRANS	Volume Optimized Transport and Storage System

1.2. Constraints for the recovery of associated gas as CNG

1.2.1. Nature of associated gas

Associated gas is a form of natural gas which is found in association with oil within the reservoir and is produced when oil arrives at the surface. Once separated from crude oil, raw natural gas usually consists of a mixture of hydrocarbons in various proportions, principally ethane, propane, butane, pentanes and small quantities of heavier components.

In addition, raw natural gas contains water vapour, carbon dioxide (CO2), helium, nitrogen, sometimes hydrogen sulphide (H2S), and other compounds. Typical compositions of associated gas are given as an example in Table 1 but each field and sometimes even each well has its own production characteristics and gas composition.

Component	**Lean Gas**	**Rich Gas**
Methane	92.32	81.62
Ethane	3.25	8.17
Propane	1.80	4.49
i-Butane	0.43	1.44
n-Butane	0.62	1.54
i-Pentane	0.00	0.28
n-Pentane	0.00	0.45
Hexane	0.00	0.11
C7+	0.00	0.09
Helium	0.00	0.01
Nitrogen	0.69	0.94
Carbon dioxide	0.89	0.86
total	100.00	100.00
Molecular weight	17.78	20.62

Table 1 – Typical associated gas composition

There are different ways to deal with the production of associated gas. Depending on the quantities involved, the field location (at sea, on land, remote or not…), and the composition of the gas (e.g. some may contain a large proportion of carbon dioxide or nitrogen), the gas can be just flared off, re-injected into the reservoir for enhanced oil recovery, used as fuel gas on the platform for electricity generation or exported by pipeline for further processing or direct injection into gas grids.

Unfortunately, today associated gas is flared rather than used in many countries and contributes to climate change.

Whatever the destination (except if flared), the gas must be treated and conditioned accordingly. This is also the case for its transportation as CNG due to the fact that the intent is to recover the gas to burn elsewhere, generally after being injected into a gas pipeline.

1.2.2. Constraints linked to CNG transportation

For economic reasons, CNG transportation especially marine CNG must maximize the ratio of the weight of the transported gas to the weight of the containment. This implies that the gas should ideally be transported athigh pressure and low temperature. Usually, transport pressures range between 100 and 250 barg giving a volumetric efficiency (reduction of the volume occupied by the gas at atmospheric conditions) of 150 to 300:1 compared to LNG (about 600:1). Some technologies also cool the gas to -30ºC.

The amount of gas that can be loaded, equipment required and operating procedures depend on several parameters:

- the gas composition,
- the pressure and temperature conditions at the field,
- the production rate of associated gas and thus the filling rate of the marine or land transport container,
- the type of CNG container,
- the gas storage conditions (pressure and temperature).

At the point of delivery, equipment required and operating procedures will depend on:

- the pressure and temperature conditions for CNG offloading,
- the possible limitation of the offloading rate,
- the required quality specification for the received gas.

All these parameters are relevant for CNG solutions at onshore or offshore gas fields but the issues are particularly important in case of marine CNG transportation for which approval is required by a Certification Society such as Det Norske Veritas (DNV).

1.2.3. Gas quality

As previously mentioned, associated gas is present in various compositions that may require the gas to be treated before being stored under pressure for transportation. Normally the gas must be dried so that no moisture will form in the container which may cause formation of hydrates and corrosion in the presence of carbon dioxide. Hydrogen sulphide is not allowed for reasons of corrosion. Furthermore, at the reception point, the gas will generally have to meet pipeline quality specifications with restrictions on injection temperature, water and hydrocarbon dew points, sulphur content and Wobbe index.

Depending on the composition and on the gas utilisation, the extent of gas conditioning required prior to transportation as CNG will be a combination of several different processes such as:

- removal of heavy hydrocarbons to avoid condensation when storing CNG,
- removal of contaminates: hydrogen sulphide, carbon dioxide…,
- dehydration.

Typical contaminant concentrations in associated or stranded well gas are:

- water vapour: 1 – 3% (gas is saturated)
- H_2S: 0 – 300 ppm
- CO_2: 0.1 – 10%
- Condensable hydrocarbons: 1 – 1000 ppmv

For onshore gas pipelines, the requirements for the content of contaminants typically are:

- water dew point: -10°C at 70 barg
- hydrocarbon dew point: -2°C at 1-70 barg
- H_2S: maximum 5 mg/m³
- total sulphur: max. 30 -50 mg/m³
- CO_2 2-3 % (molar)

These requirements could be more severe depending on the loading conditions and the gas containment material.

1.2.4. Recovered gas pressure at the production site

Separation of the oil, water and gas produced in their original phases is achieved by a stepwise reduction in pressure (usually one to three separation stages) down to nearly atmospheric pressure, flashing off the gas. Associated gas is produced at all pressure levels and additional compression equipment may be required to reach the required transport pressure..

1.2.5. Stored gas temperature

The mass of gas stored is a function of the density of the gas. Gas can be carried under chilled conditions but this requires appropriate conditioning equipment and insulation to avoid over-pressurization of the containment during transportation.

Also, one must take into account the unavoidable warm-up during the loading itself resulting from the compression of the gas into the containment especially if the latter is insulated. For example, lean gas compressed to 250 barg would increase in temperature by 40-50°C. This issue should be carefully addressed when developing the operating conditions at the loading point.

The depressurization of the cargo at the delivery point will have the opposite effect i.e. cooling, and this should also be taken into consideration when defining the offloading conditions.

1.2.6. Production rate

Oil production is generally continuous and therefore also the production of associated gas. It is generally not acceptable to interrupt the oil production and therefore CNG offtake facilities must be able to support continuous operation at the field or well gas production rate. However, the volume of gas produced is not constant and will also decline overtime. This has a direct impact on the solution to be put in place.

In this report, the production rates considered are:

- minimum 1 MMscf/d corresponding to a hourly mass flowrate of around 1 t/h of associated gas (Lean Gas of Table 1),
- maximum 15 MMscf/d corresponding to a hourly mass flowrate of around 14 t/h of associated gas (Lean Gas of Table 1).

1.2.7. Offloading Rate

As for the production rate, the offloading rate may be limited by the end user and may be required to be continuous. This has a direct impact on the offloading facilities and ship immobilization time (marine CNG) or CNG storage (onshore CNG) hence on the whole delivery chain.

1.2.8. Offloading conditions

Most of the time, the transported gas will be injected into a pipeline connected either to a single customer (e.g. a power plant) or to an existing natural gas grid which are operated within certain pressure and temperature ranges. This will require heating facilities to prevent gas temperatures being too low due to the Joule-Thompson cooling when depressurizing the CNG. A scavenging compressor would need to be provided as, at some point during the gas offloading, the CNG pressure will be insufficient to deliver the gas at the rate and pressure required by the receiving pipeline. It will also maximise CNG recovery and reduce the heel pressure, the residual pressure in the transport vessel.

1.2.9. Safety

Transporting large quantities of gas under high pressure raises three major safety issues:

- Integrity of the containment system: the stored energy of compressed gas is very high. For instance, a 30m tall 24” diameter pipe pressurized at 110 barg contains the energy equivalent of 120 MJ. Damage from a rupture can result from shock waves, flying projectile fragments from the ruptured piping, and unrestrained movement of piping and equipment propelled by the escaping gas,
- Integrity of the carrier’s hull: the tremendous weight of the containment system results in the transfer of the loads from the CNG containment to the support structure, and so must be checked for suitability. It must also be verified that the support of the containment system can sustain the loads from the ship movement in difficult sea conditions or potential collisions. Furthermore, the impact of an accidental leak of the containment system must be fully assessed and the risks mitigated by adequate safety measures being implemented throughout the lifetime of the transport unit. This requires the possibility to inspect the containment system at regular intervals or to provide a continuous monitoring system,
- Risk of explosion: The nature of the containment system, which often consists of side-by-side assemblies of cylinders, may create a confined space in the ship’s holds in which a gas leakage (not necessarily from the cylinders but from the manifolds) may create an explosive atmosphere. (N.B.: DNV’s rules require the hold space to be inerted with nitrogen or other suitable non corrosive medium).

1.2.10. CNG ship certification

The development in the early 2000’s of marine CNG alternatives to LNG led the classification societies to develop guidelines for both the containment systems and CNG carriers. New design criteria and acceptance procedures have been proposed to depart from the conventional pressure vessel codes and International Gas Code (IGC) which previously made such CNG concepts uneconomic and even practically unfeasible.

The current existing codes and standards are:

- American Bureau of Shipping (ABS): Guide for Vessels Intended to Carry CNG in Bulk,
- Det Norske Veritas (DNV): Rules for Classification of Ships – part 5 CNG Carriers,
- Bureau Veritas (BV): Rule Note NR 517 – Classification of CNGCarriers.

Any marine CNG transport design must be approved by one of the classification societies.

1.2.11. Container design for marine transport

The cargo containment system, especially the cargo cylinders (individual pressure vessels for storage of CNG) must be proven safe and reliable through the whole range of process and mechanical stress conditions, including:

- low temperatures which may occur in case of sudden depressurization including the impact on the ship hull (impingement of gas cooled by the Joule-Thompson effect),
- high and low temperatures resulting respectively from the gas compression and the gas depressurization,
- fatigue induced by the pressure-cycling in the loading and offloading process,

- external loads (deadweight, acceleration forces due to ship's or truck's movement),
- stress corrosion cracking,
- …

Governing codes applicable for high pressure gas cylinders can be conventional codes like ASME VIII div1 but several approaches have been taken to optimize the design namely to make more efficient use of material and reduce the weight of the cylinders.

ASME VIII div2 was revised in 2007 in order to promote more competitive design and div3, originally developed for design pressures above 10,000 psi (690 bar), in 2010 incorporated composite wrapped vessels for CNG.

DNV proposes to design the cylinders using its Standard for Submarine Pipeline Systems OS-F101 which, for the X-80 standard pipeline steel, allows a 50% reduction in wall thickness of the gas cylinders as compared to the IGC.

Four types of cargo tanks are differentiated in the ABS's guidelines:

- Type 1 metallic cylinders with nominal diameter 200 mm (8 ") or less,
- Type 2 metallic cylinders with nominal diameter above 200 mm (8 "),
- Type 3 cylinders constructed from composite materials,
- Type 4 cylinders constructed with an inside metal liner and wrapped outside with high strength steel wires.

This classification corresponds the current designs proposed by all the marine transportation CNG developers.

1.2.12. Onshore CNG transportation

Safety of CNG land transport is mainly concerned by the risk off collision hence by the integrity and resistance of the containment system.

Transportation of pressurized gases by road is not new and is well regulated all over the world e.g. Transportable Pressure Equipment Directive (TPED) in Europe, U.S. Department of Transportation (DOT), the Hazardous Substance Act in Thailand, the Canadian *TDG Regulations (transport of dangerous goods)*… including size and weight restrictions for vehicules.

2. STATUS OF CNG TECHNOLOGIES – MARINE CNG

The concept of marine CNG transport has a long story. A first attempt at transporting natural gas under compressed form for commercial purposes was made in the 1960's by Columbia Gas Company of Ohio. The attempt failed mainly because the weight of the gas containment designed at that time according to International Maritime Organization (IMO) code occupied too large a portion of the loading capacity of the vessel. Since then, with the use of advanced pressure vessels codes and sometimes non metallic materials (composite), several design have been proposed in order to make marine CNG transportation commercially viable.

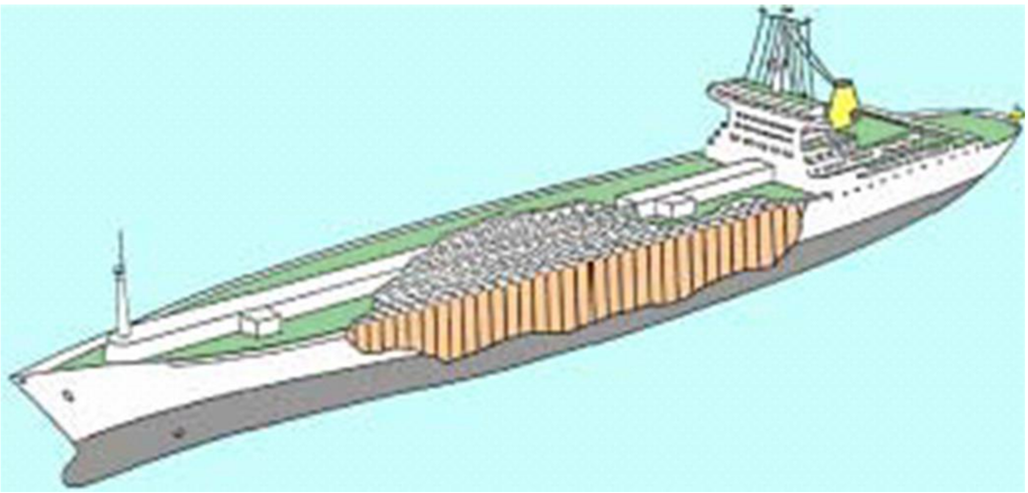


Figure 1 Columbia Gas - Ocean Transport Pressure Vessel

Many papers have been published and presented at conferences on the subject. They are referenced in appendix 1. Also information found on the website of the technology providers has been used for this report. In particular, the Canadian Centre for Marine CNG Inc. has, since its establishment in 2003, been an active promoter of large-scale marine transportation of CNG by providing technical support and testing facilities to companies involved in the development of CNG technology for offshore transport of natural gas. The current partners in the Centre include CNG technology providers, shipping companies, classification societies, natural gas infrastructure providers, offshore technology providers, petroleum producers, universities, research organizations and the governments of Newfoundland and Nova Scotia.

The following descriptions reflect the current status of the various technologies presently in the market together with considerations regarding their applicability to handle small volumes of associated gas in offshore conditions.

The current proposed concepts for CNG shipping are:

- Compressed Energy Technology AS (CETech),
- EnerSea-VOTRANS™ (Volume Optimized Transport and Storage System),
- Sea NG Corporation – Coselle,
- Trans Canada CNG technologies,
- Knutsen,
- Transocean.

2.1. Compressed Energy Technology AS

Compressed Energy Technology (CETech) is a company jointly established in 2004 by Leif Höegh & Co, Statoil and Teekay Shipping. Since June 2009, CETech has been a 100% owned subsidiary of Höegh LNG AS.

2.1.1. Technology

CETech's CNG containment system consists of cylinders built of composite material. The cylinder is now in the process of qualification testing in order to develop fabrication methodology and determine material selection.

Figure 2 Sub-scale cylinder testing (Courtesy of CETech)

2.1.2. Marine transport vessels

CETech has developed two major concepts:

- the *CNG Shuttle* that is intended to transport either natural gas from a supply location to a receiving terminal pipeline, or to transport associated gas from an oil producing unit to a receiving/processing terminal,
- the *Shuttle Producer* which can transport both oil and compressed gas and is aimed at fields which require simultaneous production and offtake of oil and associated gas.

The basic idea in the CNG ship design is to separate the CNG storage system from the vessel's hull, the latter being similar to standard oil tankers.

2.1.2.1. THE CNG SHUTTLE

The design could take two different configurations:

1) design using a vertical cylinder containment arrangement

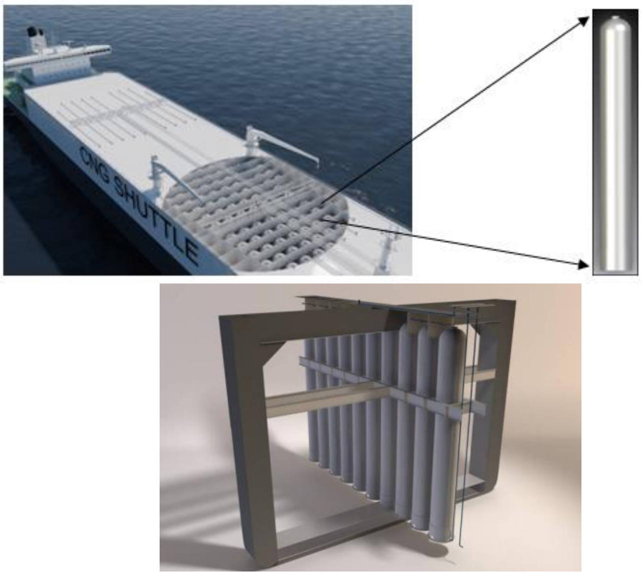


Figure 3 Courtesy of CETech

The gas is stored at 150 barg in cylinders of 3 m diameter and 30 m length. The cylinders are installed vertically in the ship in a supporting frame. No insulation of the containment system is required due to storage at ambient temperatures.

The stored gas weight per cylinder at operating pressure is 29,000 kg for the lean gas composition given in Table 1, and 37,500 kg for the rich gas composition. Higher loading capacities can be achieved by using low storage temperatures (down to minus 30°C), the cylinders having a design temperature of minus 60°C. However, an operating procedure is not available and the energy of compression could compromise achieving such low temperatures. Should it be possible, then insulation would be required to maintain the gas in its initial storage conditions during the ships voyage.

No transportation capacity has been communicated by CETech. If we assumed the cylinders were to be installed in standard oil tankers, 250 to 500 MMscf could be transported.

Therefore the maximum daily production of associated gas considered in this study could be stored in just 10 cylinders which would represent a small portion of the total ship storage capacity.

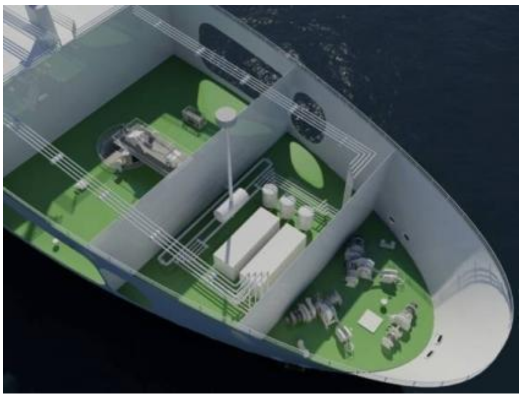


Figure 4 Courtesy of CETech

The ship is provided with a cargo compartment that contains a heating system for use during gas offloading and also has a small gas processing unit that may be required by the gas conditions at the loading location. In that respect, liquids that are separated from the gas can be stored in dedicated tanks or, says CETech, "*be spiked into the tanks together with the gas"*.It is not clear how the liquid would be recovered at the delivery side.

2) Design using a horizontal pipe system

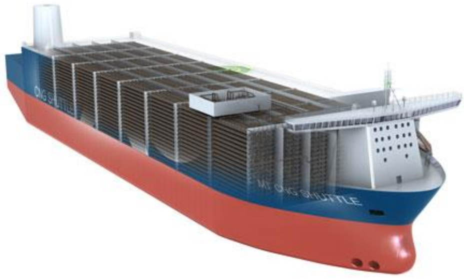


Figure 5 Courtesy of CETech

This CNG containment system consists of stacked layers of 200 m long horizontal pipes mounted within and on the ship's deck. The pipes, made of high strength X-80 steel, are 1.2 m diameter with a wall thickness of about 36 mm.

The proposed ship would contain a total of 510 pipes with a total volume of about 120,000 m^3. The gas will be stored at a high pressure of 250 barg which gives a ship transport capacity in the range of 30 to 35 million standard cubic metres (1,000 to 1,200 MMscf).

CETech claims to have been looking at *CNG Shuttles* with horizontal pipe system having gas transportation capacities of 300 to 1,200 MMscf to be considered when compared with the maximum production rate of 15 MMscf/ d for this study.

The ship can be equipped with processing facilities so that it can accommodate gas from a production platform or directly from seabed facilities via a connecting buoy. At destination, both alternatives may be contemplated (jetty or buoy).

2.1.2.2. THE SHUTTLE PRODUCER

The concept is a very versatile solution aimed at collecting simultaneous production and off-take of oil and gas in several configurations, the objective being floating production units with a minimum of process equipment onboard. It could be applicable for:

- transport of un-stabilized crude oil to an onshore processing plant,
- intermittent or continuous production and storage of oil and gas depending on the reservoir characteristics,
- stationary at well with offshore transfer service,
- connection to a production platform, or directly to seabed facilities via a connecting buoy.

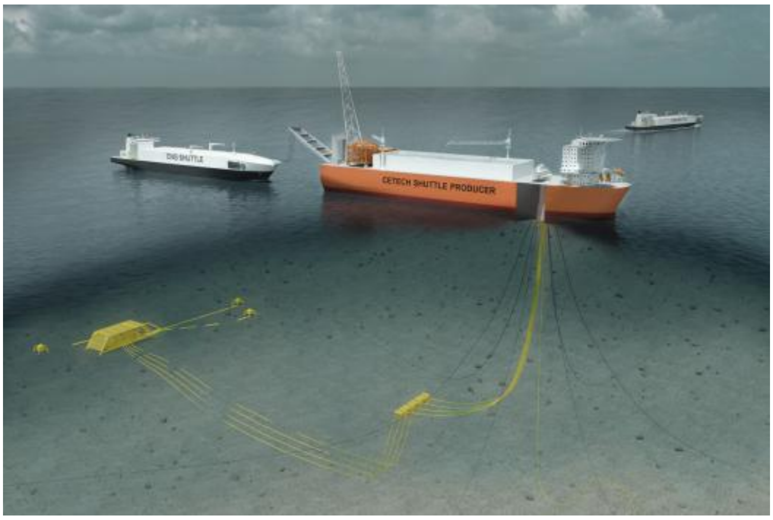


Figure 6 Floating Production Storage and Offloading (FPSO) with offloading to dedicated shuttle tankers (Courtesy of CETech)

The *Shuttle Producer* will use the hull of conventional oil tankers with horizontal gas pipes as previously described mounted above the oil tanks. The design considers two sizes of vessels:

1) one based on Aframax vessels

The ship would be able to carry 60 to 70,000 m³ of oil and 8,000 m³ of gas.

Assuming a pipe length of about 145 m for a Aframax with a length of 245 m (length between perpendiculars (LPP)) and a breadth of 44 m, 48 pipes would be required to achieve a volume capacity of 8,000 m³ giving a transportation capacity of around 80-85 MMscf at 250 barg.

2) one based on Suezmax vessels

The ship would be able to carry 120,000 m³ of oil and 30,000 m³ of gas.

Assuming a pipe length of about 200 m for a Suezmax with a length of 285 m (LPP) and a breadth of 48 m, 130 pipes would be required to achieve a volume capacity of 30,000 m³ giving a transportation capacity of around 300-320 MMscf at 250 barg.

2.1.2.3. CONTAINERIZED SOLUTION

In addition to the development of marine CNG carriers, CETech has entered into a cooperation agreement with Hexagon Lincoln (Lincoln, Nebraska, USA), a wholly owned subsidiary of Hexagon Composites (Ålesund, Norway),for the utilization of their TITAN compressed natural gas modules to serve as mobile pipelines for marine CNG applications.

According to Hexagon Lincoln, the design of the TITAN gas cylinder is based upon Lincoln Composites' TUFFSHELL® technology. It has a high density polyethylene (HDPE) liner, a filament wound carbon fibre/epoxy composite shell (the primary structural member of the container), plus a polyurethane coating applied to the outer surface. The composite cylinders weigh 75 percent less than equivalent steel tubes.

The TITAN™4 Module is a 40 ft ISO 1496 certified shipping container which contains four TITAN cylinders. Each cylinder is almost 12 m in length and over 1 m in diameter and is designed to operate at 250 barg. In these conditions, one module can contain 7 to 8,000 kg of CNG or about 0.36 MMscf with a module tare weight of 15,649 kg.

Therefore 3 to 42 TITAN^{TM}4 Modules could respectively store the daily associated gas production range of this study namely 1 to 15 MMscf.

CETech has presented the conversion of an existing vessel using seven blocks of 21 containers each for a total transportation capacity of about 50 MMscf at 250 barg.

This containerized solution would enable more or less tailor-made conversions of available ships into ship-containers. However we would expect that such a configuration would require a very dense piping and valves system.

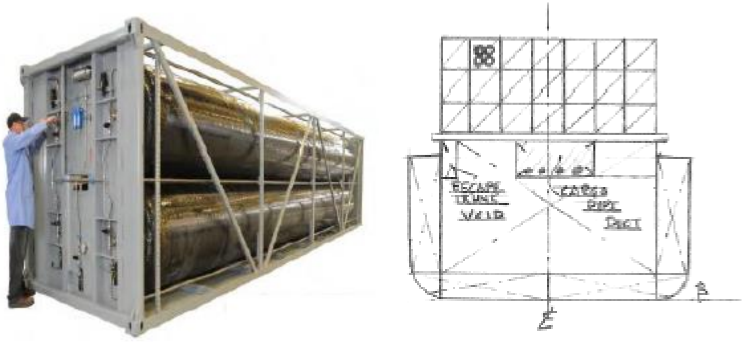


Figure 7 TITAN 4 Module and proposed ship conversion (Courtesy of CETech)

2.1.3. Certification

CETech's CNG Shuttle concept has received Approval in Principle from classification society DNV.

The ISO container module is ABS approved for onshore and marine CNG transportation.

2.1.4. Key features and Comparison LNG

A summary of the CETech CNG systems is given below compared with the same volume of LNG expressed as energy content (btu/btu).

For the cargo/containment weight ratio, only the weight of the gas container is considered without piping, valves and supporting frame.

Type	**CNG system**	**CNG Capacity (MMscf)**	**Cargo/Container weight ratio (ton/ton)**	**Energy ratio LNG/CNG (btu/btu)**
CNG Shuttle (V)	Vertical composite cylinders – 154 barg	200-500	0.70	3.3
CNG Shuttle (H)	Horizontal X80 pipes – 250 barg and oil tanks	300-1,200	0.24	2
Shuttle Producer (Aframax)	Horizontal X80 pipes – 250 barg and oil tanks	85 (& 70,000 m^3 oil)	0.24	2
Shuttle Producer	Horizontal X80	319	0.24	2

(Suezmax)	pipes – 250 barg and oil tanks	(&120,000 m³ oil)		
Container-vessel	TITAN™ 4 modules Composite cylinders – 250 barg	Assumed to be variable	0.79 (0.52 incl'module)	2

Table 2: A summary of the CETech CNG systems

2.1.5. Commercial References

None.

2.1.6. Targeted Markets

CETech considers that CNG is expected to be profitable within a transport range of 300 (production volume 18,000 MMscf/y) to 2,000 nautical miles (production volume of 100,000 MMscf/ y).

2.1.7. Potential Application for 1-15 MMscf/d Gas Production

Considering the range of possibilities proposed by CETech, a tailor-made CNG chain could be developed to fit demand either with the Aframax type Shuttle Producer or with the container vessel using TITAN 4 modules depending on the characteristics of the oil reservoir.

2.2. EnerSea – VOTRANS™

EnerSea Transport LLC is a company founded in 2001 in partnership with, among others, the shipping company Kawasaki Kisen Kaisha Ltd ("K" Line) and the ship builder Hyundai Heavy Industries Co. (HHI). The company has developed a CNG marine transport system named VOTRANS™

2.2.1. Technology

VOTRANS™ technology intends to address several issues relating to the transport of gas under high pressure i.e.:

1) by optimizing the gas cargo/containment weight ratio,
2) by avoiding pressure transient conditions when loading the gas,
3) by minimizing the heel pressure so increasing the net CNG transport capacity.

2.2.1.1. GAS CARGO/CONTAINMENT WEIGHT RATIO

For a non-perfect gas, the pressure, volume and temperature are related by the expression PV = zRT, where R is a constant and z is the compressibility factor. Depending on the gas composition, the VOTRANS™ system is designed to operate at or near the minimum compressibility factor Z for the gas. One may observe on the figure below that, for a given gas temperature, the Z factor reaches a minimum for an associated pressure which tends to decrease with temperature.

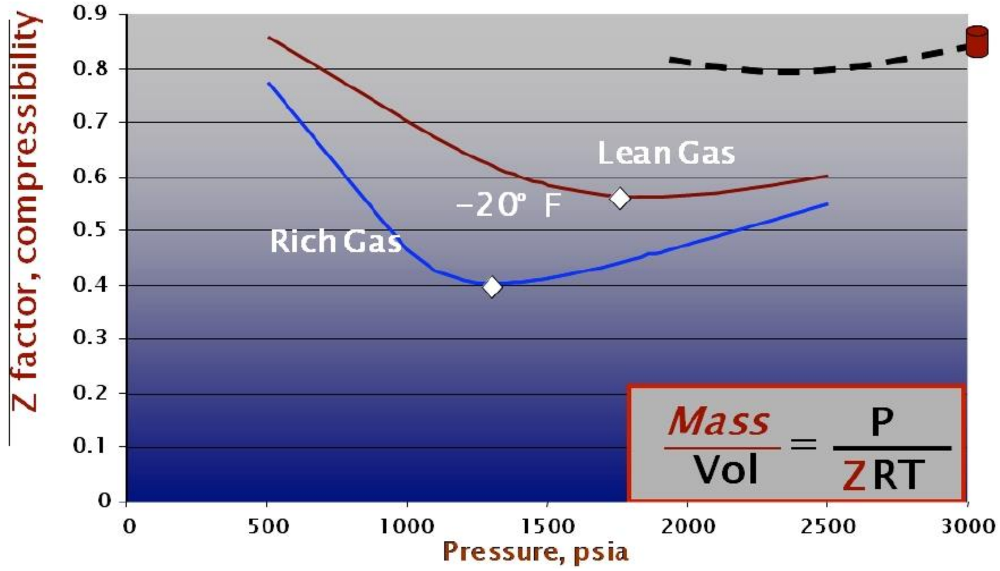


Figure 8 Z compressibility factor as function of pressure at constant temperature (Courtesy of EnerSea)

A temperature/pressure pairing can be chosen so that the mass of CNG is maximized with respect to the weight of the containment, the latter being proportional to the stored gas pressure.

With the VOTRANS™ system, the gas is compressed and cooled prior to being loaded into the ship containment system. EnerSea mentions that typical stored conditions can be 125 barg and -30°C.

The benefit of this compared to other systems operating at higher pressures and ambient temperatures is to reduce the containment cost by using a lower storage pressure (more or less half the pressure), thereby allowing thinner walled cylinders, while keeping a relatively high gas transportation capacity.

2.2.1.2. DISPLACEMENT FLUID

EnerSea uses a patented liquid displacement system to handle the gas during loading and offloading operations. EnerSea’s CNG cargo containment system consists of several sets of storage cylinders configured into multiple tanks and tiers (two or more tanks configured to load and offload together).

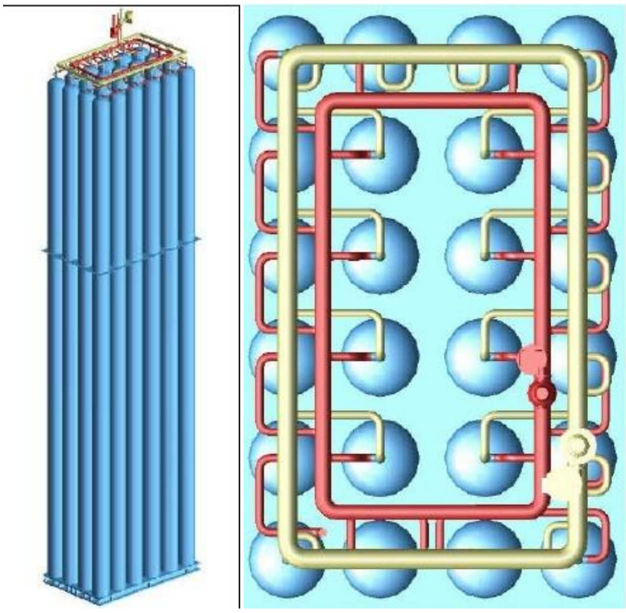


Figure 9 VOTRANS CNG Tank Module (*Courtesy EnerSea*)

After compression and chilling, the gas flows into the ship containment system against a pressurized ethylene glycol/water solution. Gas loading proceeds progressively from one module of cylinders to the next, so cascading the glycol/water solution ahead of it. When all the modules are filled with gas, the glycol solution is stored in an insulated dedicated tank onboard the ship. The required inventory for the ethlyne glycol/water solution is 8-10% of the total containment system capacity.

At the delivery side, the same method is applied in reverse by pushing the gas out with the pumped glycol solution. The VOTRANS^{TM} system has several advantages:

- the gas handling is performed in constant conditions avoiding the transient situations that require gas conditioning and close control during operations. The gas can be maintained in dense phase all through the loading and unloading operations,
- according to EnerSea, the system with gas kept in a dense phase can accommodate a wide range of gas compositions, including rich and associated gas,
- gas offloading rate is easily controlled by the glycol/water pumps that may deliver high rates if required,
- the displacement fluid piston prevents gas auto-cooling in the cylinders during offloading, again allowing high offloading rates,
- low cost for liquid pumping compared with the higher Opex of a scavenging gas compression system needed for CNG offloading using a blowdown method.

2.2.1.3. HEEL PRESSURE

The use of a displacement fluid allows for lower residual gas volumes (2-5%), against 10-15% for conventional high pressure blowdown systems.

2.2.2. Marine transport vessels

2.2.2.1. CNG VESSEL

The engineering program, concluded with “K” Line and HHI, has resulted in the design and general specification of a vessel targeted to carry 700 MMscf of lean gas. The vessel is a 75,000 m³ compressed natural gas carrier. The design utilizes vertical cylinders with all manifold connections at the top of the tanks. The cargo containment consists of one hundred cylinder modules, each comprised twenty-four 1,100 mm diameter cylinders with a length of about 39 m (cylindrical part). The cylinders are constructed from API 5L X80 grade carbon steel and have a 19mm wall thickness for the 125 barg design pressure. The modules are grouped in twelve separate holds which are inerted with nitrogen to enhance safety.

The interior of the cargo spaces is insulated by polyurethane foam (PUF) in order to maintain the low temperature of the stored gas and avoid over-pressurization of the cylinders due to heat ingress. The tank modules sit upon a denser layer of foam material that can support their weight.

The cargo handling system is located forward of the cargo block. Internal submerged turret loading/offloading has been incorporated into the design so that the process handling system is well away from the accommodation block. The concept can accommodate loading/unloading at jetty or buoy systems as well as uninterrupted loading or delivery.

By optimizing the pressure/temperature combination for the two gas compositions given as example in §1.1, the VOTRANS™ V800 class vessel would have a gas transport capacity as follows:

	Lean Gas	**Rich Gas**
Total gas containment volume (m³)	75,000	75,000
Stored gas temperature (°C)	-30	-15
Stored gas pressure (barg)	124	110
Stored gas density (kg/m³)	206	219
Total gas cargo (MMscf)	725	665

Table 3: VOTRANS™ V800 gas transport capacity

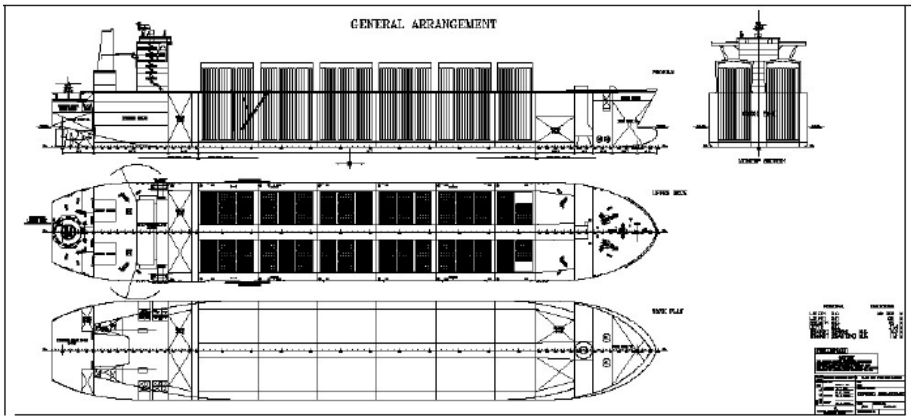


Figure 10 V-800 VOTRANS^{TM} CNG Ship General Arrangement (Courtesy EnerSea)

EnerSea has developed a range of vessel size classes, including the V600 and V1000 for smaller and larger transport needs respectively, in order to offer a wider option range adaptable to specific project requirements. A horizontal pipe configuration could also be contemplated.

Figure 11 V-800 VOTRANS^{TM} CNG Ship (Courtesy EnerSea)

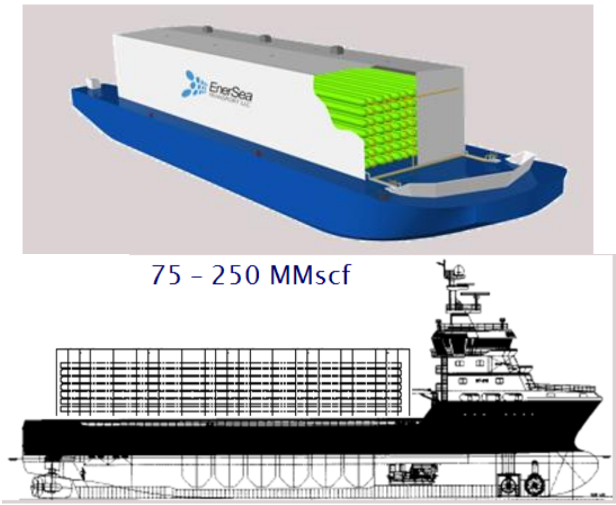


Figure 12 CNG Barge 25-75 MMscf and 75-225 MMscf vessel (horizontal pipe configuration) (Courtesy EnerSea)

2.2.2.2. BARGE CONCEPT

EnerSea's CNG barge system, using the same VOTRANS™ technology, provides solutions for gas delivery needs in the range of <10 MMscf/d to over 100 MMscf/d over transit distances ranging from 50 to 75 miles.

The barge-based system can employ an articulated tug-barge design (ATB), wherein the tug is coupled directly to the barge. The ATB will provide for better speed, efficiency and maneuverability in the open seas than towed barges, which results in a low-cost service.

2.2.2.3. GAS PRODUCTION STORAGE AND SHUTTLE

Additionally, EnerSea claim that its technology can be used for gas production and transport using its Gas Production Storage and Shuttle (GPSS™) system. The GPSS™ eliminates a separate Floating Production Unit (FPU) and long pipelines in any type of environment, including remote, deepwater and arctic areas. The GPSS™ system consists of a fleet of CNG ships, each having raw gas production and gas handling facilities onboard to condition the water-saturated produced fluids, including gas/water separation. The gas is then compressed (if required), chilled and stored in gas containment holds, while the extracted water is treated and discharged. Any natural gas liquids (NGLs) are stored as un-stabilized liquid in pressure vessels similar to those designed for CNG.

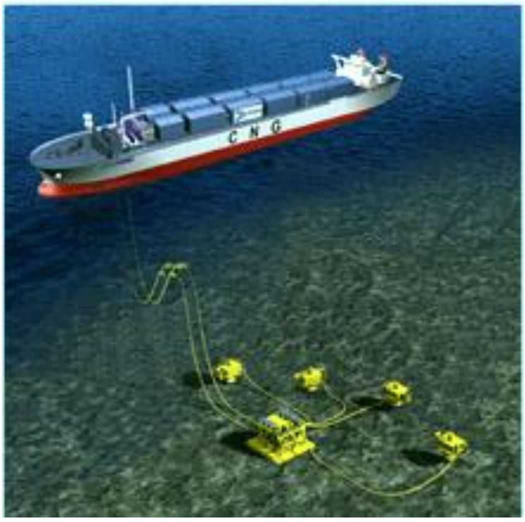


Figure 13 Gas Production Storage and Shuttle (GPSS™) system (Courtesy EnerSea)

2.2.3. Key features and Comparison LNG

A summary of the contemplated VOTRANS™ CNG systems are given below compared with the same volume of LNG expressed as energy content (btu/btu).

The cargo/containment weight ratio is only given for the V800 vessel class as the other versions are still only in the planning stage; only the weight of the gas container is considered without piping, valves and supporting frame.

Type	**CNG system**	**CNG Capacity (MMscf)**	**Cargo/Container weight ratio (ton/ton)**	**Energy ratio LNG/CNG (btu/btu)**
Barge	Horizontal pipe arrangement	<10-100	-	-
(unknown)	Horizontal pipe arrangement	75-225	-	-
V600	Vertical X80 cylinders – 125 barg	600	-	-
V800	Vertical X80 cylinders – 125 barg	800	0.35-0.39	2.1
V1000	Vertical X80 cylinders – 125 barg	1,000	-	-

Table 4: VOTRANSTM CNG systems

2.2.4. Certification

ABS granted ‘Approval in Principle’ for the design and operating plans for the V-800 VOTRANS™ ship in 2003.

ABS has confirmed that EnerSea’s CNG barge design is within the Approval in Principle certification that was granted to EnerSea’s VOTRANS™ CNG ship system.

2.2.5. Commercial references

None.

2.2.6. Targeted Markets

The figure below illustrates the expected economic rate/range relationship for the current VOTRANS™ fleet of gas carriers.

One may see that the VOTRANS system targets to support production rates of between 150 and 700 MMscf/d (54,000 to 255,000 MMscf/y) depending on distance that ranges between 250 and 3,000 nautical miles.

However the development of system on barges and smaller ship design (horizontal pipes) would allow covering coasting trade and smaller yearly production rates.

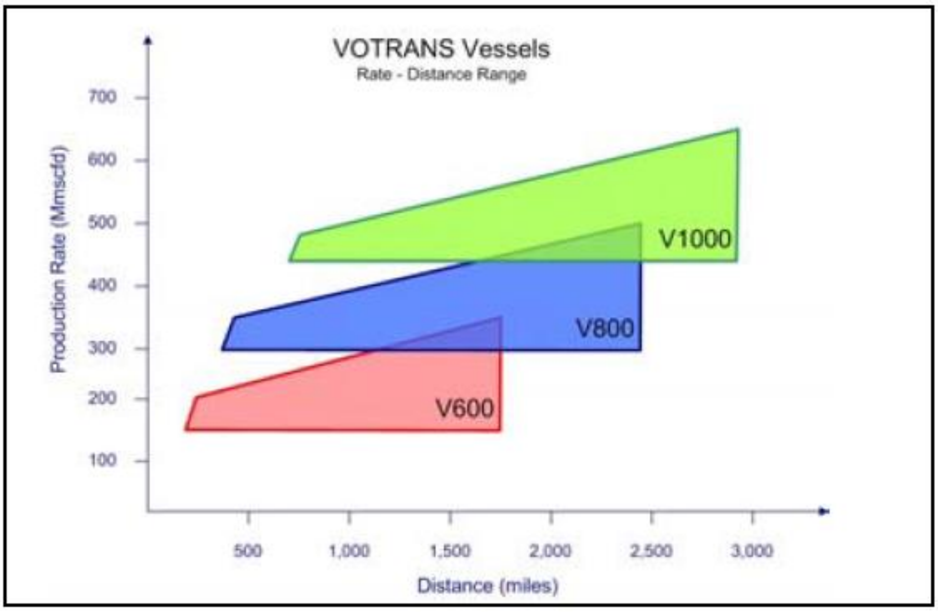


Figure 14 Range of expected commercial transport service for the VOTRANS™ fleet (Courtesy EnerSea)

The VOTRANS™ barge would be competitive between 50 and 750 nautical miles.

2.2.7. Potential Application for 1-15 MMscf/d Gas Production

Considering the number and size, VOTRANS™ CNG systems can be scaled to fit demand and would depend on daily production rates from the reservoirs.

The barge system could be more appropriate for the small production range considered in this report, provided that the production platform is equipped with gas treatment and compression facilities.

The GPSS™ system contemplated by EnerSea, appears to specifically target gas/condensate reservoirs (non-associated gas) and not gas associated with oil production.

2.3. Sea NG COSELLE™

Sea NG Corporation is a Canadian company engaged in the development and commercialization of technology for marine transportation of CNG. Sea NG has formed an alliance with Marubeni Corporation, Teekay Corporation and Enbridge Inc. to jointly develop marine CNG projects, (Sea NG Alliance). The Sea NG Alliance will finance, build and own ships utilizing the Coselle™ technology.

2.3.1. Technology

Sea NG was formed in 2005 to acquire the rights to an innovative marine CNG technology -- the Coselle™ invented by Cran & Stenning. The Coselle™ is a large-volume, high-pressure gas storage module. Coselle™ is a contraction of the words "***co***iled pipe in a carou***sel***".

The central idea behind the Coselle™ concept is to create a large CNG storage system that overcomes the issues resulting from the utilization of large diameter pressure cylinders or pipe sections namely:

- the severe strength requirements for a CNG cargo container design that must meet the following limit states (ABS technical paper) : bursting, local buckling and collapse, fracture, fatigue, out-of-roundness and corrosion. This is all more challenging with large diameter containers,
- Marine CNG containment requires fabrication and installation ofa large number of pressure vessels that could create upward pressure on manufacturing costs and production delays,
- the large number of pressure vessels to be manifolded together makes the system complex with numerous valves, connecting pipes, flanges and fittings which are potential sources of leakage,
- configuration of the pressurized gas containment must accommodate regular inspections requiring access to each of the components.

In that respect, the Coselle™ system appears to respond to all the aforementioned issues. Its innovative design consists of a large coil of pipe wound into a cylindrical storage container. Up to ten miles of conventional six-inch, ¼" wall, high-strength X70 line-pipe is coiled into a reel-like structure, called a carousel. The carousel provides support and protection for the transportation and stacking of Coselles™. Inspection can easily be performed with an intelligent pig device.

The size of a Coselle™ ranges from 15 to 20 metres in diameter and 2.5 to 4.5 metres in height and can weigh 550 tonnes. A single Coselle™ carries about 3.0 MMscf of natural gas, depending on Coselle™ dimensions, and gas temperature, pressure and composition. By design, fewer Coselles™ are required for a given transportation capacity hence reducing the complexity of the manifolds. For the Lean Gas composition given in §1.1, a loaded capacity of 2.7 MMscf can be achieved with 213 barg (3,087 psig) and 25°C but 4.3 MMscf if the pressure is increased to 266 barg (3,860 psig).

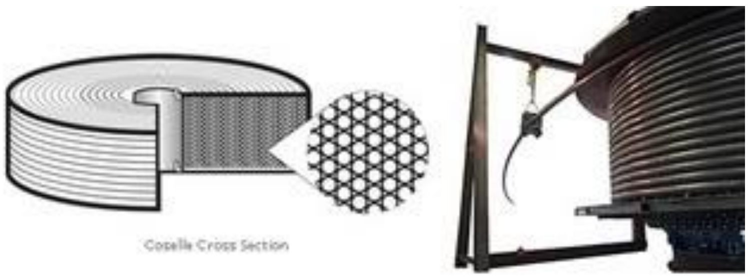


Figure 15 Coselle™ Cross Section (courtesy of Sea NG)

2.3.2. Marine transport vessels

Coselle™ CNG carriers are essentially bulk carriers with Coselles™ installed in their holds. Sea NG developed the standard Coselle™ CNG carrier around a double-hulled 60,000-dwt Panamax bulk carrier. In this design, Coselles™ are carried in stacks of six high within the ship's holds.

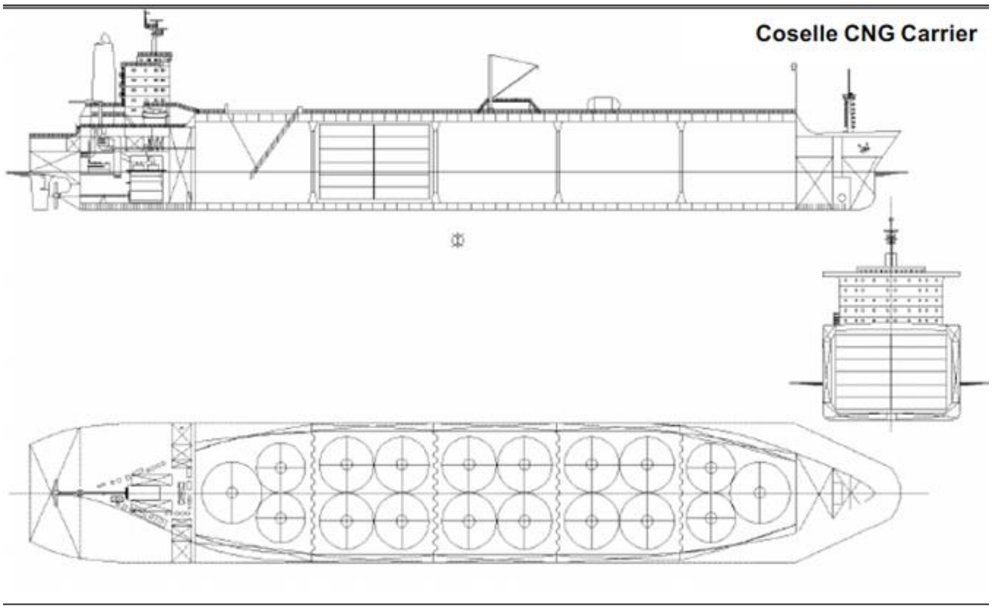
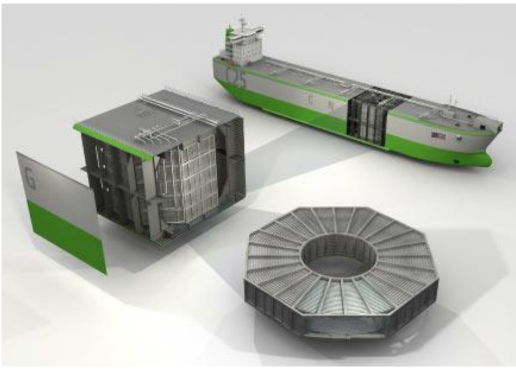


Figure 16 (courtesy of Sea NG)

In total there are 18 stacks of Coselles™ and 108 Coselles™ per ship. Each Coselle™ holding 3.0 MMscf of CNG, the ship's transportation capacity is 323 MMscf.

For safety the holds are inerted with nitrogen in order to eliminate the danger of fire below the deck. All valves and fittings are installed above deck to facilitate servicing.



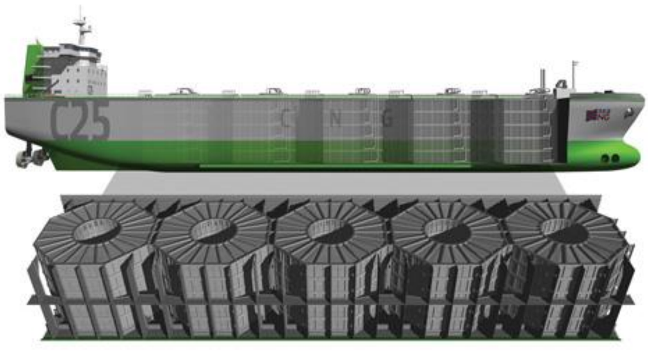


Figure 17 The Coselle™ CNG Ship (courtesy of Sea NG)

The Coselle™ ship may be subject to multiple design variations for different project applications. The table below gives an idea of the possible ship characteristics. It is noteworthy that the announced net gas capacities are related to load pressures of 275 barg.

Ship	C16	C20	C25	C30	C36	C42	C49	C84	C112	C128
Coselles	16	20	25	30	36	42	49	84	112	128
Net Capacity* (million scf)	66	83	104	125	149	174	203	349	465	531
(million scm)	1.8	2.3	2.8	3.4	4.1	4.8	5.8	9.9	13.2	15
Length OA (m)	137	137	160	160	180	201	201	234	257	278
Breadth (m)	23.5	23.5	23.5	28.5	28.5	29.5	31.0	46.0	46.0	48.0
Loaded Draft (m)	7.3	7.5	8.0	7.9	8.2	8.3	8.8	8.7	10.5	10.5

* Net Capacity is net of heel gas and assumes lean gas at 27 ºC

Figure 18 Sea NG Ship Fleet (Courtesy of Sea NG)

For smaller volume and/or distance projects, it would be possible to mount the Coselles™ onto a barge. An articulated tug barge unit was designed by Sea NG that carries 80 MMscf of gas in 28 Coselles™, stacked two high on deck.

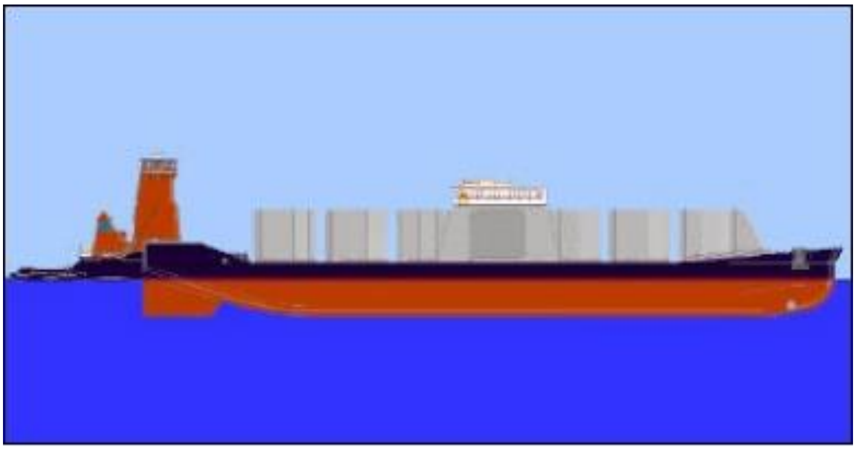


Figure 19 Coselle™ tug barge (Courtesy of Sea NG)

2.3.3. Key features and Comparison LNG

A summary of the Coselle™ C16 and C108 class ship are given below compared with the same volume of LNG expressed as energy content (btu/btu).

For the cargo/containment weight ratio, only the weight of the gas container is considered without piping, valves and supporting frame, keeping in mind that the Coselle™ ship contains fewer valves and fittings and thus the gas cargo/total deadweight ratio could actually be better. The gas cargo is calculated for the Lean gas composition given in §1.1 with loaded pressure and temperature of respectively 266 barg and 25°C.

Type	CNG system	CNG Capacity (MMscf)	Cargo/Container weight ratio (ton/ton)	Energy ratio LNG/CNG (btu/btu)
Coselle™ C16	6inch coils – 16 Coselle™	51	0.12	1.9
Coselle™ C108	6inch coils – 108 Coselle™	344	0.18	1.9

Table 5: Coselle™ C16 and C108 class ship

2.3.4. Certification

The Coselle™ design and prototype was fully approved by ABS and DNV at an operating pressure of 275 barg (4000 psi).

ABS granted 'Approval in Principle' for the design and operating plans for the C16 Coselle™ ship in 2009.

2.3.5. Commercial references

None.

2.3.6. Targeted Markets

Sea NG says that the Coselle™ CNG technology has the potential to be the least cost gas-delivery system when the market is less than 2,500 miles from the gas source. Sea NG adds that CNG is potentially significantly less costly (combined tariff capex+opex) than LNG or pipelines when the transport distance is between 300 and 1 500 miles.

The production range, based on Sea NG available information, should be between 20,000 and 120,000 MMscf/ydepending on the distance.

2.3.7. Potential Application for 1-15 MMscf/d Gas Production

The lower limit of the production range corresponds to a daily production of 65 MMscf.

On that basis, time to fill a Coselle™ C16 class ship would range between 65 and 4 days as a function of the production rate. The long immobilization period for the ship could adversely impact the project economics.

2.4. TransCanada CNG Technologies

TransCanada CNG Technologies Ltd is a subsidiary of TransCanada Corporation Overseas which is a natural gas pipelines operator and power producer in Canada. In 2006, TransCanada entered into a strategic partnership with Overseas Shipholding Group, Inc. (OSG) to commercialize new technology for CNG transportation.

Under the agreement, OSG would own and operate a new type of vessel, capable of moving large quantities of CNG. The ships would utilize TransCanada's patented technology for the design, construction and operation of Gas Transport Modules (GTMs) for the storage of the CNG.

The partners worked under their joint venture TransCNG International (TCI). The present status of this joint venture, as well as TransCanada’s continued interest in marine CNG, is not clear. A press article (TradeWinds Oct2010) mentioned that TransCanada had the intention to sell its CNG transport system, including the company’s license to build its patented composite reinforced pressure vessel for marine use. Nothing has been publicly revealed about anyactions taken after that decision. Nevertheless, a description of the technology is given below as the GTM module may present some advantages.

2.4.1. Technology

TransCanada's technology is entirely based on the utilization of a proprietary composite reinforced steel pressure container system manufactured under license from NCF Industries Inc.

The Gas Transport Module (GTM) is a steel welded pressure vessel wrapped circumferentially on its exterior surface with composite layer reinforcement. The patented manufacturing process is made in such a way that the composite reinforcement produces lower hoop stresses in the steel shell at operating pressures. Typically, according to NCF, the composite reinforcement adds 20% to the weight of the vessel while increasing the pressure capability by 100%. AGTM module has 40% less weight per volume compared to steel built to the same standards.

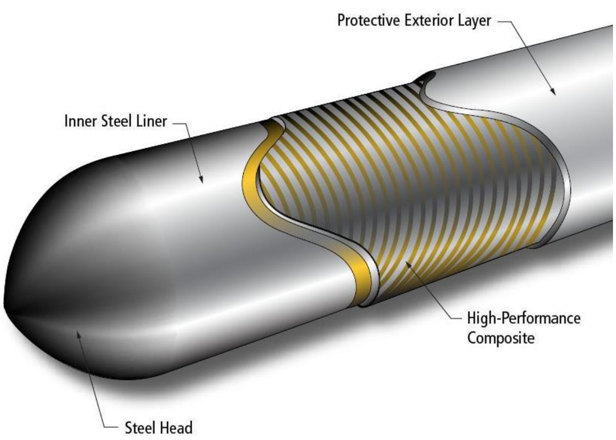


Figure 20 (Courtesy TransCanada)

TransCanada awarded a manufacturing license to the Floating Pipeline Company which developed the GTM modules. The GTM module has been designed in 24 or 30 meters length with a diameter of 1 meter (40 ’’) and a service pressure of 206 barg (3,000 psi). Each has a storage capacity of 0.2 MMscf of natural gas.

2.4.2. Marine transport vessels

TransCanada's concept was initially intended to be used for small ships or barges with a cargo capacity range from 35 to 100 MMscf;TransCanada also claim to have developed in-house models that would envisage vessels carrying between 500 and 8,000 GTMs representing a gas transportation capacity between 100 and 1,600 MMscf.

The figure below partially shows how the 24 m GTMs are placed longitudinally in the vessel’s holds and manifolded together.

Figure 21 CNG Ship mounted modules (Courtesy TransCanada)

In the shallow-draught carrier (left-hand) picture below, the GTM modules appears to have been assembled in six stacked layers each comprising ten elements. The overall dimensions of such assembly of modules would be of approximately 25 (l) x 15 (w) x 9(h) meters. The cargo content of one assembly would be of 12 MMscf.

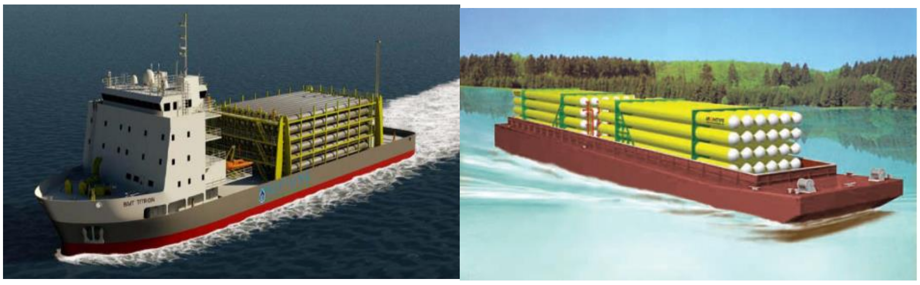


Figure 22 Shallow-draught carrier Barge concept (Courtesy TransCanada)

The barge as drawn on the above (righthand) picture appears to contain two assemblies of 6x6 GTM modules which correspond to a cargo transportation capacity of two times 7 MMscf.

2.4.3. Key features and Comparison LNG

A summary of TransCanada GTM system is given below compared with the same volume of LNG expressed as energy content (btu/btu).

For the cargo/containment weight ratio, only the weight of the gas container is considered without piping, valves and supporting frame. The gas cargo is calculated for the Lean gas composition given in §1.1 with loaded pressure and temperature of respectively 207 barg and 25°C. Calculation is also made for a Tug/Barge design with the same loading conditions.

Type	CNG system	CNG Capacity (MMscf)	Cargo/Container weight ratio (ton/ton)	Energy ratio LNG/CNG (btu/btu)
Tug/Barge	2x36 composite reinforced steel GTMs	14	1.5	2.4
Shallow-draught carrier class'60'	60 composite reinforced steel GTMs	12	1.5	2.4
Ship class 100	500 composite reinforced steel GTMs	98	1.5	2.4

Table 6: TransCanada GTM system

2.4.4. Certification

TransCanada received Approval in Principle for ocean going vessels from Lloyds Register in 2003. The cylinders or Gas Transport Modules (GTMs), developed by NCF, which would contain the gas, have already been fully approved.

Conditional approval for inland barge use has been received from ABS.

2.4.5. Commercial references

None.

2.4.6. Targeted Markets

TransCanada has made a first assessment using the 'rule of thumb' graph below to determine if CNG could provide a reasonable transport solution. One can see that the targeted market is for low volumes (<200 MMscf/d) and short distances (<500 nautical mile).

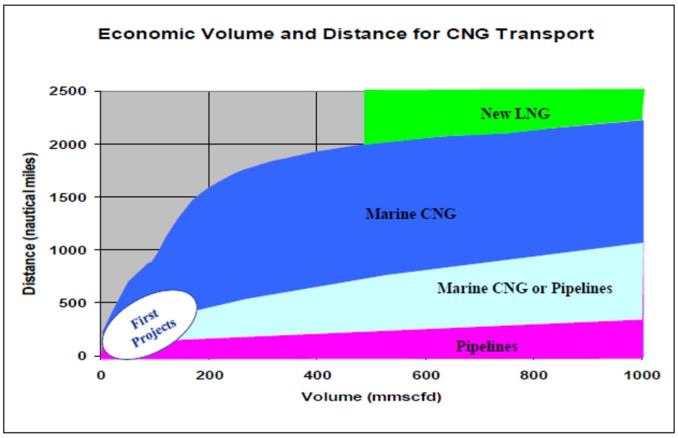


Figure 23 (Courtesy TransCanada)

2.4.7. Potential Application for 1-15 MMscf/d Gas Production

The considered associated gas production is within the range targeted by TransCanada, provided the distance between the gas source and the delivery location remains below 500 nautical miles.

The proposed solution would be a tug/barge system with possible various tug/barge combinations and sizes depending on the specification of the project.

However, the GTM concept as a whole only addresses one important facet of the problem (the storage and transport). The gas conditioning, loading and offloading issues are set aside and assumed to be handled by the producer and the customer respectively. No gas handling facilities are provided on the tug/barge system as shown below on the typical process schematic.

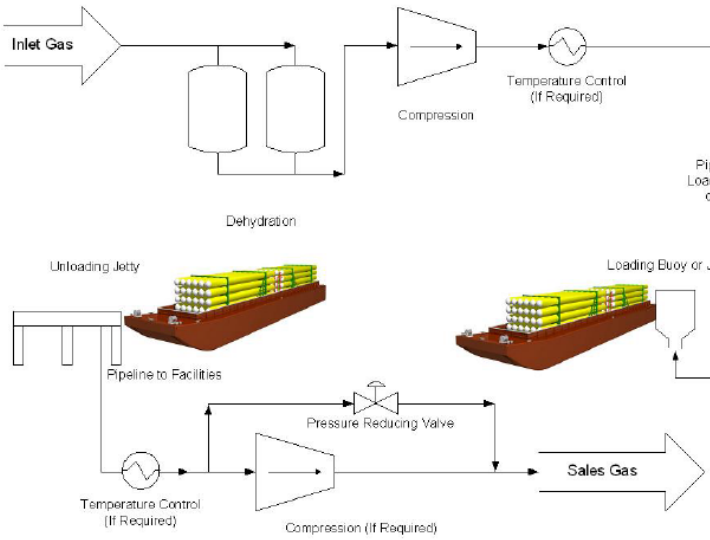


Figure 24 Typical process schematic (*Courtesy TransCanada*)

2.5. Knutsen OAS Shipping AS

Knutsen OAS Shipping AS has developed its CNG system with the assistance of the ship classification society DNV and the steel pipe manufacturer Europipe GmBH.

'PNG®' for Pressurized Natural Gas, is Knutsen OAS Shipping's registered Trade Mark for their CNG concept.

2.5.1. Technology

The main principle on which the concept was developed is to apply high pressure gas pipeline standards to the design of CNG cylinders.More specifically apply the DNV standard, DNV-OS-F101- Submarine Pipeline Systems which is in line with the evolution of the construction codes for very high pressure vessels.

Firstly, a risk based approach (QRA) according to IMO code MSC 72/16 is used to address the cargo containment hazards of the Knutsen PNG ship.

The acceptance criteria for the development of PNG® cylinders were in accordance with the following DNV standard requirements:

- proper selection of the pipe material (for the PNG®, grade X80 line pipe);
- application of failure mode analysis considering burst and fatigue design criteria;
- full scale testing such as fatigue tests, burst test, cooldown, verification, crack propagation analysis due to cooldown or cold spots resulting from an accidental gas leak…this to be undertaken on the basis of Probabilistic Limit State Design Criteria.

Observance of these design principles has enabled the PNG® concept to reduce the steel weight by 50% from what would have been required by the IGC.

The main characteristics of the PNG® Cargo Tank Cylinder (CTC) are illustrated below.

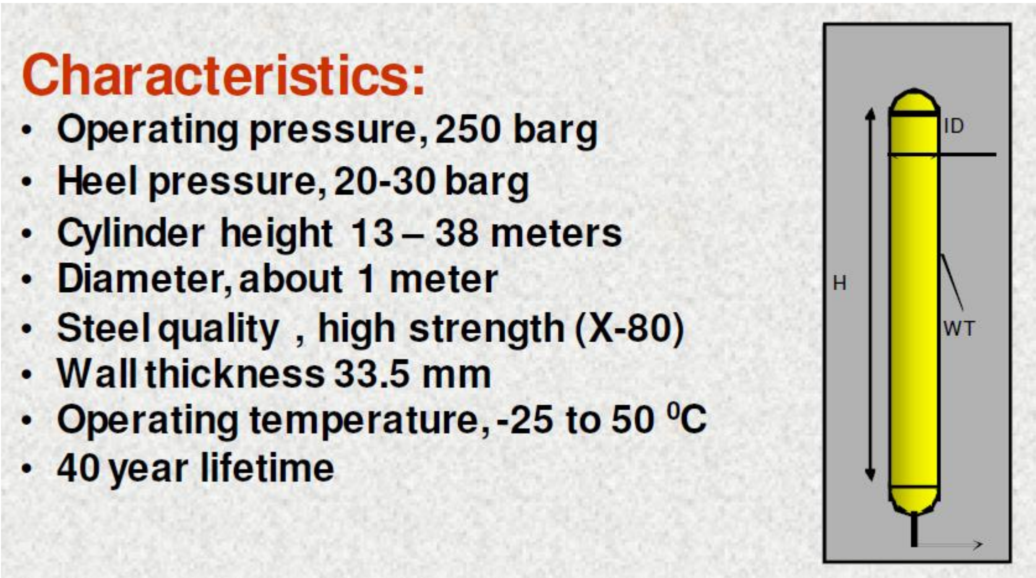


Figure 25 PNG® Containment System (Courtesy Knutsen OAS Shipping AS)

2.5.2. Marine transport vessels

Knutsen OAS Shipping has developed two different types of vessel:

- an offshore loading and discharging type PNG® vessel,
- a terminal-to-terminal type PNG® vessel.

The PNG® ship is a combination of an ordinary crude oil tanker and a CNG container ship.

The offshore loading type vessel can apply a submerged turret loading (STL) system from advanced production and loading (APL) systems for gas, while other types of offshore loading systems may also be considered. Area is allocated on the ship for such facilities, together with space for process facilities that either could be used for gas processing or compression.

The figure below shows the cargo tank cylinders arrangement on-board the Knutsen standard type offshore loading vessel. The vessel contains 2,672 PNG® cylinders of 36 m height giving a total cargo capacity of about 800 MMscf for the Lean gas composition given in §1.1 and a pressure of 250 barg.

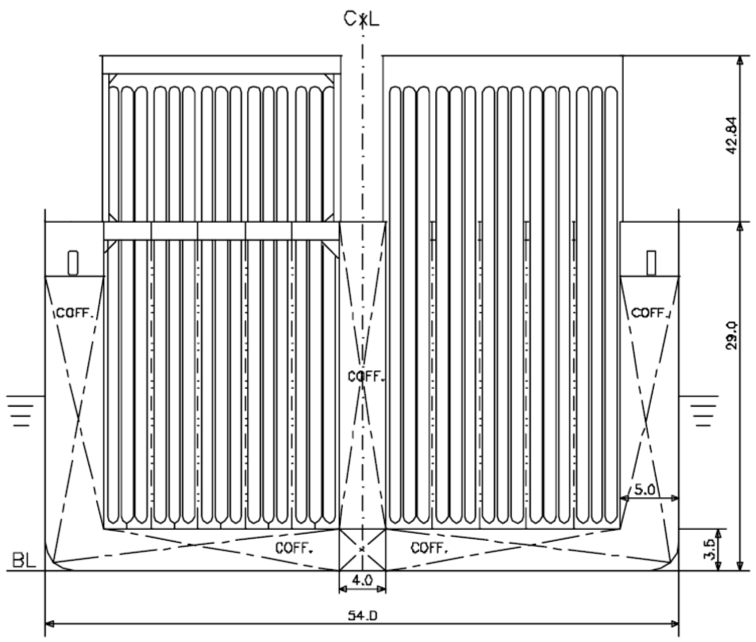


Figure 26 CTC arrangement on-board the vessel (Courtesy Knutsen OAS Shipping AS)

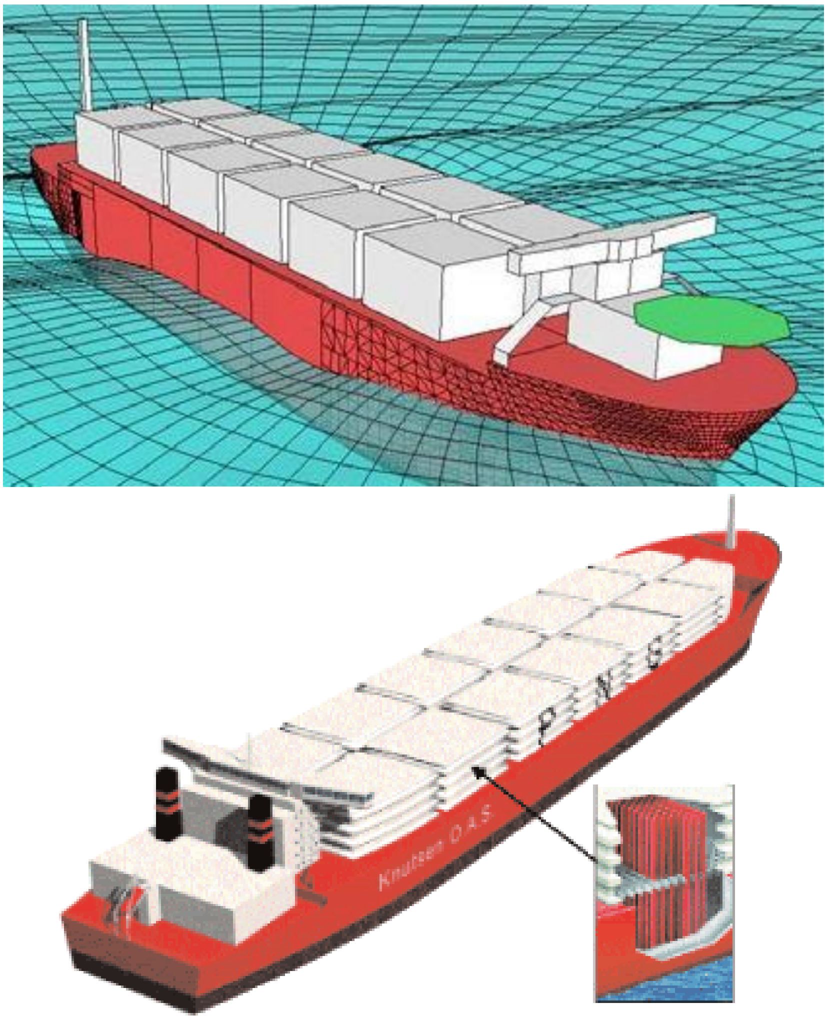


Figure 27 Type of PNG® vessels (Courtesy Knutsen OAS Shipping AS)

Knutsen OAS Shipping has developed a generic design applicable to several vessel sizes from small PNG® carriers with gas carrying capacity down to 70 MMscf to large PNG carriers with carrying capacity more than 1,200 MMscf.

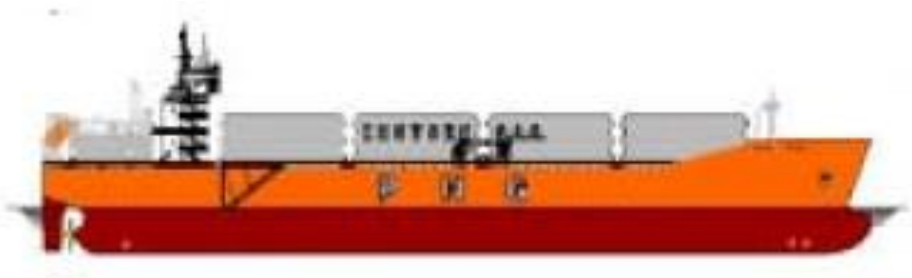


Figure 28 Small PNG vessel type (Courtesy Knutsen OAS Shipping AS)

2.5.3. Key features and Comparison LNG

A summary of the Knutsen OAS Shipping PNG® system is given below compared with the same volume of LNG expressed as energy content (btu/btu).

For the cargo/containment weight ratio, only the weight of the gas container is considered without piping, valves and supporting frame. The gas cargo is calculated for the Lean gas composition given in §1.1 with loaded pressure and temperature of respectively 250 barg and 25°C. Two vessels type are considered: the standard type offshore loading vessel with 2,762 PNG® cylinders and for the smaller type assuming 660 PNG cylinders of 13 m height.

Type	CNG system	CNG Capacity (MMscf)	Cargo/Container weight ratio (ton/ton)	Energy ratio LNG/CNG (btu/btu)
Offshore Loading PNG®	2,762 vertically mounted X80 cylinders	794	0.21	2
Small ship type	660 vertically mounted X80 cylinders	70	0.21	2

Table 7: Knutsen OAS Shipping PNG®

2.5.4. Certification

All the full-scale tests required by DNV for the containment system qualification have been successfully completed and approval in principle was granted for the design and fabrication methods of the cylinders.

Formal Approval has been given by DNV to EUROPIPE that they are qualified as supplier for the PNG cylinders according to the DNV Class Rules for Compressed Natural Gas Carriers.

2.5.5. Commercial references

None.

2.5.6. Targeted Markets

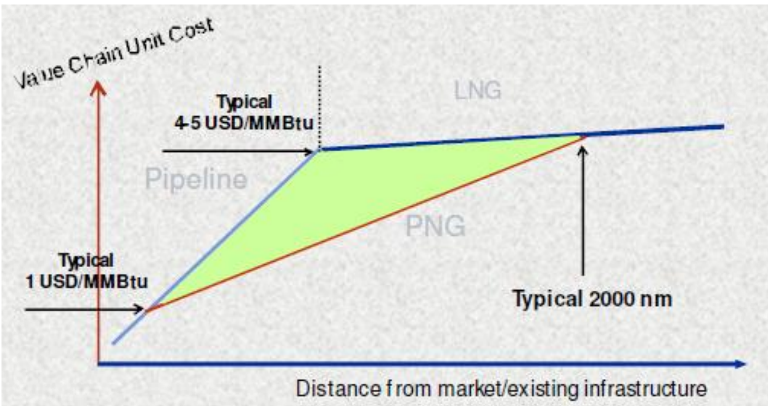


Figure 29 PNG® versus pipeline and LNG -2010 (Courtesy Knutsen OAS Shipping AS)

According to Knutsen OAS Shipping, the above figure shows how the PNG® technology could be economically viable for certain volumes and distances in the market compared with LNG or pipeline. The PNG® system falls between pipeline and LNG and would be much more attractive for smaller volumes over relatively long distances. The volumes and distances considered are respectively 150-500 MMscf/d and 100-3,000 nautical miles.

In that respect, Knutsen proposes several possibilities using their PNG system with, as examples, a FPSO equipped with gas/LPG (liquefied petroleum gas) mix storage and a CNG chain of terminal-to-terminal type vessel for evacuation of the produced gas and transportation to the customer(s).

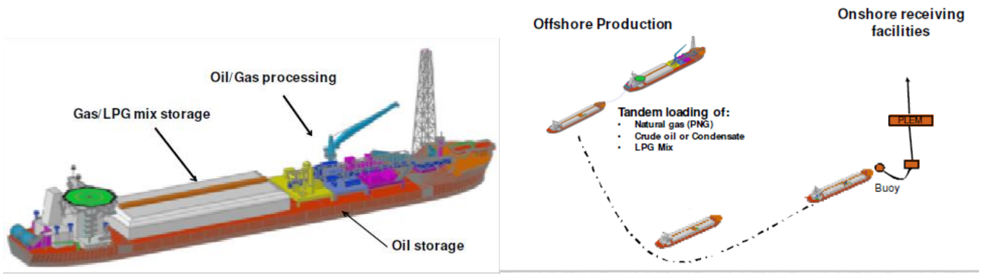


Figure 30 (Courtesy Knutsen OAS Shipping AS)

2.5.7. Potential Application for 1-15 MMscf/d Gas Production

The PNG® solution utilizes pressurized containers that can be combined in small or large configurations. It is a flexible solution that can be tailor-made to optimize a value chain. The smallest PNG® vessel proposed by Knutsen has a CNG cargo capacity corresponding to between 70 and 5 days production for the quantities of associated gas production considered for this report.

2.6. Trans Ocean Gas

Trans Ocean Gas Inc. (TOG) is a natural gas transportation technology development company. It is a privately owned company, composed of a team of Oil & Gas industry experts, located in Newfoundland, Canada.

TOG owns the patent rights to storing and transporting compressed natural gas by road, rail and sea in Fiber Reinforced Plastic (FRP) pressure vessels.

2.6.1. Technology

Initially developed for road and train transport, the TOG Inc cylinder, named Type-4, has a laminate shell made by winding high-strength carbon fiber around HDPE liner. The corrosion resistant HPDE liner provides a high level of safety over steel systems when natural gas contains corrosive contaminants. It is complemented by a corrosion resistant stainless steel port boss at both ends.

For the marine transport of large volumes of natural gas, TOG Inc proposes a laminate shell made of high-density polyethylene (same as for the liner) wrapped with continuous lengths of high-strength fibreglass. According to TOG Inc, the pressure vessels will weigh significantly more than the carbon fiber wrapped cylinder, but the cost to produce it will be approximately fifty percent lower.

Figure 31 Prototype 1-Meter Diameter Pressure Vessel (Courtesy TOG Inc.)

The TOG Inc pressure vessel is designed to withstand 750 barg pressure. Using a factor of safety of 3.0, the allowable operating pressure will be 250 barg. It can also withstand operating temperatures from -40°C to +40 °C .

2.6.2. Marine transport vessels

The TOG Inc ship-based concept is designed to easily convert a container ship into a gas carrier. Two types of containers combination, (which, under United Nations (UN) guidelines, is defined as a multi-element gas container or MEGC), are proposed by TOG Inc:

2.6.2.1. THE 40-FT ISO SHIPPING CONTAINER MEGC

It consists of eight large diameter (0.5m) pressure vessels secured inside an insulated 40-foot shipping container. The MEGC will carry 255 MMscf of Lean gas as given in §1.1 at 250 barg and 25°C. Should the gas be loaded at -30°C, then the gas cargo would increase to 355 MMscf, but the possible loading temperature is highly dependant on the gas composition due to the high pressure. For instance, the Rich gas as given in §1.1 would require a minimum temperature of 22°C to remain in dense gas conditions. At 25°C, the Rich gas cargo would be 268 MMscf.

The tare weight (empty) of the shipping container and pressure vessels is about 16,000 kg.

Figure 32 Standard ISO container design - (Courtesy TOG Inc.)

2.6.2.2. THE MODULAR CASSETTES SYSTEM

The containment system is fabricated in modular cassettes for ease of installation and hook-up. Steel truss frames are used to vertically house and contain a number of FRP cylinders in each cassette. Cassettes frame are stacked several frames high to form a gas containment module.

The cylinders are connected with duplex steel manifolds on both the top and bottom of each cassette.

According to TOG Inc., the cassette system allows for 100% visual inspection while in service and the removal of condensed natural gas liquids during the voyage.

Based on the arrangement illustrated below, the cylinders would have a diameter of 1 m and a length of about 5 m. The gas cargo capacities are the same as for the 40-ft MEGC.

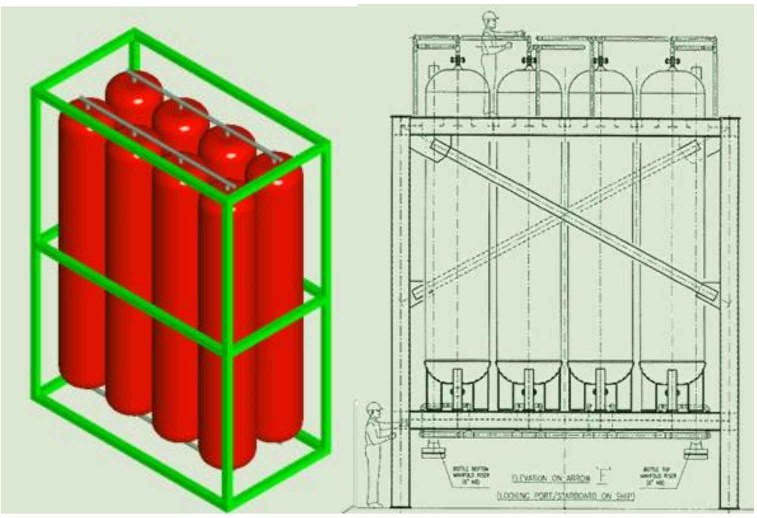


Figure 33 Modular Steel Frame (Courtesy TOG Inc.)

Figure 34 Ship contemplated concept (Courtesy TOG Inc.)

While TOG Inc. has not developed a real ship concept, it is contemplating installing the MEGC modules or 40ft-containers on a barge, or on a retrofitted container ship.

No information is provided on the way the pressurized gas will be handled at both loading and delivery points.

2.6.3. Key features and Comparison LNG

A summary of TOG Inc. MEGC system is given below compared with the same volume of LNG expressed as energy content (btu/btu).

For the cargo/containment weight ratio, only the weight of the gas container is considered without piping, valves and supporting frame. The gas cargo is calculated for the Lean gas composition given in §1.1 with loaded pressure and temperature of respectively 250 barg and 25°C and -30°C.

Type	CNG system	CNG Capacity (MMscf)	Cargo/Container weight ratio (ton/ton)	Energy ratio LNG/CNG (btu/btu)
TOG Inc. MEGC	FRP pressure vessels mounted in a 40-ft ISO shipping container (8 cylinders)	0.255@25°C 0.355@-30°	0.34 0.47	2 1.4
TOG Modular cassettes	8 FRP pressure vessels vertically mounted in a supporting frame	0.255@25°C 0.355@-30°	0.34 0.47	2 1.4

Table 8: TOG Inc. MEGC system

2.6.4. Certification

ABS awarded approval in principle (AIP) to the Trans Ocean Gas concept in September 2003.

Trans Ocean Gas Inc. was seeking financial support to launch the certification of its TOG Inc MEGC with its type-4 containers (2010). No more information is available for the present report.

2.6.5. Commercial references

None.

2.6.6. Targeted Markets

According to Trans Ocean Gas Inc., some of the applications that potential customers have indicated as a use for the TOG MEGC are listed below:

- The transport of stranded natural gas from an offshore marine location,
- The transport of stranded gas from a pipeline-restricted gas well,
- The transport of associate gas where flaring is restricted,
- The transport of natural gas from the production testing of a new well.

2.6.7. Potential Application for 1-15 MMscf/d Gas Production

The modular concept with cassettes or 40ft-shipping container might be applicable to the range of production rates considered in this report.

A major effort was made for the development of the MEGC, but integration in a complete CNG transportation chain has still to be undertaken. These include facilities for loading and delivery, the connection between cassettes, modules and main loading headers on the ship itself whichwould require careful consideration.

2.7. Marine CNG – Comparison of technologies

While some proponents, Sea NG Coselle^{TM} and EnerSea VOTRANS^{TM} and to some degree CETech, appear to be advanced in the definition of their overall system, including loading and offloading operations, the others still need to develop fully integrated systems.

The main characteristics of the different technology providers are summarised in the following table.

	CETech	EnerSea VOTRANS™	Sea NG Corporation Coselle™	TransCanada CNG Technologies	Knutsen OAS Shipping	TOG
Type of Containment	Composite or X80 pipe steel ; composite (Iso container)	X80 steel cylinders	coiled X70 line pipe forming a carrousel (Coselle™)	Composite reinforced steel Gas Transport Modules (GTM)	X80 steel cargo tank cylinders (CTC)	Composite HDPE and fibreglass cylinders (MEGC)
Containment arrangement	Vertical or horizontal pipes or ISO container	Vertical tank modules or horizontal pipes	Coselles™ in holds of bulk carrier	GTM stacked layers	Vertically stacked CTC's	Shipping container or modular cassettes with vertical cylinders
Gas pressure (barg)	150 – 250	125	200-266	206	250	250
Transport temperature (°C)	-30 / ambient	-30/0	ambient	ambient	ambient	-30 / ambient
Cargo /Container weight ratio	0.70 (composite) 0.24 (X80) 0.52 (container)	0.35-0.39	0.12-0.18	1.5	0.21	0.34-0.47
Development status	concept stage	advanced concept stage	advanced concept stage	concept stage	concept stage	Concept stage for MEGC container only
Safety	Aframax & Suezmax with gas cylinders on deck	ship's holds under nitrogen inerting	ship's holds under nitrogen inerting – leak impact limited by coil diameter	no information provided	no information provided	no information provided
Ship transport capacity (MMscf)	85-319 (+ 60 to 120,000 m^3oil) 200 – 1,200 variable (container)	75 – 1,000 (ship) 10-100 (barge)	51 -531 (ship) ?-80 (barge)	12-100 <1,600 (hypothetical)	70-1,200	variable as function of number of containers
Targeted market (MMsfd / nautical miles)	49-275 / 300 -2,000	150-650/250-3,000 (ship) 10-100/50-750 (barge)	55-328/300-1,500	10-200/ <500	100-500/100-3,000	
Operability [(1)]	+/- full chain (except multi container solution)	full chain	full chain	containment concept only	full chain	containment concept only
Applicability to associated gas (1 to 15 MMscf)	Possible (combined oil/gas or containers)	Possible (barge)	n.a. (ship) possible (barge)	Possible	Possible	Possible

Operability means that the solution of the technology provider may cover the whole CNG transportation chain including ship configuration, gas treatment, loading and offloading operations.

Table 9 Marine CNG comparison

2.8. Elements of Costs

2.8.1. CNG transportation costs

Costs found in the literature are generally related to daily transported volume far beyond the production rate of 1-15 MMscf/d considered in this study.

Based on the information published between 2002 and 2013, mainly from SeaNG Coselle (C16 class carrier) VOTRANS™ and Knutsen, a consolidated unit cost per MMBtu was calculated (2014 updated) for marine CNG transportation as a function of transported volumes and travel distances.

The unit price includes the cost of the loading and offloading facilities whether located on the ship or at source and delivery locations.

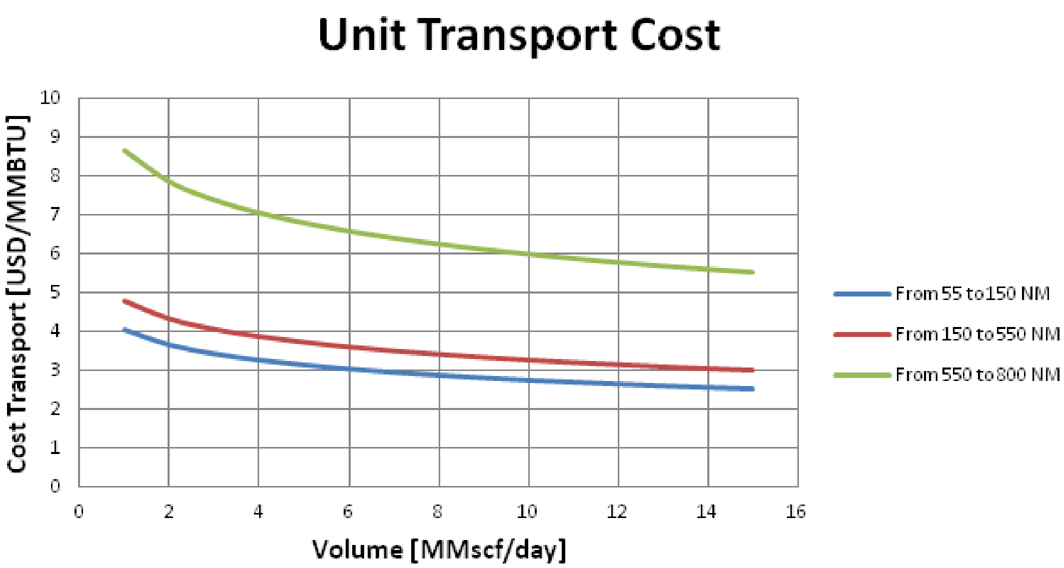


Figure 35 Cost of CNG transportation as function of daily volume production and distances (nautical miles)

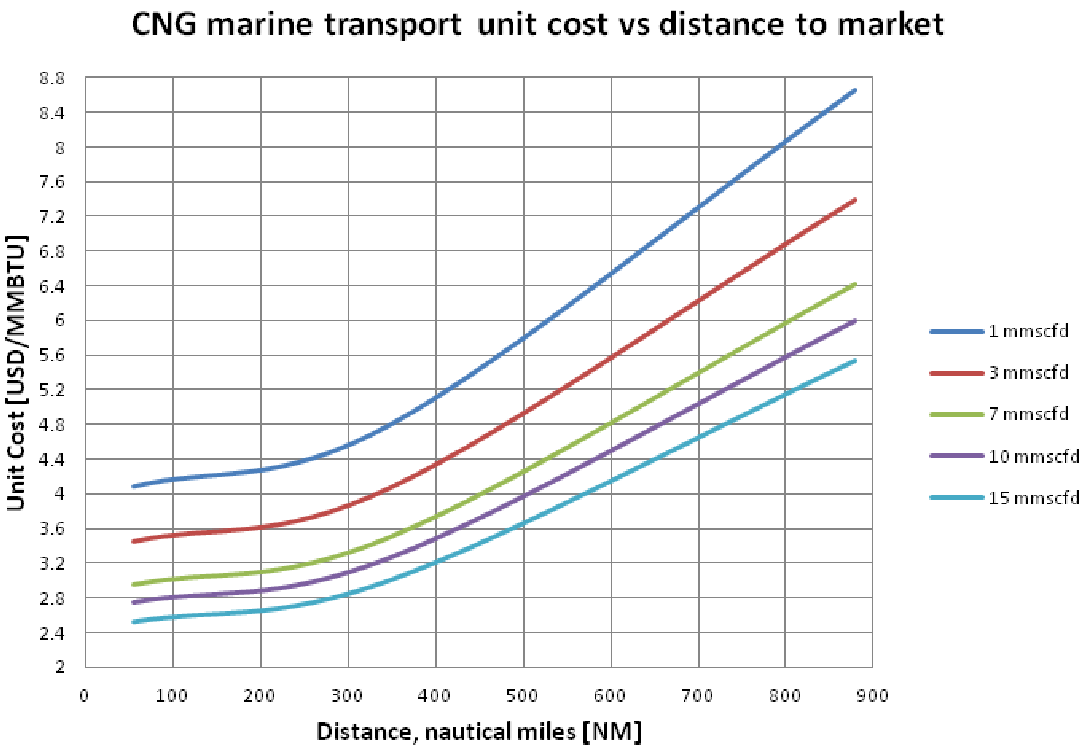
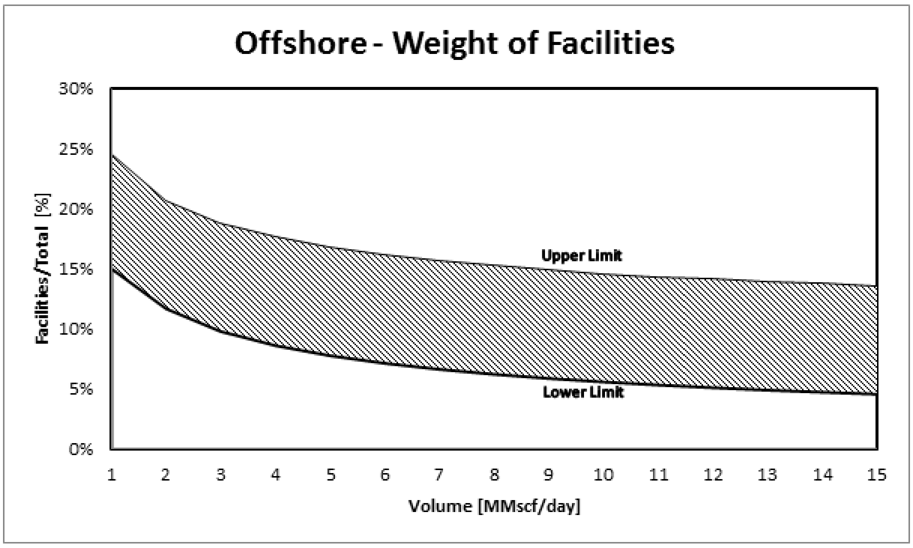


Figure 36: Marine CNG transportation costs vs distance to market



37 Figure Impact of facilities on total cost

As shown on the above graph, the costs of facilities may vary depending on the project particulars (type of ship, jetty or buoy,..). They represent on average 12-22% of the total cost which is higher than the percentage claimed by the technology proponents (10-15%) but for larger volumes.

2.8.2. Gas treatment costs

Due to the nature of associated gases, one may expect that the gas will have to be treated/conditioned prior to loading. An additional unit cost should therefore be considered for the gas treatment units which would comprise:

- An H2S removal,
- A dehydration and CO_2 adsorption unit,
- A hydrocarbon dew point control unit.

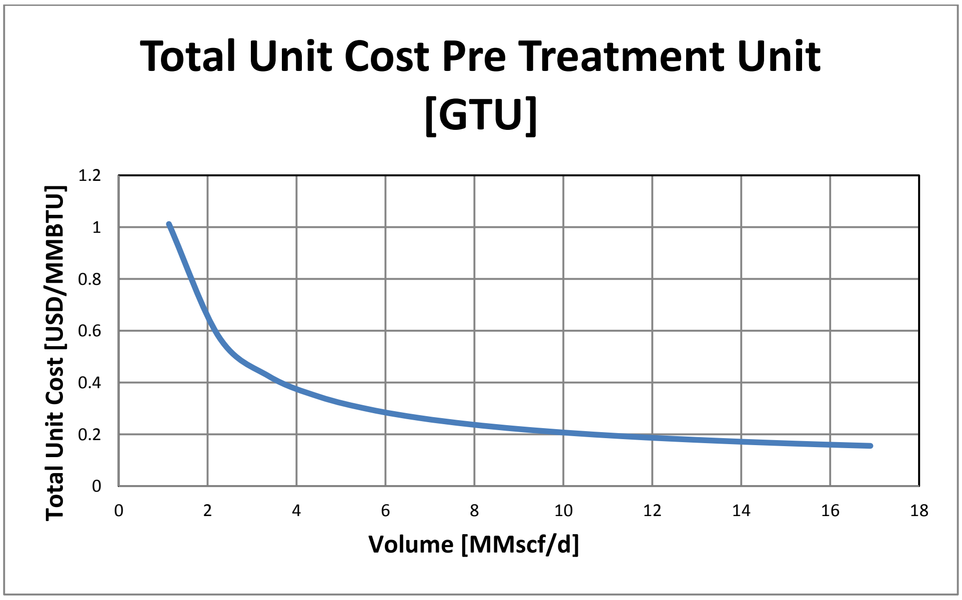


Figure 38 Cost of associated gas treatment as function of daily volume of production

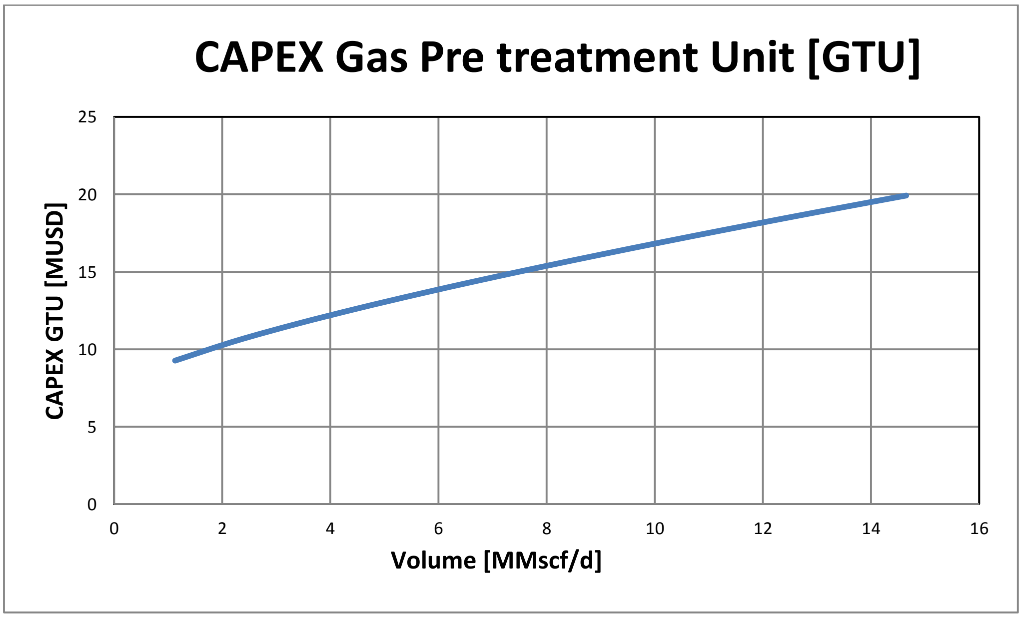


Figure 39 Capital Expenditure of the gas treatment as function of daily volume of production

If we neglect the scenarios involving long transportation distances which lead to prohibitive unit costs, the unit price of gas delivered as CNG, including the normally required pre- treatment, would range between 5-6 USD per MMBtu for low volumes and 3-3.5 USD per MMBtu for volumes close to 15 MMscf/d.

2.9. Conclusions for marine CNG

This report addresses the possibility to recover gases associated with offshore oil fields and to transport them under pressurized compressed gas form (CNG) to potential customers. It specifically addresses gas volumes of production ranging between 1 and 15 MMscf/d.

The various marine CNG systems developed in the 2000's were designed for gas volumes much higher than those considered for this study. The capital cost of the ship being by far the major determinant of the project's profitability, the current proposed designs here do not match the range of produced volumes. In simple terms, the ships are too big. This issue has already been raised in 2009 by the Centre for Marine CNG in a paper prepared for the Offshore Technology Conference (OTC 20145).

The proposed barge systems are questionable as they were not really developed by the technology providers. The SeaNG's smallest C16 class carrier would be underutilized while it could be a solution for the upper limit of the production range.

However, the combined oil and gas Aframax design, proposed by CETech, offers interesting possibilities as combining a crude oil cargo with the CNG helps reduce the otherwise high unit cost. Furthermore, gas is stored in horizontal pipes on the ship's deck is an advantage from a safety point of view (leakage, regular inspection...) and would also remove the costfor nitrogen consumption.

As a conclusion, one may say that marine CNG for small volumes of associated gases is at the limit of economic viability. Viability must be determined on a case by case basis, and depends mainly on the ship or barge design, transportation distance and volume, and also the need for and level of pre-treatment required at the source location.

3. STATUS OF CNG TECHNOLOGIES – ON-SHORE CNG

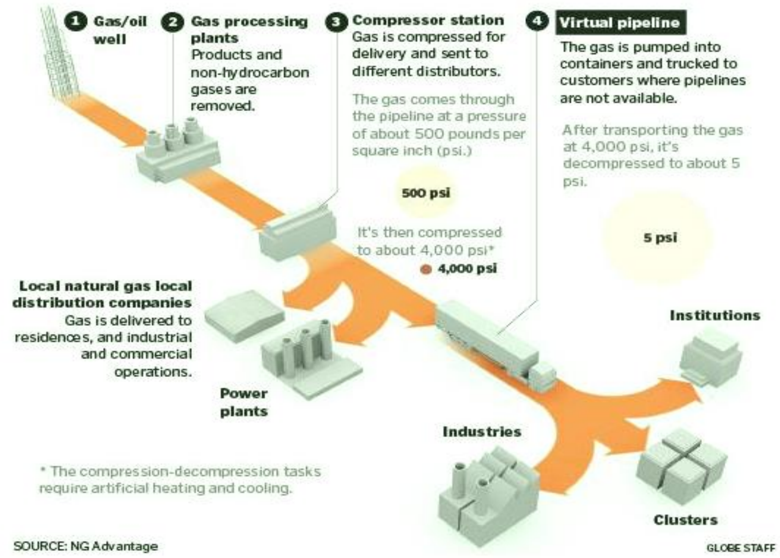
3.1. Background

On-shore CNG is a proven gas transport technology that has been around for decades. Natural Gas has seen an expanding interest in all parts of the world (Europe, North- and South-America, Asia) mainly driven by environmental concerns and to a lesser extent by the evolution of fuel costs including taxes. Natural gas has an increasing role in transportation especially in urban areas for community fleet vehicles like buses or refuse collection trucks where, compared to petroleum fuels, natural gas contributes to cleaner and healthier ambient air.

Additionally, many rural areas are unlikely ever to receive pipeline gas because the relatively few customers do not justify the costs of extending the pipelines to these locations. Therefore several companies have developed CNG systems that will compress natural gas so it can be loaded onto trucks and delivered to those industrial and commercial customers without access to pipelines, creating what is called “a virtual pipeline”.

The CNG system consists of:

- natural gas compression and truck loading facilities at the source location,
- truck offloading, heating, pressure letdown and metering facilities at the customer site.



The main technical constraints in bulk CNG transportation are:

- the weight of the containers, which impacts the operational cost,
- the filling operation which should ideally proceed quickly, but which induces high temperature due to the compression of the gas; high temperatures limit the pressure and therefore fill capacity of the container with a negative effect on the logistical costs (more trucks).

In most onshore CNG ventures, natural gas is usually withdrawn from an existing gas pipeline. In CNG transportation at pressures ranging between 200 and 250 barg, the gas must be further dried to prevent potential issues for condensation, hydrate formation and freezing which can occur during filling and offloading operations.

In the case of associated gas, as for marine CNG, gas treatment and conditioning will be necessary to ensure a safe and reliable carriage of the gas under high pressure.

3.2. Road bulk CNG transportation

Various CNG bulk transport systems are used by energy companies promoting virtual pipelines associated with clean fuel usage.

3.2.1. Steel tube trailers

The high pressure containment systems were first constructed of bundles of steel cylinders and, later on, made of higher strength steels for deliveries of compressed industrial gases (hydrogen, helium...). The cylinders are mounted on a trailer or chassis.

Figure 40 Super Jumbo Tube Trailer (Courtesy FIBA technologies Inc.)

Their capacity is limited due to the weight of the steel cylinders and the road weight limitations (commonly 40-42 tons for such trailers).

The latest generation are Jumbo and Super Jumbo tube trailers capable of carrying respectively 160-180,000 and 260-290,000 scf of natural gas at around 185 barg.

3.2.2. GTM Type III cylinders module

Figure 41 Five Pod unit (Courtesy Luxfer-GTM Technologies)

Luxfer-GTM Technologies has designed a complete line of GTMs for the storage and transportation of CNG. Constituted of an aluminum inner wall wrapped with carbon fiberglass resin, the cylinders, much lighter than the traditional steel cylinders, can be placed in scalable frames which are “manifolded” together. The frames can then be mounted on truck beds or inserted into 10 ft pods, or 20 ft. and 40 ft long ISO shipping containers. These containers can then be transported on truck chasses. A five pod unit has a transportation capacity of 439,000 scf (12,488 m3) of CNG

3.2.3. Lincoln TITAN™ 4 composite cylinders

Developed by Hexagon Lincoln, the design of the TITAN™ gas cylinder is based upon Lincoln Composites' TUFFSHELL® technology. It has a HDPE liner, a filament wound carbon fibre/epoxy composite shell plus a polyurethane coating applied to the outer surface. The composite cylinders weigh 75 percent less than equivalent steel tubes.

The TITAN™4 Module is a 40 ft ISO 1,496 certified shipping container which contains four TITAN cylinders. Each cylinder is almost 12 m in length and over 1 m in diameter and is designed to operate at 250 barg. In these conditions, one module can contain 7 to 8 000 kg of CNG or about 360,000 scf with a module tare weight of 15,649 kg.

Figure 42 TITAN™4 Module (Courtesy Hexagon Lincoln)

3.2.4. Galileo Virtual Pipeline®

Figure 43 PAD platforms and MAT® gas storage modules (Courtesy Galileo)

The Galileo Virtual Pipeline® consists of a complete operational CNG chain based on a transport and storage module named MAT® that includes:

1) Modular CNG compression stations, placed on specially designed platforms (PAC) or provided on a skid, that compress the gas up to 250 barg into transport and storage modules,
2) MAT® modules are used for storing and transporting CNG on a trailer, specially designed with an easy-to-operate exchange racking system to load/unload modules,
3) PAD platforms are designed with a simple connection system to minimize both loading and unloading times,
4) At the delivery location, a pressure regulating plant (PRP) including heating system, filtration and metering, can be provided to meet the required delivery pressure and temperature conditions.

Figure 44 Galileo MAT® gas transport module (Courtesy Verdek)

The transport and storage module MAT® consists of several ISO 9809 steel cylinders manifolded together and mounted in a box designed, together with ST racking system, for facilitating the handling, filling and offloading operations at both ends of the virtual pipeline.

One MAT® module contains 34 or 39 cylinders each of 150 litres hydraulic capacity. It can store 44,000 to 55,000 scf of natural gas at a pressure between 200 and 250 barg.

Galileo has developed three models of transport systems respectively with two, three and four MAT's, with a maximum transport capacity of 200,000 to 250,000 scf at 250 barg.

3.2.5. Comparison of CNG transport and storage containers

Summarised in the following table are the main characteristics of the CNG containment type for trailers ("+" is more favourable, "-" is less favourable):

	Tube type	Luxfer-GTM type III	Lincoln type IV	Galileo MAT
Container material	Steel – High strength steel	Aluminum inner wall wrapped with carbon fiberglass	Carbon fibre/epoxy composite	ISO 9809 steel cylinder
Trailer max capacity (MMscf)	up to 0.29	up to 0.44	up to 0.36	up to 0.25
Pressure (barg)	187-227	248	250	200-250
Corrosion resistance	-	?	++	-
Gas/container weight ratio (t/t)	0.24	0.41	0.79	0.2
Comparative cost	base case	++	++	+

Table 10: Comparison CNG containment type for trailers

The effective capacity highly depends on:

- the gas composition including the possible contaminants (corrosion),
- the loading conditions (fast fill or slow fill, cold gas filling) are also linked to the containment material and its capability to dissipate the heat of compression (plastic liners do not dissipate heat as efficiently as steel),
- the residual quantity of gas (hauling efficiency) prior to being returned for refilling.

All these elements may significantly impact the capacity of the delivery chain.

3.2.6. Potential Application for 1-15 MMscf/d Gas Production

High-way tube trailers have been used since the 1950's for deliveries of compressed industrial gases. Later designs, with the introduction of light weight composite material or use of higher strength steels, allowed higher filling pressures and higher cargo volumes while remaining within permissible weights loads on highways.

However, the transport weight restriction in practically all countries dramatically limits the weight of the tractor, trailer and payload. The following table gives for the theoretical maximum trailer capacity along with the number of trucks to be loaded per day for a number of associated gas production rates.

	1 MMscf/d			
Trailer type	Tube trailer	Luxfer-GTM	Lincoln TITAN	Galileo
Capacity (scf)	290,000	440,000	360,000	250,000
Nbr to load/day	4	3	3	4
	5 MMscf/d			
Trailer type	Tube trailer	Luxfer-GTM	Lincoln TITAN	Galileo
Capacity (scf)	290,000	440,000	360,000	250,000
Nbr to load/day	18	12	14	20
	10 MMscf/d			
Trailer type	Tube trailer	Luxfer-GTM	Lincoln TITAN	Galileo
Capacity (scf)	290,000	440,000	360,000	250,000
Nbr to load/day	35	23	28	40
	15 MMscf/d			
Trailer type	Tube trailer	Luxfer-GTM	Lincoln TITAN	Galileo
Capacity (scf)	290,000	440,000	360,000	250,000
Nbr to load/day	52	35	42	60

Table 11: Comparison for different production rates

Export of gas by truck is not sustainable, not only due to the huge truck traffic required, but also the size of loading and offloading facilities that would need to be put in place.

Gas composition and presence of contaminants have a direct impact on the facilities costs at the oil field location.

3.2.7. Elements of Cost

3.2.7.1. CNG TRANSPORTATION COSTS (CAPEX)

The Total Unit Cost estimation is mainly based on information retrieved for Galileo's 'Virtual Pipeline' system. The Total Cost (Capex) is composed of the Facility Cost and the Transport Cost.

The Facility Cost includes the loading compression station, the unloading station and the recompression (to the required user or pipeline pressure) facility. The Transport Cost includes the container (MAT module), the support (VST module) and the truck.

The cost evolution is a function of the number of trucks, transport modules and gas handling facilities according to the increased distances and volumes with the following assumptions:

Distance	1 truck route 250 miles / day
Container Capacity (MAT)	60,000 scf
Truck transport capacity (four MAT)	240,000 scf
Max loading/offloading time	6h
Payback period	10 years

Table 12: Cost estimation assumption

On this basis, the unit prices per transported MMBTU were calculated as a function of the travelled distances and the required volume of gas to be exported from the field. The results are illustrated by the following graphs:

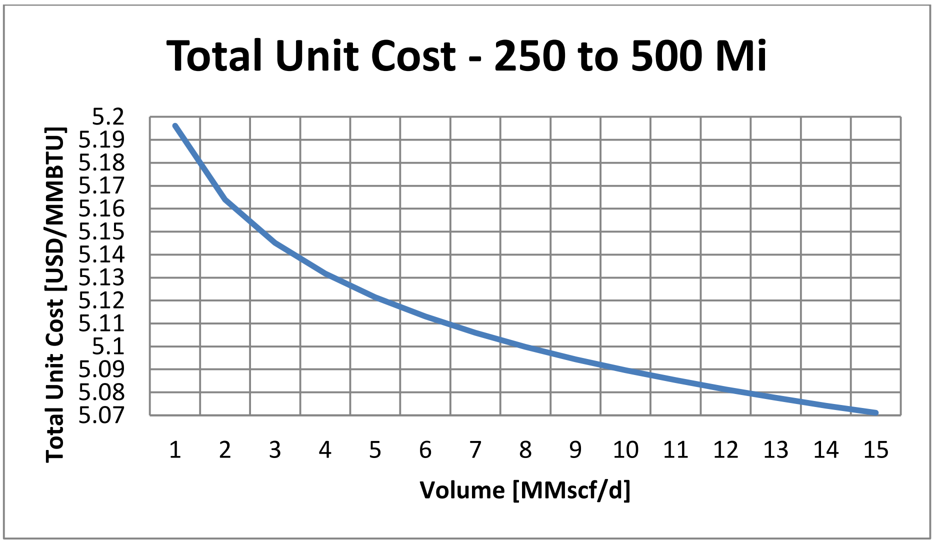


Figure 45 CNG transportation - Unit Prices for 250 to 500 miles

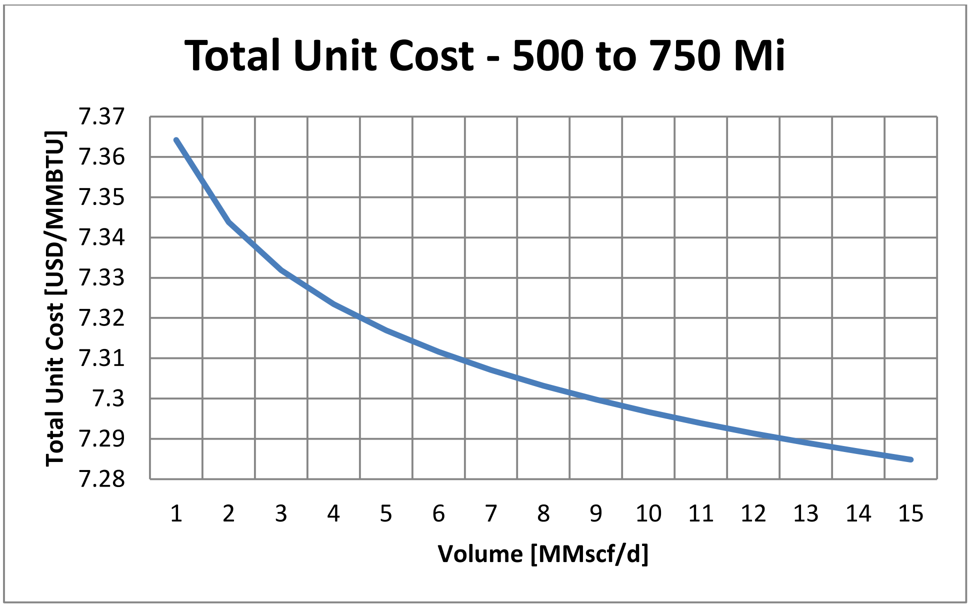


Figure 46 CNG transportation - Unit Prices for 500 to 750 miles

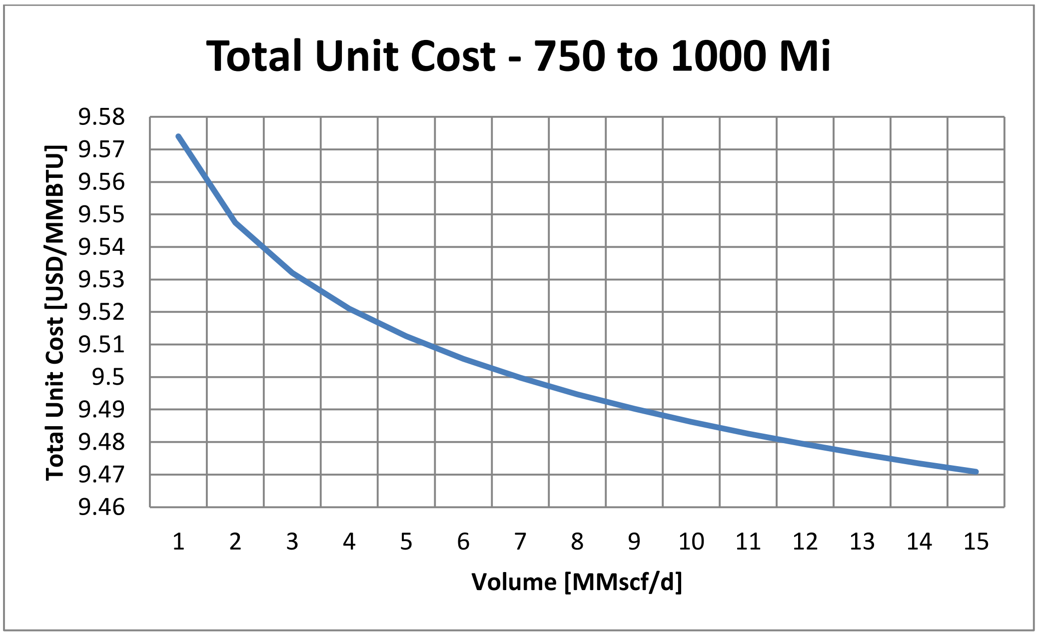


Figure 47 CNG transportation - Unit Prices for 750 to 1,000 miles

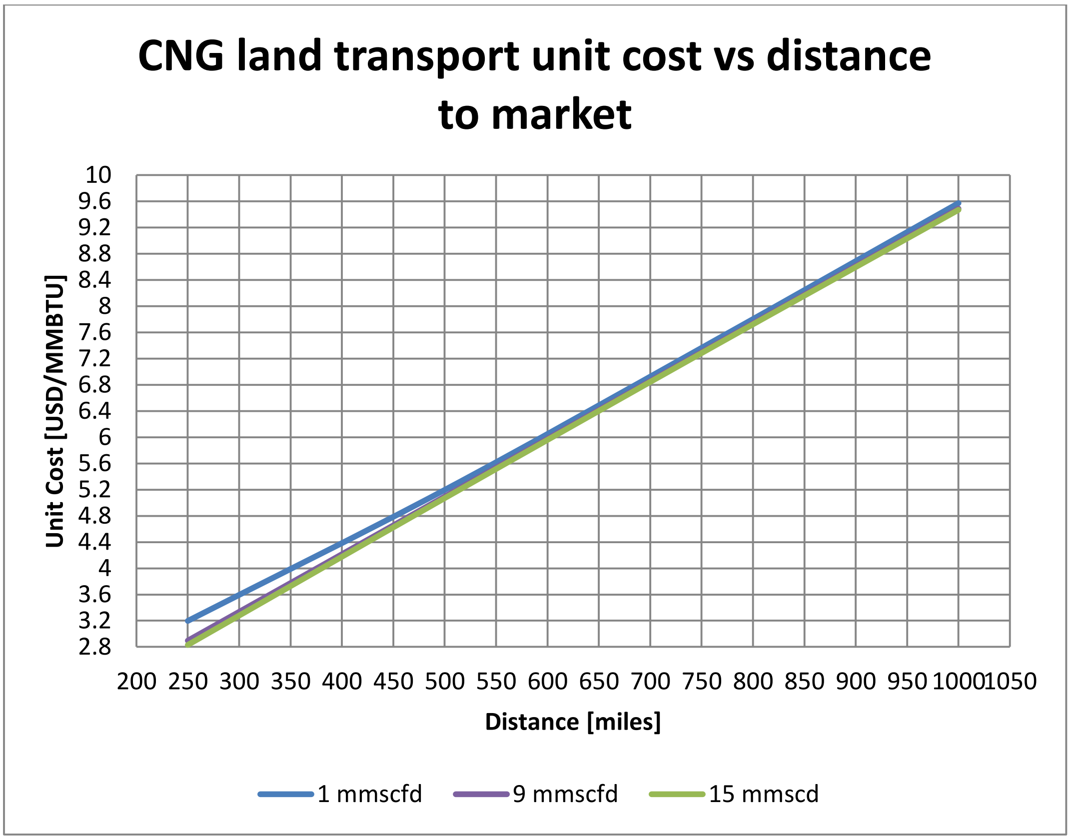


Figure 48CNG land transport unit cost vs distance to market

3.2.7.2. OPERATING COSTS

The above delivery costs are given as an example for the specific Galileo technology. These costs depend on the type of transportation system (tube trailer or others). In that respect, it is interesting to compare the fuel consumption of the various types of CNG transport by truck. The following graphs give an idea of the fuel consumption for the lower and upper ends of the considered export range, knowing that, in general, fuel equates to about 30% of total operating costs of the truck fleet.

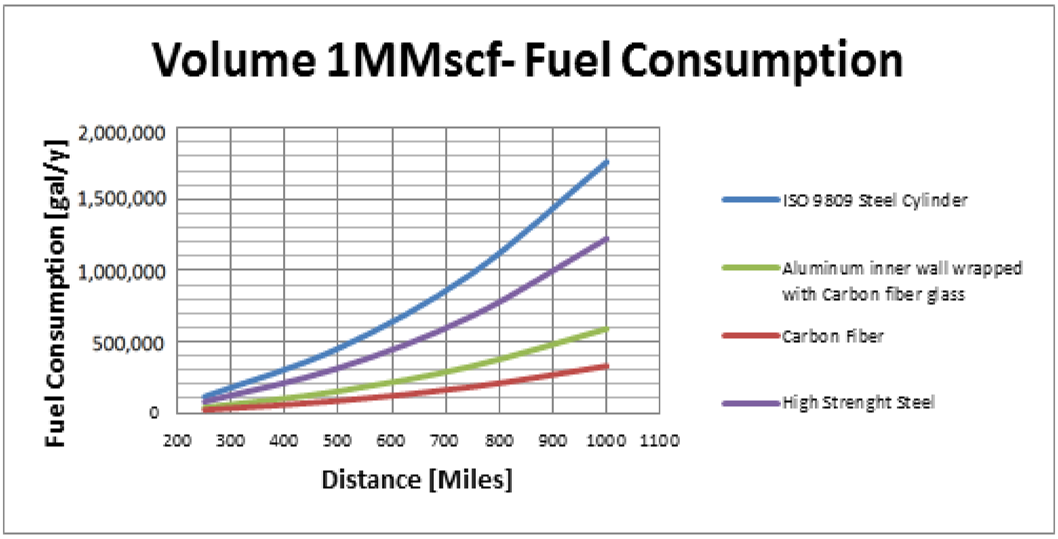


Figure 49 Fuel consumption for CNG transport of 1MMscf as function of trailer type

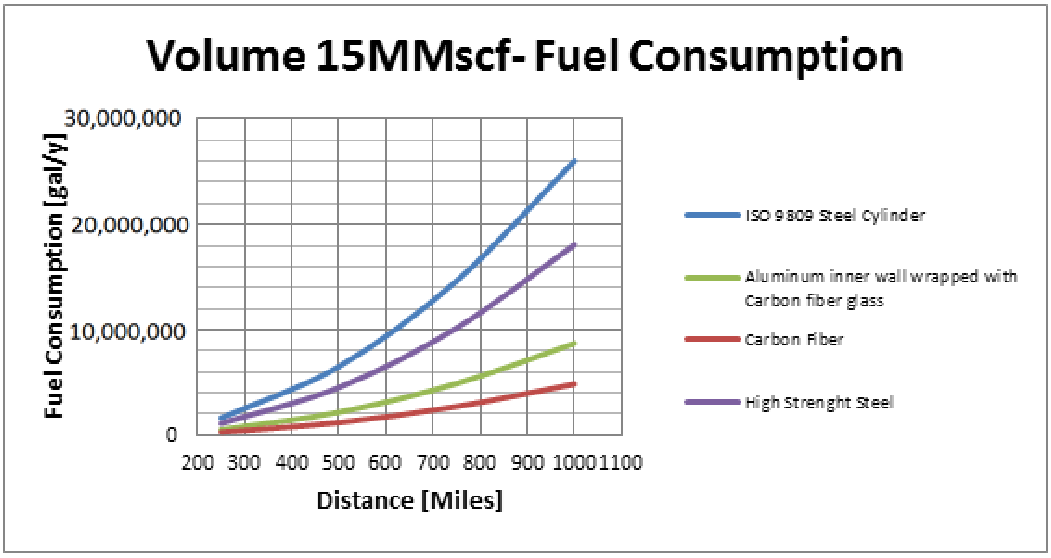


Figure 50 Fuel consumption for CNG transport of 15MMscf as function of trailer type

3.2.7.3. GAS TREATMENT COSTS

Due to the nature of associated gases, one may expect that the gas will have to be processed/conditioned prior to loading. An additional unit cost should therefore be considered for the gas treatment units which comprise:

- A hydrogen sulphide removal unit,
- A dehydration and CO_2 adsorption unit,
- A hydrocarbon dew point control unit.

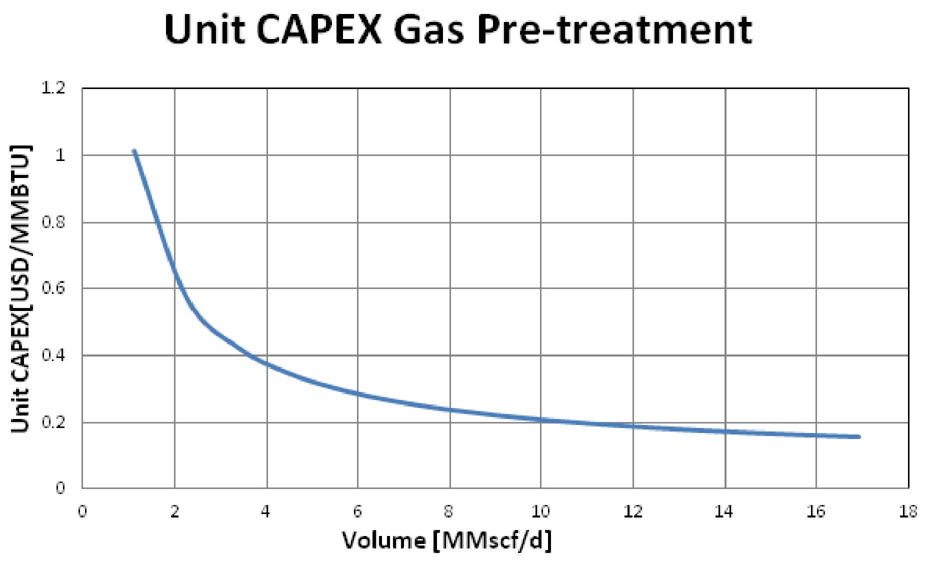


Figure 51 Cost of associated gas treatment as function of daily volume of production

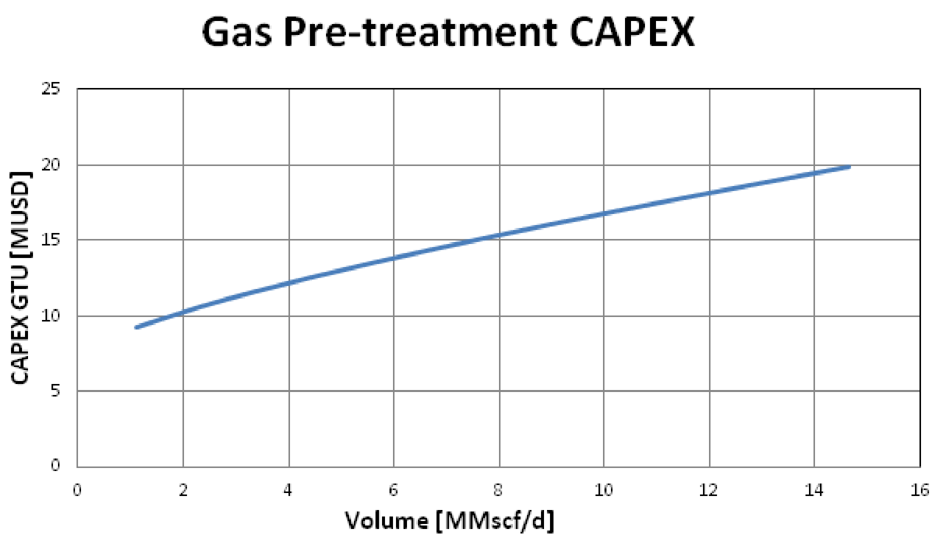


Figure 52 Capital Expenditure of the gas treatment as function of daily volume of production

3.3. Conclusions for on-shore CNG

It is now economically viable to utilize high capacity CNG trailers to transport natural gas to areas unreached by pipeline supply, but only for relatively small volumes of gas.

In the context of this report, CNG transportation by truck reaches its practical limit when the volume of associated gas to be exported exceed about 5 MMscf/d.

In simple terms, in contrast to the comment made about the size of CNG ships being too large, the trucks are too small.

For volumes lower than about 5 MMscf/d and distances shorter than about 500 miles the total unit cost is around 5 USD/MMBtu. For longer distances, the cost and complexity of transportation as CNG becomes prohibitive.

4. ALTERNATIVE SYSTEMS FOR NATURAL GAS TRANSPORTATION

4.1. Transport as natural gas hydrates (NGH)

The transport of natural gas in a hydrate form is attractive as the gas is transported in a solid state at moderate pressure and negative temperature. The negative storage temperature is maintained by active cooling.

The principle for a hydrate based natural gas transportation system is:

- To produce hydrate pellets
- To transport the pellets
- To dissociated the pellets and recover the natural gas

The production of hydrate pellets is based on mixing natural gas and water under appropriate operating conditions. The mixture is then worked to form pellets. The pellets are then cooled prior to be stored. The energy needs to produce hydrate pellets are similar to liquefaction process.

A key issue during transport is to control the pressure and temperature conditions of the storage such that the hydrates stay in their solid form while optimizing energy consumption. Energy needs for transport are similar to CNG and are significantly higher than LNG as the volume of hydrates is about 4 times the volume of LNG for the same amount of gas.

At the reception facilities, the hydrates are dissociated by heat exchange with sea water. The gas is compressed and fed into the pipeline network after drying, which is energy intensive as dissociation takes place at close to atmospheric pressure.

It is to be noted that hydrates dissociation is not straightforward as the rate of dissociation varies significantly along the process. It is to be noted the natural gas composition influences the rate of dissociation.

4.2. Pressurized LNG (PLNG)

LNG liquefies, and remains liquid, at a higher temperature when kept under pressure. The PLNG concept utilizes pressure to increase the storage temperature of the liquefied gas. Liquefaction of LNG requires considerable pre-treatment and has large power requirements, and pressurizing the LNG brings significant reduction of these requirements. The power required for liquefying the gas would be around 60 % of that required for conventional LNG. Also the limits on CO_2 and heavy hydrocarbon content are less severe than for conventional LNG liquefaction.

The concept has been developed by ExxonMobil, is still at the conceptual stage, and its economic viability is yet to be demonstrated.

The optimal PLNG conditions for transportation were identified as follows compared to LNG and CNG:

	LNG	PLNG	CNG
Pressure (barg)	1	17	200-250
Temperature (°C)	-160	-110	25
Cargo density (kg/m³)	440	350	188-223

Table 13: PLNG conditions for transportation

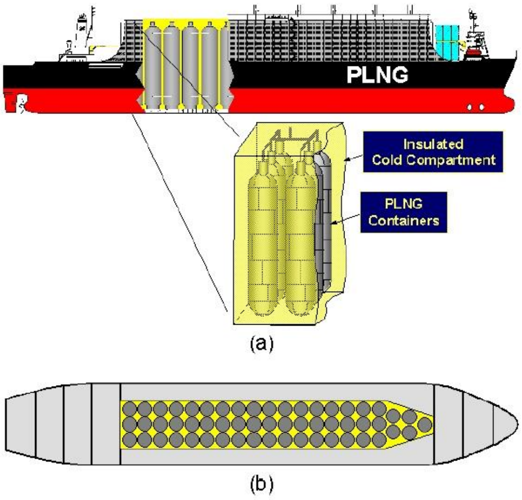


Figure 53 Conceptual 200,000 m³ PLNG ship design (Courtesy ExxonMobil)

The potential benefits of PLNG should therefore come from a significant reduction in LNG export facilities: footprint, facilities, gas treating units… and also in the receiving terminals. However, application of PLNG for natural gas transportation would require a whole new delivery chain: liquefaction plants, PLNG carriers, PLNG storage vessels, PLNG receiving and regasification facilities..

4.3. Adsorbed natural gas (ANG)

In recent years, there have been attempts to store natural gas under adsorptive form especially to increase the autonomy of natural gas vehicles. ANG is based on the property of solid material to adsorb gas molecules. Activated charcoal, for example, has a very large surface area because of its porous nature. This gives it the ability to adsorb large quantities of natural gas at relatively low pressures compared to CNG.

Several operational issues must be addressed for ANG:

- significant heat is generated during adsorption, and desorption of the gas required heating. The heat conductivity of the adsorbent material is therefore important,
- high performance carbons have higher densities, and a compromise must be found between the weight of the adsorbent and its capacity to store gas,

- storing and delivering the gas implies cyclic operations that, over time, have detrimental effects on the storage capacity and mechanical resistance of the adsorbent (attrition);
- the ANG storage is depressurized at nearly the atmospheric pressure in order to maximize the net storage capacity with as consequence that a discharge compressor be needed to achieve the required delivery pressure.
- gas composition may be a serious issue as heavier hydrocarbon molecules are large compared to methane and may not be so readily adsorbed,
- the presence of contaminant, even in small quantities in the feed gas, can accumulate preferentially on the adsorbent.

The viability of this method for large transportation capacities is questionable, but it may provide substantial benefits as containers for vehicles or cooking applications.

5. CNG MARKET IN USA

5.1. CNG as fuel for vehicles

From the early 1990s, compressed natural gas (CNG) fuelling infrastructure experienced a rapid development in USA. The 1992 Energy Policy Act, which sought to increase clean energy use and to improve overall energy efficiency, marked the first governmental incentive for traditional fuelled vehicle users to switch to alternative fuelled vehicles. It gave the US Department of Energy the power to determinate the minimum light duty alternative fuel vehicles share required in Federal fleets. By 1999, 75% of vehicles acquired by the Federal Government were required to be alternatively fuelled.

In 1995, the Natural Gas Vehicle (NGV) Industry Strategy, issued by the National Gas Vehicle Coalition, Gas Research Institute and American Gas Association, was developed to set a unified vision of the market industry and to boost the use of natural gas in transportation. In order to set a strategy, the industry stakeholders first defined their areas of action as shown in the following figure.

THE NGV STAKEHOLDERS

● Current Significant of Primary Role
○ Potential Significant or Current Secondary Role

	Producers	LNG Providers	Pipelines	LDCs	Equipment Suppliers	Vehicle OEMs	Engine / Chassis Companies	Conversion Companies	Vehicle Component Suppliers	Retail Distributors	Fleet Operators	Private Vehicle Owners	Public	Government	Environmentalists	Investors
Supply and Deliver Natural Gas	●	●	●	●						○						
Supply Fuelling Equipment					●											●
Produce and Sell Components, Engines,, and/or Vehicles					○	●	●	●	●					●		●
Retail Fuel		●	○	●						●						
Purchase and Operate Vehicle	●	●	●	●							●	●	○	●	○	○
Aftermarket Support					○	○	○	○	○							
Other Roles													●	●	●	●

Figure 54 Source: NGV Industry Strategy, 1995

As part of the strategy to develop the NGV marketplace, the NGV Industry Strategy set the following key goals:

- To position NGVs to compete on an economic basis (reducing life cycle costs and taking advantages of governmental programs),
- To penetrate high fuel use fleet applications,
- To ensure availability of vehicle and fuel facilities, products and services in order to satisfy the demand,
- To deploy public open access and private onsite fuelling facilities when appropriate (transit agencies, refuse trucks, delivery fleets among others).

The NGV Industry Strategy working group developed actions to pursue these key objectives and achieved a significant growth of the industry in the period 1992-1995.

As part of the industry approach, local NG distribution companies became involved in marketing to secure a bigger share in the marketplace, and also got closer to the main manufacturing associations in order to promote more evolved NGV equipment. Furthermore, these distribution companies begin to use NGV technology in their own fleets, requiring large quantities of fuel. As the typical CNG stations in USA at that time were not able to provide those volumes, a significant effort was required to design and implement adequate fuelling infrastructure sized for these fleets.

The promotion of CNG was encouraged in spite of the decline in local gas production and the growth of natural gas imports by pipeline and vessel (LNG). While CNG has remained cheaper than diesel or gasoline, until recently the gap between them was not sufficient to justify the investment in vehicle conversion to CNG. Fleet managers rather chose flex-fuel ethanol vehicles over NGV due to their convenience and minimal conversion cost, resulting in significant growth of ethanol fuelled vehicles in the USA as illustrated below.

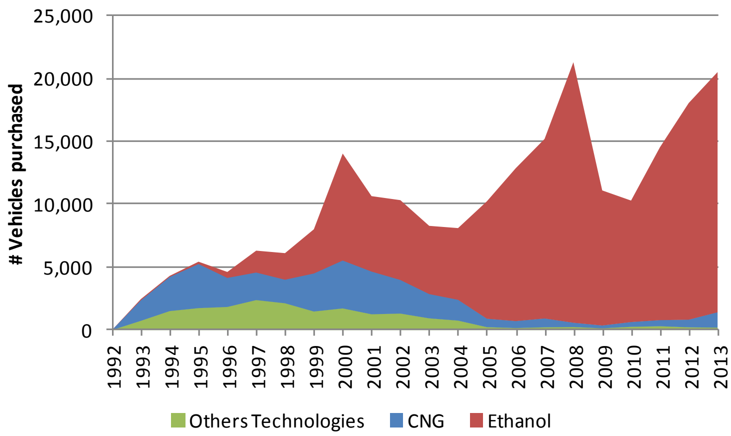


Figure 55 Energy Policy Act Vehicle Acquisition history - Source: Alternative Fuels Data Center

NGV supply infrastructure expanded until 1997 then, deflecting the preference for flex-fuelled ethanol vehicles, declined to a low of 721 stations in 2007. Investment then began to increase again at a moderate pace until 2011 (47 new stations per year on average), and more aggressively later (177 new stations per year on average) as shown in the graph below.

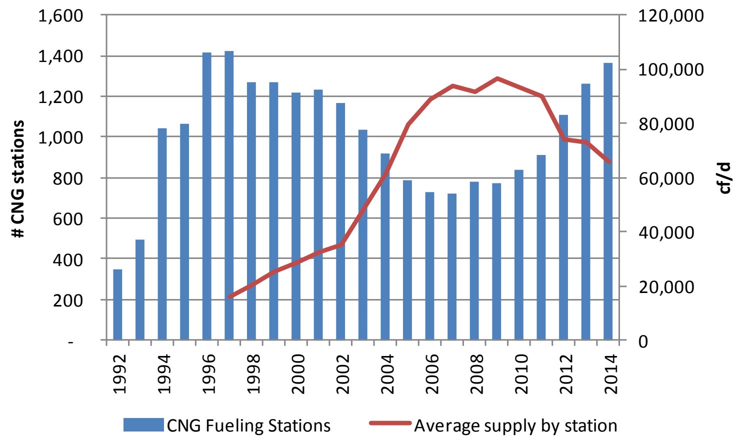


Figure 56 NGV Fuelling Stations History - Source: Alternative Fuels Data Center, DOE & NGV Journal

This recent expansion (2008 - 2014) is explained by plateau or minor increasing of NG prices (as a result of the unconventional natural gas boom) against the large raise of diesel and gasoline prices and a severe excise duty increase on ethanol in 2011, which made it economically less attractive.

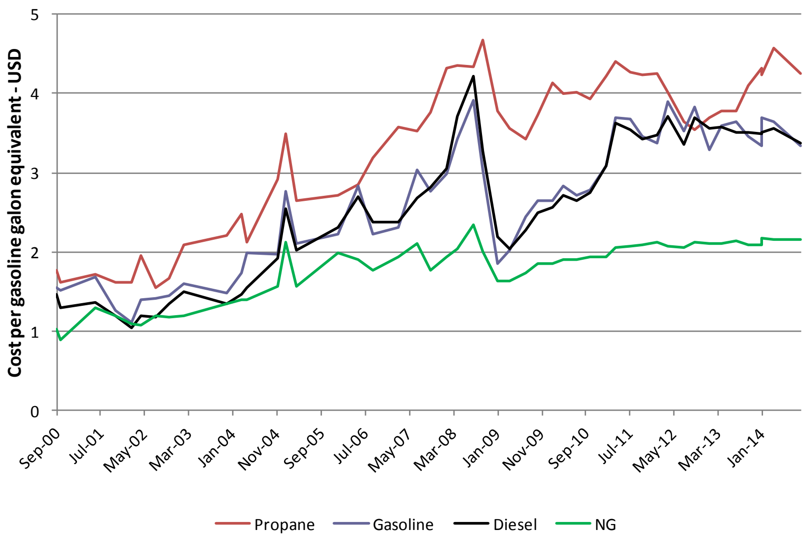


Figure 57 USA´s Average Retail Fuel Prices- Source: Alternative Fuels Data Center

The NGV infrastructure business faces a significant conundrum. To grow demand requires investment in infrastructure, but the cost of CNG stations is quite high and achieving the required volume of sales to deliver an economic return is often slow, thus discourage investment in the infrastructure. Several industry stakeholders have been calling for governmental measures to mitigate the impact of these competing factors that impede market growth.

Nonetheless, NGV fuel supply has been steadily increasing as shown in the graph below. However, the market remains very small (90 MMscf/d in 2014), taking into account the potential of the country.

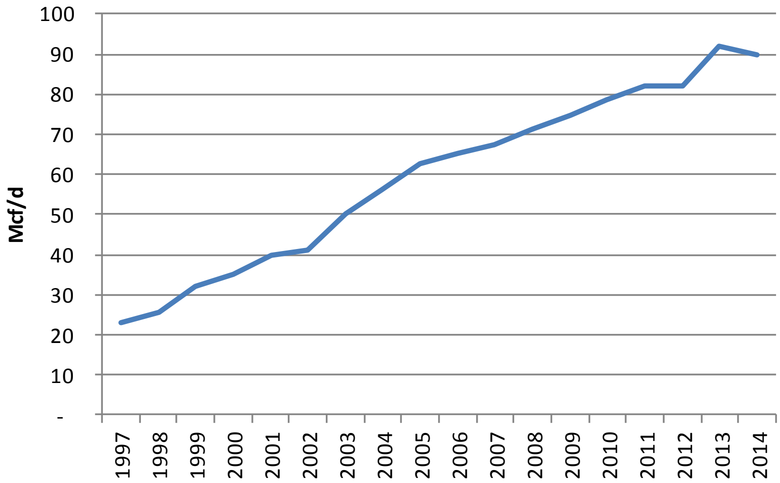


Figure 58 Natural Gas Vehicle Fuel Supply- Source: US Energy Information Administration

In 2014, USA had almost 1,500 CNG operational filling stations across the country, with160 stations planned to be built in the near future. California ranked top in the list of states with 286 CNG stations, followed by New York, Oklahoma, Texas and Utah, which have about 100 stations each.

In terms of access, the share of the CNG filling stations is 33% private (i.e. tied to supplying a specific vehicle fleet), 54% public and 13% addressed to private-government fleets. The graph shows the number of stations by access in 2015.

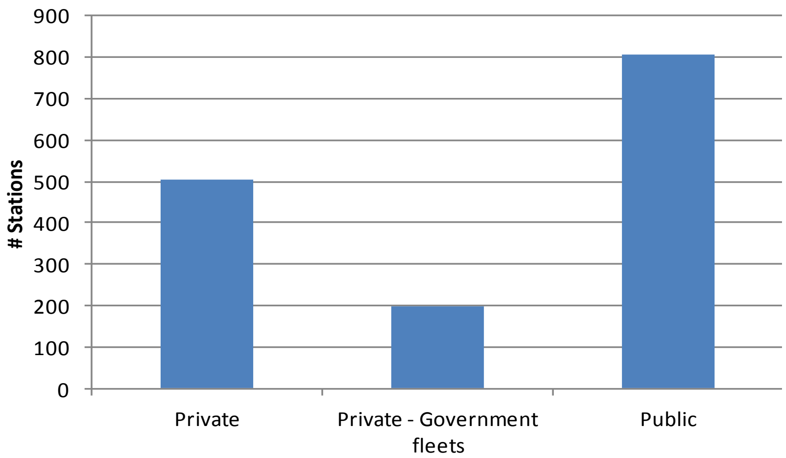


Figure 59 CNG Filling Stations by Access - Source: Alternative Fuels Data Center

While the market is open to new players (according to US Energy Information Administration 120 companies were operational in 2013), just 3 of them represent 74% of the NGV market: Southern California Gas Company (37%), Clean Energy (28%) and Pacific Gas and Electric Company (9%).

Southern California Gas Company currently serves 20 million customers (residential and NGV supply). The company has more than 100 public CNG stations in the state and also promotes a home refuelling appliance.

Clean Energy is focused on NG for transportation. The company owns its stations and also manufactures, sells and installs NG station components to its clients. Its nationwide network relies on 500 NG fuelling stations (LNG for heavy duty and CNG for light and medium duty vehicles).

Pacific Gas and Electric Co. (PG&E) provides natural gas and energy to 16 million customers in California. Based on data from the US Department of Energy, its fleet operation is one of the nation´s largest for a public utility, and includes 3,400 alternative fuelled vehicles (natural gas, hybrid and electric) [1]. The company also owns 32 private CNG and LNG fuelling stations[2].

With regard to demand, the number of CNG vehicles has followed the same pattern as that of the NG stations, with a decline over the period 2002-2010 followed by a recovery after 2011.

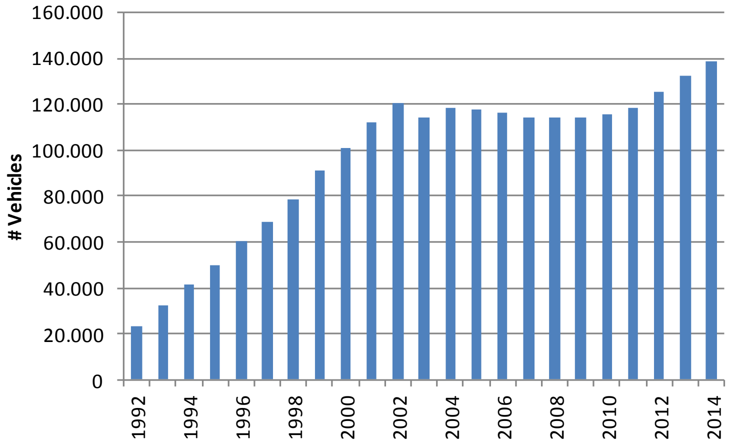


Figure 60 CNG Vehicles in Use - Source: Consultant based on Alternative Fuels Data Center & NGV Journal

Even though demand and supply have been following a similar pattern, the USA´s average supply per station is below that of other countries. This means that the growth in the number of stations has outstripped demand and stations are, on average, underutilized.

[1] http://www1.eere.energy.gov/cleancities/pacific_gas.htm

[2] http://www.pgecurrents.com/2014/01/13/fleetowner-magazine-tabs-pge-as-top-vocational-fleet/

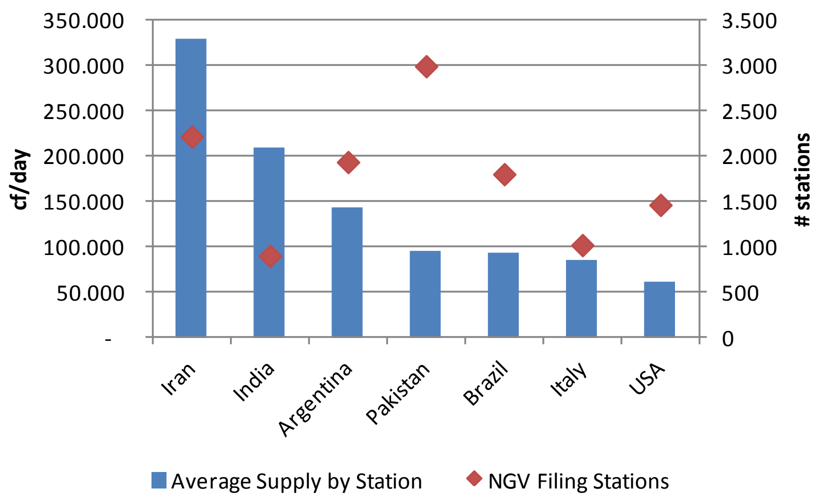


Figure 61 Average Supply by Station for Selected Countries (2014) - Source: NGV Journal statistics

5.2. Flaring gas utilization experiences

CNG and LNG use has not had a significant impact in reducing gas flaring in the USA. Based on the 2012 update of the National Development and Reform Commission (NDRC) Natural Gas Utilization Policy only 0.1% of the current flared gas could be reduced by these technologies. Recently however, a number of new developments have raised interest in using CNG to reduce flaring.

General Electric & Statoil have developed a low-cost prototype to capture flared natural gas in the Bakken field in North Dakota. The system, “CNG in a box”, consists of process equipment to remove the natural gas liquids (butane and propane) for petrochemical uses, the remaining methane (CNG) being used to power dual fuel engines on converted drilling rigs, replacing 40% of the diesel normally used. Statoil estimates that more than 60 MMMscf, 5% of currently flared gas, could be saved (used and reducing emissions) every day if the pilot project is replicated in all rigs operating in the Bakken field. Currently Statoil is proposing to convert the fracturing equipment and light truck fleet in the Bakken to CNG fuel using gas currently flared.

Finally, Mobile Fuel Solution (MFS) recently announced implementation of ‘virtual pipelines’ consisting of CNG trucked from oil fields to consumption areas in New York. The trucks are designed with 2 pods of gas cylinders holding the equivalent of 715 gallons of gasoline. The virtual pipelines are intended to supply NG fuelled vehicles in areas with no access to the gas grid. MFS will launch the first virtual pipeline in February 2015 with the beverage industry's distribution fleet among the first customers, and a refuse collection fleet and the Environment Remediation Department as other potential users. Long Island will act as the main station of from which the system of mobile stations will be provided. MFS will launch a second virtual pipeline in July 2015 which main station would be at Orangetown, located in the north of New York State.

5.3. CNG as fuel for vessels

The first attempts to ship CNG by sea date back to the 1960s. The Columbia Gas Company developed a CNG containment system on board a converted ship, the “MV Sigalpha”, with a 1.3 MMscf capacity. The ship made a dozen successful trips (around New York Harbor). However, the operations ceased due to the high capital cost of the ship technology.

Figure 62 MV Sigalpha- Source: Centre for Marine CNG

However, marine CNG has been identified as a niche technology that could complement LNG and pipeline technologies for stranded gas monetization. As a result, in the last decades several less expensive CNG transportation technologies have been developed.

It is important to note that one of the major benefits of CNG transportation over LNG technology is the small fixed capital asset: there is no requirement of liquefaction and regasification terminals and the main asset is transportable (the CNG vessel). Consequently, depending on gas supply agreements, seasonality and/or life of field, the ship can be relocated. According to a study carried out by Wood Mackenzie, a CNG supply chain costs a quarter of a LNG chain, based on equivalent gas volume.

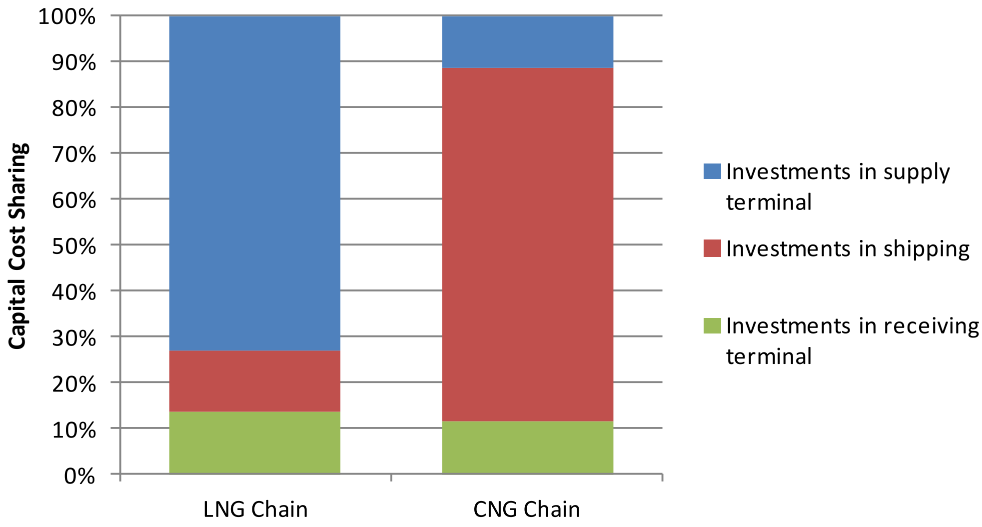


Figure 63 Breakdown of investments in LNG and CNG marine supply chains- Source: Consultant based on Wood Mackenzie

6. CNG MARKET IN CHINA

China´s concerns about environmental issues and securing energy requirements for the future have triggered an official policy to pursue a rapid rise in natural gas use. As it was mentioned in the LNG Report, the 2010 five-year development plan called for the share of natural gas in the total primary energy matrix to be increased from 5% in 2011 to 8% by 2015. To achieve the objective, the Government applied a number of measures to promote the use of gas.

At the end of 1980s, the first CNG filling stations came online in China, specially addressing taxis and light commercial vehicles. But the most populous country in the world made a significant deployment of CNG five years ago, when cities, such as Beijing, Chengdu and Hong Kong, converted buses and taxis to CNG in an effort to reduce notoriously toxic urban air pollution. Currently, it is estimated that there are almost 3 million NG fuelled vehicles on the road, six times as many as just five years ago, when deployment of NGVs took off.

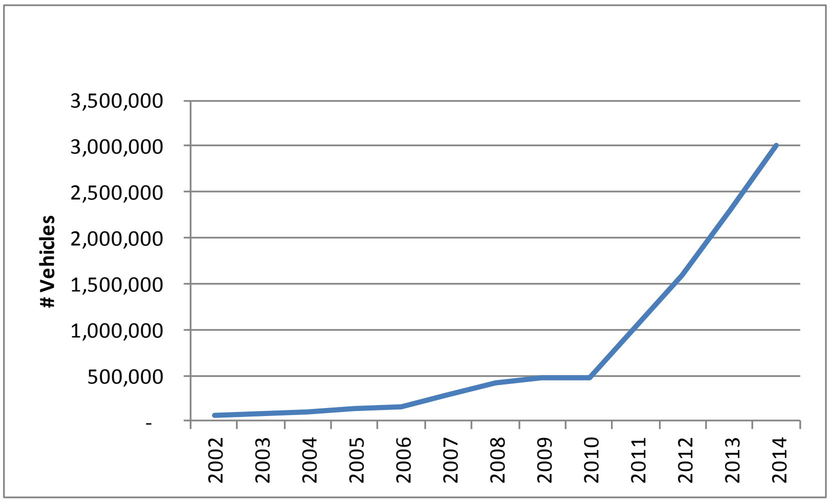


Figure 64 NG (CNG and LNG) vehicles in China- Source: NGV Journal

Driven by energy security and urban air quality concerns, Beijing, the capital of China, has made concerted efforts to increase the use of natural gas economy-wide, especially in transportation. Based on the 2012 update of the National Development and Reform Commission (NDRC) Natural Gas Utilization Policy, NGV have been deemed a priority use of natural gas over power generation and the chemical industry. As a result, a domestic industry has been developed to supply NGV equipment and infrastructure, with state-owned enterprises taking the lead to expand this market.

Several cities, such as Chongqing, Urumqi, Xi'an, Lanzhou, Xining, have a natural gas transportation and distribution system through a pipeline grid. In these cases, 95% of the taxis and inter-city buses are CNG fuelled.

Large disparities exist among cities in terms of natural gas use. Mega cities like Beijing, Shanghai, Chongqing and Chengdu began to promote natural gas use in the public transportation system (mainly in buses and taxis) in the late 1990s. After more than 10 years of development, these cities have become mature systems and several lessons have been learned from their experience. Medium and small sized cities are following the trend by exploring the application of natural gas, firstly in public transport and later in private motor vehicles. Dongguan is a good example.

Dongguan, a medium sized city, located in the south of Guangdong Province, has been plagued by acid rain for years. In 2006, the municipality began to encourage agreements between natural gas providers and interested taxi car owners to initiate mixed fuel taxi retrofits. In order to further promote natural gas application in public transport, the municipality published The Implementation Plan of Natural Gas Vehicle Fuelling Project Promotion in Dongguan in 2008. As an encouragement measure, the Plan offered subsidies for refuelling stations, buses and taxis that would convert from oil to gas technology over the period 2008-2010. The Plan also set out the expansion goals for the following years.

Goals / Year	2007	2008	2009	2010	By 2015
#CNG Refueling Stations	2	5	10	15	60
#CNG Taxis	100	800	2,800	4,800	>90%
#CNG Buses		100	500	1,000	>90%

Figure 65 Expansion Plan goals - Source: Implementation Plan of Natural Gas Vehicle Fuelling Project Promotion in Dongguan

Selected long distance bus terminals and urban bus stations were encouraged to participate in the CNG transformation in Dongguan. Measures were taken to accelerate conversion of traditional vehicles to CNG/mixed fuel, including setting time schedules for CNG bus purchases, refusing licenses to non-converted buses, and introducing charges to taxis that exceeded limit emission level. The Plan also required CNG refuelling station locations to be consistent with the overall urban development plan and compliant with industry standards.

Dongguan is a successful case in terms of natural gas promotion but, the application is still struggling with several issues: regulation and supervision of pricing and quality of service in a market where there is no competition. In conclusion, medium and small sized cities might take into consideration Dongguan experience, planning and lessons, in an attempt to apply a successful natural gas program.

The Chinese NGV manufacturing industry is growing quickly. There are more than 60 NGV vehicle manufacturers in the country, and production of components for NGV filling stations (pressure reducers, electronic control units and gas nozzles) is increasing. China has developed its own purification facilities, storage facilities, compressors and dispensers for stations and this equipment meets 90%, sometimes even 100%, of the domestic market. Locally-developed vehicles and facilities reduce the cost of vehicles and stations. Nevertheless, the scale of production is comparatively small, since many manufacturers produce only small volumes. It should be noted that, as well as passenger cars, minibuses, and light-duty trucks, Chinese light duty NGVs include motorcycle, CNG or bi-fuel rickshaws, and bi-fuel tricycles for disabled persons.

In order to support a nationwide transition toward increased NG fuelled vehicles, the government faces an important challenge: to supply gas for the rapidly increasing number of natural gas fuelled vehicles. Public and private operators of NGV stations realize the need of expanding the refuelling supply capacity all over the country.

Even in countries with well-developed gas pipeline infrastructure, there are locations that are not reached by the grid, and mother/daughter stations can play a key role ensuring access to CNG. However, the system presents some restrictions: while daughter stations are well-suited for light duty CNG vehicles, they may offer design and operational challenges for heavy duty CNG vehicles.

The economic incentive to switch to CNG in China is not as strong as in USA, mainly explained to higher gas prices, the government support is stronger than North America.

The main lesson of China CNG policy is that government action - through state-owned enterprises investments - can be effective to achieve a sustainable scale, breaking the vicious circle produced by the coordination problem in the market.

7. CNG MARKET IN PAKISTAN

Pakistan is ranked as the 6th most populated country in the world with 185 million people in 2014. Taking in view its growth rate of 9% during the last 30 years, it is expected its population will reach around 250 million people in 2025. Even if the urban population of the country is almost 37%, far lower than the five most populated countries of the list, Pakistan is in the 10th top ranking position of urban population. In other words, Pakistan has been and will be dealing with pollution issues in the main cities.

The natural gas story in Pakistan started in 1952, with the discovery of gas field at Sui in Balochistan. The initial consumers were the power generation industry, widen later to other industries and residential and commercial sectors.

Taking into account the lack of domestic fuels and the already deployed infrastructure network for transmission and distribution (pipeline grid), the Government of Pakistan identified domestic natural gas, particularly CNG, as an adequate alternative fuel for vehicles. Even if the first CNG stations were implemented by the Hydrocarbon Development Institute of Pakistan (HDIP) in Karachi 1982 and Islamabad in 1989, the Petroleum Policies launched in 1992, 1995 and 1998 set the framework for the CNG promotion. The main objectives of these policies were to decrease imports of gasoline and diesel oil and to improve environmental conditions in the cities. Promulgation of CNG safety rules, approval of infrastructure required and a number of incentives to private investors set the beginning of a CNG era. As part of these incentives, the Government of Pakistan established a liberal approval to obtain licenses for CNG retailing, a free market consumer price of CNG, natural gas tariff linked to petrol price, priority of natural gas connection to CNG stations and exemption of import duty and sales tax for CNG station and vehicle conversion equipment. Unlike some other countries, the promotion of the CNG industry in Pakistan did not set a direct subsidy. Even more, power and CNG sectors pay proportionally higher prices to cross-subsidize the fertilizer and residential sectors. Furthermore, the 1998 policy announced a 2 year target of establishing 150 CNG stations and converting 100,000 vehicles.

By middle of 2000s the replacement of gasoline vehicles by CNG technology was a very successful. However, imported diesel oil still represented a significant bill for the Government and the air pollution was very severe. The small gap price between gas (as it is shown in the figure 61) and diesel and the high conversion cost were not attractive enough to encourage the sought conversion. As part of the promotion the Government of Pakistan launched programs to gradually phase out diesel buses in the major cities of the country and increase CNG fuelled vehicles.

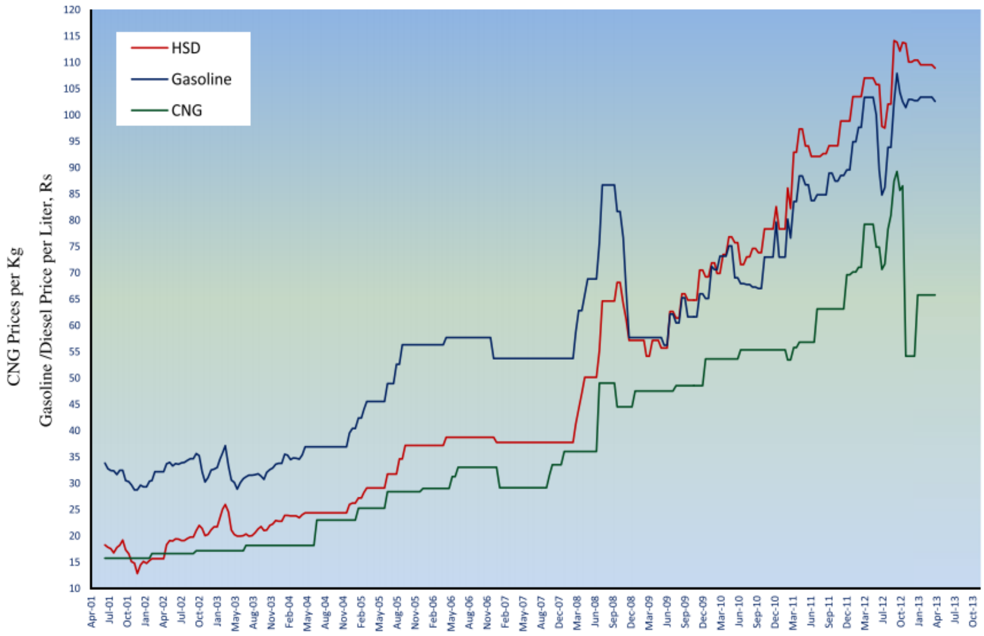


Figure 66 Evolution of Retail Fuel Prices in Pakistan - Source: Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects

Over the following years, the CNG market increased rapidly. In the period 2000-2010 the number of CNG stations has increased from 150 to 3,331, while the number of vehicles running on CNG has risen from 120,000 to 2,740,000. Based on Statistics and Europe (2013) the country has 3.1 million vehicles running on CNG, which represents almost 90% of the cars of the country[3]. Based on International Association of Natural Gas Vehicles Statistics (IANGV) Pakistan has the second largest CNG vehicles fleet in the world, second only to Iran.

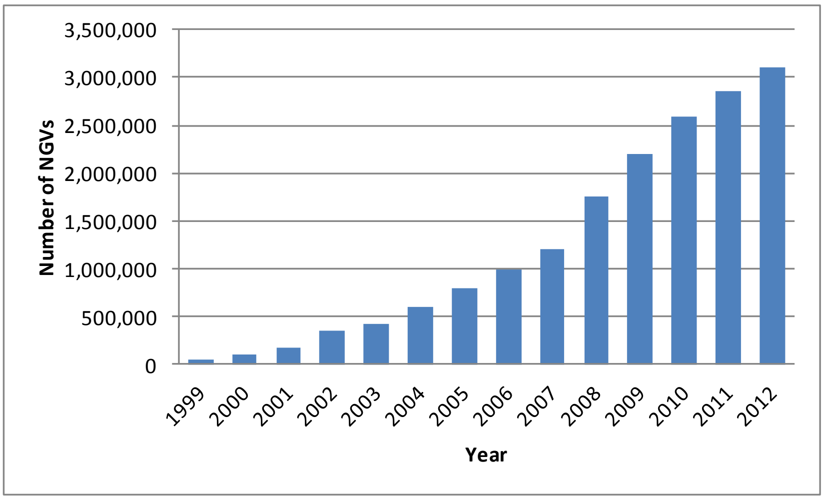


Figure 67 Evolution of NGVs in Pakistan - Source: Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects

[3] Medium-Term Market Report 2013 - International Energy Agency (EIA).

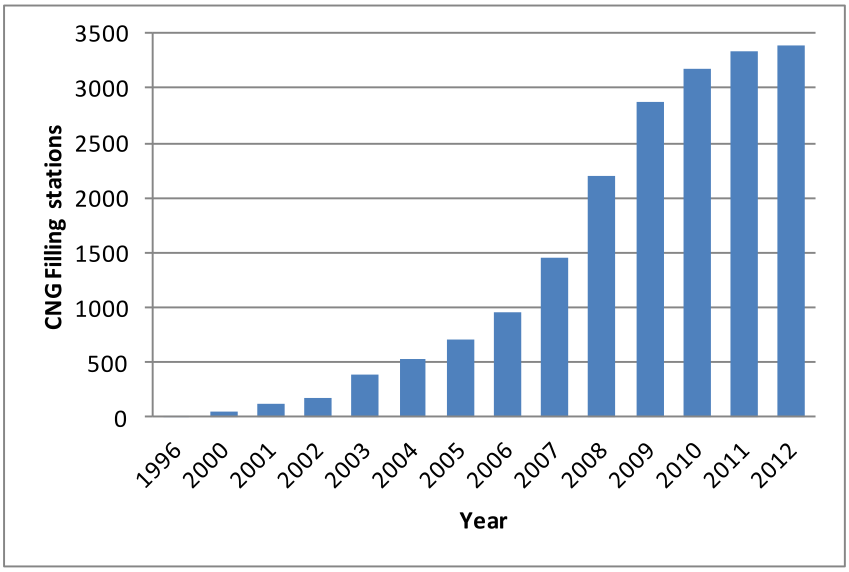


Figure 68 Evolution of CNG Filling Stations in Pakistan - Source: Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects

Regarding demand, in the period 2000 – 2010 the CNG industry consumption has been raising at a rate of 11% annually, reaching currently 325 MMscf/d, which represents 9% of the production of gas in Pakistan. In the following figure is exposed the evolution of fuels share in the sector.

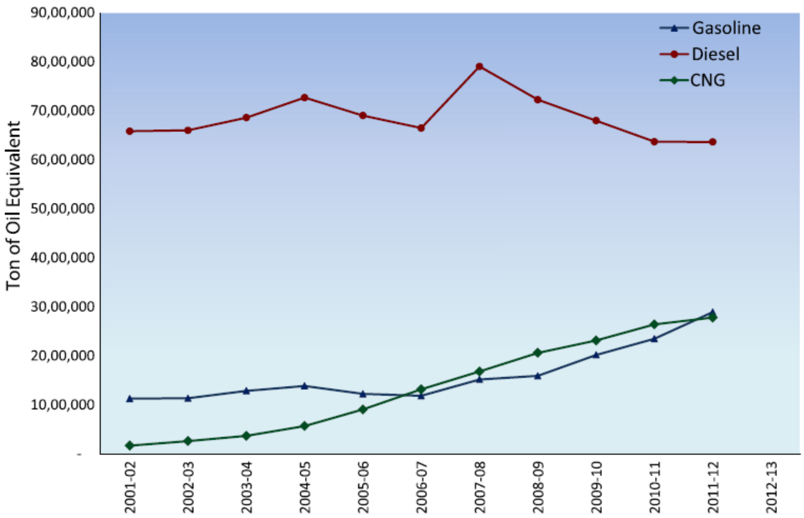


Figure 69 Evolution of Fuel consumption by transport sector in Pakistan - Source: Development of natural gas as a vehicular fuel in Pakistan: Issues and prospects

The energy crisis that the country is suffering has led to natural gas shortages (due to the decrease in indigenous gas reserves and production since 2008, as it is shown in the Figure 65, which are affecting some key sectors of the Pakistani economy such as power generation and industry (fertilizers, cement and textile among others). Consequently, the Pakistan's economy has been shrinking proportionately, dropping from a GDP growth of 6.8% in 2007 to a GDP growth of 1.6% in 2010. However, last two years growth has been increasing reaching 4.4% in 2013 due to a faster than expected manufacturing sector recovery.

The Pakistan government launched a plan in 2010 looking to step down the natural gas demand for transportation use. The plan included “the gas holidays”, where gas supply to CNG stations is cut off for several days in the week, an imposed ban on import of CNG conversion kids and cylinders. Recently, restrictions to several OEM companies to stop conversion of CNG vehicles were implemented, without previous negotiation, leading to an incipient tension between the Government and stakeholders.

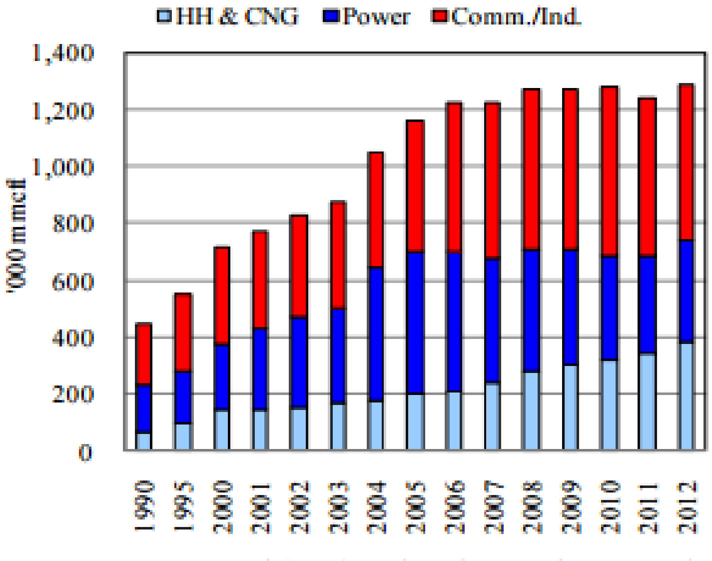


Figure 70 Evolution of Gas Production and Consumption by sector in Pakistan - Source: Energy Year Book (EYB), Hydrocarbon Development Institute of Pakistan (HDIP)

Pakistan is currently looking at a number of alternatives to solve its natural gas shortage. Based on the State Bank of Pakistan, if gas well-head prices were properly formulated and gas companies were run strictly on a commercial basis, will force to a more efficient use of the gas, prioritizing industrial and generation sector over CNG and household. In this scenario the following implications are foreseen:

1. “*Existing gas fields that are commercial unviable would automatically come on-line, which could increase Pakistan’s gas production quite significantly;*
2. *Competitive well-head gas prices would also encourage fresh exploration, which could increase total gas reserves in the country;*
3. *Although the cost of gas production would automatically increase, we think more reflective pricing would incentivize more efficient usage*.”

There are also two LNG import projects under study: Floating Regasification and Storage Unit (FSRU) at Port Qasim and a second FSRU near Karachi. With the arrival of LNG in the country, the Pakistan government expects to reduce the petrol consumption by almost two billion litres per annum and recover the industry and CNG as fuel which has suffered natural gas restrictions over the last 4 years. However, progress has been very slow and it is uncertain whether their plans will materialise over the medium term.

8. APPLICATIONS FOR OTHER COUNTRIES

8.1. Opportunities for small scale CNG

Currently, there are several transportation technologies vying to monetize natural gas. In order to design an efficient project, it is very important to determine the best technology in each case. There are two main parameters to take into consideration: the volume to supply and the distance to transport the resource. According to the SBC Energy Institute, the most economic technologies with regard to distance and volume (order of magnitude) are shown in the following graph.

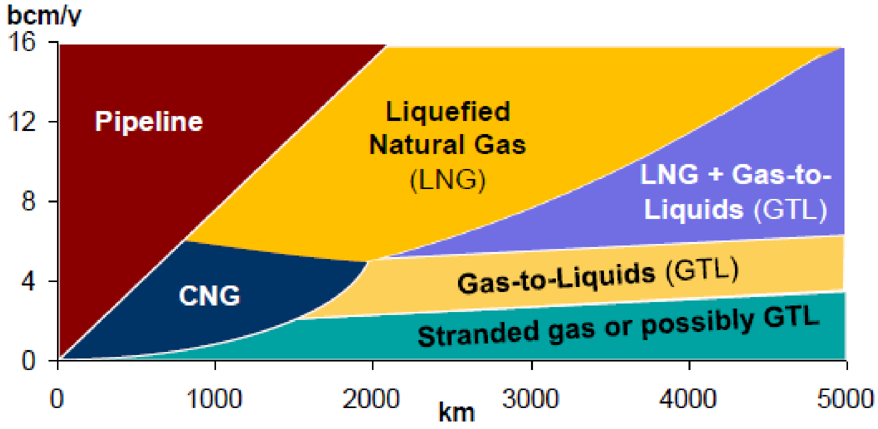


Figure 71 Options to monetize natural gas- Source: Introduction to Natural Gas –SBC Energy Institute

According to this very broad-brush analysis, CNG is primarily competing with pipeline gas. CNG is attractive up to 2,000 km and 5-6 Bcm/year (equivalent to 175 - 210 Bcf/y), while for short distances and larger volumes, a pipeline is typically more attractive than CNG. For larger volumes and distances, LNG or GTL are preferred options.

Regarding flaring reduction, several investment projects are in development to minimize and, thus, monetize the produced associated gas being flared. These projects can be classified into three major groups, namely: export oriented (LNG), domestic oriented (60% used for power generation) and field utilization (Gas lift, re-injection and natural gas as fuel for field uses).

The monetization of natural gas has not been a business option for major and marginal oil field companies. It was perceived as an unwanted by-product of crude oil production and natural gas flare off was not a problem for oil and gas managers. In recent years, only export-oriented large-scale LNG projects were considered a good prospect to monetize flared gas.

Nowadays, the situation is slowly beginning to change. Alternatives to monetize natural gas in the domestic market are gaining momentum. The small-scale use of CNG is currently considered a business strategy to produce benefits for firms and utility services consumers. Among other profits, it might reduce natural gas flaring (economical inefficiency and environmental pollution) and develop a nationwide local market for natural gas utilization.

Probably, new technologies such as “CNG in a Box” can be applied to flaring sites, not only by strictly economic reasons but also environmental issues.

8.2. Nigeria

The small-scale use of CNG is slowly progressing in power generation, transportation and industrial sectors in Nigeria.

It must be considered that environmental problems linked to climate change, such as gas flaring, make Nigeria very vulnerable. This problem, plus the increasing value for money of the natural gas business provides room for cost-effective small scale CNG projects. It was underlined by the Minister of Petroleum Resources Mrs. Diezani Alison-Madueke while citing examples from the country’s oil industry experience on environmental issues called on global operators of the oil and gas industry to re-strategize on sustainable policies for the sector in a Conference organized by the James Baker Institute for Public Policy Rice University in December 2014. The Minister assured that Nigeria is leveraging the Clean Development Mechanism (CDM) to access funds for major projects. She emphasize the gas flaring problem and the environmental degradation in the Niger Delta wrought by the activities of major International Oil Companies operating in Nigeria and moves by government to outlaw gas flaring.

The main issue in Nigeria is not the supply of natural gas, but an inadequate gas transmission and distribution infrastructure, and a low level of industrialization hampering development of potential anchor demand. Domestic demand is only about 400 MMscf/d, which is very low considering the large population.

However, several sectors could be potential “anchor” demands for CNG, such as: “peak’ power generation (especially for “peaker” plants), small isolated power generation for industries, electric power for marginal fields and transport.

8.2.1. CNG as fuel for power generation

The Island Power Project, a Public Private Partnership (PPP) between Lagos State Government (LASG) and Island Power Limited (IPL), currently supplies electricity generated using CNG supplied gas to several hospitals, judicial buildings, commercial buildings and shops, and public lighting installations on 22 Streets on Lagos Island. The reliability of power supply was drastically improved from 35% to 99.4%. The project was executed in 9 months and is considered one of the most successful Independent Power Projects in Nigeria.

The objective of the second stage of the project is to increase the generation capacity of the power plant from 10MW to 114MW using natural gas supplied by pipeline to supply power to Lagos Island central business district.

These examples show the room for business opportunities based on CNG solutions fuelling power stations in Nigeria. According to the Petroleum Gas University of Ploiesti, in particular the east part of the country, especially Port Harcourt, has a great potential for CNG technology, and it should be exploited.

Gas Network Services Limited (GNSL) has installed a CNG mother station (CMS) facility on the Ilasamaja on Oshodi-Apapa express way in Lagos State that supplies customers in the Lagos and surroundings areas that are not reached by the grid. This CMS facility was designed for an initial output capacity of 5.25 MMscf/d at a discharge pressure of 250 barg. CNG is loaded into mobile tube trailers for onward delivery to daughter stations customer locations, and will serve customers within a 200km radius. The facility has also dispensing points for filling Natural Gas Vehicles (NGVs). Gas supply to the CMS comes from a service line that taps into an existing Gaslink Nigeria Limited pipeline along the Oshodi-Apapa Express Way.

8.2.2. Small scale power generation for isolated industries

The reliable power demand of isolated industries (not connected to the grid) is encouraging small-scale CNG projects in Nigeria. Typical industries using CNG are steel, aluminium, fertilizer/agriculture, cement and glass.

Nestlé Nigeria Plc. pioneered the use of CNG as a fuel source for its Flowergate factory, reducing electricity costs by 30%. The choice for CNG hinged on the fact that, aside from being a reliable fuel source of power generation, it is highly cost effective and clean. As for the Island Power Project described in the section above, the use of CNG at this factory is expected to be a transition solution while a gas pipeline is built.

Oil and Gas companies are also active in providing CNG solutions. Shell Petroleum Development Company of Nigeria Limited (SPDC) provides CNG as fuel for several isolated industries and power generation facilities over a 100 km radius in the Niger Delta.

Substitution of expensive fuels by CNG is also a developing option. GE created a 60 km ‘virtual pipeline’ (2 trucks deliveries a day) to provide gas for industrial activities substituting diesel by CNG in Sagamu (Ogun state, Nigeria) in 2012. The substitution resulted in a 45% reduction in fuel costs.

8.2.3. CNG as fuel for transport

The use of CNG for transportation provides the opportunity to reduce emissions from flaring and, at the same time, to diminish emissions from their own transportation energy use. Additionally, there is a persistent gap between supply and demand of gasoline.

However, adoption of CNG as a transportation fuel has been a slow process. CNG as vehicular fuel was first proposed in Nigeria in 1997 with 25 vehicles converted to run on natural gas. In 2013, there were still only 2,210 NGV and 8 refuelling stations (Ogunlowo, 2014).

It can be argued that some policy instruments can be used for promoting natural gas vehicles in Nigeria: government action - through state-owned enterprises investments (as in China) and availability of inexpensive gas to this market (as in USA).

Regardless of what is the best set of governmental policies, some private companies are doing business in the CNG market at Nigeria. For instance, IMW Industries (Clean Energy Compression Corp.) and Borkir International Co. Ltd. (member of the Dangote Group of Companies) have announced the development of CNG fueling stations in Nigeria, beginning in the first quarter of 2013. The Dangote Group has approximately 5,000 trucks in their own fleets to convert to CNG and will also be supporting CNG fuelling and conversions. They have a CNG truck conversion facility in Ileka, Lagos state.

8.2.4. Natural Gas from Marginal fields

In 2003, the Federal Government of Nigeria awarded twenty-four (24) marginal fields to indigenous companies for exploitation. These marginal fields featured : low reserves of crude oil (less than 20 million stock tank barrels of crude oil), low crude oil daily production rates (expected or producing less than 4,000 stb/day), 8-15 years economic life, low to moderate net present values (NPVs), and low natural gas reserves (less than 100 Bscf: AG and NAG) .

Many marginal fields are using less than one percent of their produced associated natural gas. Therefore, small-scale CNG solutions appear to be an alternative to monetize natural gas, to enhance the economic performance of these marginal fields and achieve an effective gas flare reduction with subsequent environmental benefits.

An example is Lekoil's plan for the Otakikpo field in OML 11, located near the coast in the Niger Delta, Lekoil plans to use the associated gas for its plant utility, plant power generation and external electrical power supply to the immediate community. Surplus associated gas will be offered to a third party at the battery limit (p. 53, Chandler et al., 2014).

Source: Lekoil.

It is expected that projects such as Lekoil´s or the USA´s “CNG in a box” could be replicated in other marginal fields of Nigeria.

8.3. Iraq

Iraq has the 12th largest natural gas reserves in the world; however NG use in the primary energy mix is quite insignificant (1%). Furthermore, in 2011, the country flared 7.5% of the world total. Thus, the country´s picture offers an interesting opportunity to reduce flaring and monetize the produced associated gas.

Different technologies could be used to achieve this objective: LNG, CNG amongst others. Nevertheless, Iraq has not yet made significant steps in this direction and opportunities identified below may need a natural gas market to be a developed prior to introducing even small scale CNG projects.

8.3.1. CNG as fuel for power generation

The lack of fuel for power generation is a nationwide issue in Iraq. However, Kurdistan seems to be addressing this issue in a more efficient way than the rest of the country. According to Dana Gas, which is currently the main provider of natural gas to the power generation sector, Kurdistan had only two hours of electricity per day in 2007. By 2008, the Company (in partnership with Crescent Petroleum) launched the production, compression and delivery of natural gas from the northern fields of Khor Mor and Chemchemal to supply the two power plants in the area: Erbil and Chemchemal. The facility consists of two brand new gas processing and LPG extraction plants, which have a combined capacity of 270 MMscf/d and an enhancement production facility to increase the production to 330 MMscf/d. The gas production is shipped by a 180 km pipeline to the power plants (2,000MW), which represent 2/3 of Kurdistan generation capacity in 2013. In conclusion, KRG has already tripled its 2015 target for gas fired power generation one year earlier. It is important to note that LPG experiences could be a preliminary stage to CNG development in small power generation plants.

Based on the Belfer Center for Science and International Affairs of Harvard Kennedy School, in Kurdistan the power generation system, gas fuelled, supplies twenty hours of the day, however in the rest of Iraq, the population suffers frequent and severe power outages that can last for almost an entire day.

Regarding the national picture, according to the expert Khaled Abubarkr, political instability is the major constraint for monetizing gas reserves in the country, since any investment in this field requires certain stability on the political and regulatory framework.

Besides, “any future decision to export gas without domestic demand being fully satisfied will likely be met by strong public opposition”. In other words, the development of the natural gas market would be possible only if the Government send clear signs of stability, and, the project has the following order: first, to supply the local market, and then, to export the rest of the resource.

This scheme seems to be in line with the Dana Gas business plan in Kurdistan, which affirmed that the company will address its gas production to export, "after fulfilling the gas demand in the local market". In fact, the company plans to export to Europe through the Turkey pipeline 350 billion cubic feet (Bcf) by 2020 -2025. The rest of Iraq, which is one step behind, has a promising path to move along if the supply of local demand is kept as a priority. The oil production growth, destined to export, will continue to increase gas flaring; of which monetization will be a key factor in the development of the domestic gas market.

As already identified, the knowledge and experience acquired in Iraq in the gas field could leave room in the future for CNG developments, and furthermore small scale CNG projects. As observed in the Chinese and USA´s markets, a learning curve is necessary to succeed in the small scale developments.

8.3.2. CNG as fuel for transportation

The 270 km Iraq – Iran pipeline was completed in 2014 to export 875 MMscf/d from Iran to Iraq, starting with 245 MMscf/d; however, the inauguration of the pipeline has been suffering delays due to unrest in Iraq. The main goal of the pipeline is to supply the Al Mansoureh power plant; nevertheless, Iranian private companies, which run the project in venture with the state owned company, have been commissioned to build the first ten CNG stations in Iraq. Their construction will begin as soon as the pipeline becomes operational.

Transportation is a growing market in Iraq. The average motorization rate in 2010, 100 vehicles per 1,000 inhabitants (Kurdistan being the region with the highest rate), was quite high compared to countries like India or China. Furthermore, it is expected this rate will grow in the future driven by the high GDP growth perspectives: 175 vehicles per 1,000 inhabitants by 2020 and 200 vehicles per 1,000 inhabitants by 2035.

Taken into consideration that Iran has a developed and mature market of CNG (Iran has the largest CNG utilising fleet in the world with 3 million vehicles) and the promising growth of private fleets in Iraq, the implementation of Iranian CNG stations could be the first step of a new market in Iraq. Private Iranian firms experience in CNG, National Oil Companies as "market makers", could provide the required knowledge to give birth to the CNG market in Iraq.

8.3.3. CNG as fuel for industries

North Oil Company (NOC) is a state owned company which operates oil and gas fields in the north of Iraq (from Baghdad governorate to Nineveh and Erbil governorates). NOC offers separation and compression of associated gas process, in order to supply the North Gas Company (NGC). The major share of this processed gas is the industrial sector, which use it as fuel. This company might be a key driver to develop CNG solutions for industries and public power plants in Iraq.

In Kurdistan, according to Dana Gas, a Gas City Project, which consists in the supply of an industrial zone and several residential and commercial areas, was being studied in 2014. The implementation of this project is the next challenge for the company, which aims to open the gas market to new local users.

8.3.4. CNG as fuel for military sector

Iraq´s military sector has a significant demand of traditional fuel which could be replaced by natural gas use. However, according to the Assistant Secretary of Defense for Operational Energy Plans and Programs, the conversion from traditional fuel to natural gas by its bases would present several inconveniences for the USA tactical fleet. Main reasons are availability, compatibility and energy density. Firstly, in regard of availability, the USA forces need to rely on a source which can be globally sourced and distributed, and natural gas does not respond to this requirement. Secondly, regarding compatibility, natural gas vehicles need a particular technology engine, which requires an investment in infrastructure and engine adaptation. Finally, in terms of energy density, natural gas vehicles have significant less autonomy than gasoline or diesel vehicles (due to the size of the storage tank), which is a key factor in the military sector. Currently, USA has not considered CNG for its military bases in Iraq; however its further appreciation on this point could be interesting.

It is important to note that all these barriers only apply to operational fleet in the bases, which is the 75% of the bases energy demand. The other 25%, which is explained by domestic installations, could have less constraint to make the conversion to natural gas fuel. Since the military bases are spread all over the country, the grid does not reach all of them, and according to the required demand volume, an infrastructure investment would not be cost effective. In those cases small scale CNG technology could be a solution worthwhile of a study.

8.4. Indonesia

Indonesia is a seismically active archipelago with more than 17,000 islands, making pipeline and interconnecting transmission power system very complex. Gas transportation facilities and power transmission infrastructure is mostly located in Java and North Sumatra, while they remain almost non-existent in the other islands.

According to the country's economic projected growth and the government´s goal to minimize dependency on oil, the expansion of domestic gas utilization (transported by new technologies) might be an answer. This application may provide also a cleaner and cheaper alternative fuel for electricity generation.

Indonesia has the 14th gas reserves in the world, spread in several fields (Natuna, South Sumatra, East Kalimantan and Tangguh Papua). A large share of these gas resources are committed to long term supply agreements with other countries (through LNG liquefaction terminals).

8.4.1. CNG as fuel for power generation

Considering that natural gas is a large energy source (even if it is dispersed) and the domestic natural gas distribution infrastructure is deficient to satisfy current and future demand, Indonesia has a strong interest in developing alternative technology solutions.

Perusahaan Listrik Negara, State Electricity Company (PLN) considers CNG marine transportation as one of the most adequate options. Unlike pipelines and LNG projects, the great majority of CNG project capital is re-deployable to other applications if needed, providing a useful risk management solution in case unexpected events occur in the supply chain, including reservoir, market, commercial and political risks. Furthermore, projects are easily scalable by adding vessels. Loading and unloading plants are low capital intense.

PLN is currently carrying out a pilot stage project, which consists of shipping gas from Gresik facilities to a receiving point located in Lombok (about 300 nautical miles from Gresik) via CNG carrier. Two power plant (60 MW) would be fuelled in order to cover electricity peak demand. The carrier, which will be the world's first compressed natural gas, will be built by China to fulfil the order from Pelayaran Bahtera Adhiguna, a subsidiary of PLN. The ship design has 110 meters length, 14 knots speed and a nominal capacity of 77 MMscf. The CNG carrier is valued at 200 million USD, being the most expensive asset in the supply chain, and it is expected to be delivered in May 2016.

Figure 72 Gresik and Lombok locations- Source: Consultant based on Google Earth

Marine CNG would allow using cheaper natural gas instead of liquid fuel for power generation. If the pilot project succeeds, marine CNG technology would be applied to other power plants across the country, shown in the graph, with similar capacities.

Figure 73 Power Plans Location in Indonesia- Source: Enipedia

Furthermore, particularly for peak demand, it is necessary to provide a large power swing for a short period of time (6 hours a day). This energy could be supplied by complementary small thermal power plants which could be fed either by diesel, fuel-oil or natural gas.

Another example of power generation supply by CNG is Maxpower´s project, which recently launched the first marine CNG-fuelled power plant. The project, located in Bintan island, took two months to be completed and consists of supplying two power plants (Type 6) by CNG transported via virtual pipeline (barge or truck). The alternative solution represented fuel savings of 35% to Maxpower and an investment of 4 MMUSD. This small scale CNG solution could be replicated by other power generators, who are currently using gasoline or diesel in the country.

8.4.2. CNG as fuel for transportation

Indonesia has been interested on developing natural gas use in transportation for more than a decade. The main reasons of the Ministry of Energy´s fuel diversification were to reduce oil fuel dependency and to face the rising air pollution in the cities.

Based on PT. Raja Rafa Samudra, Indonesia launched the first NGV program called "Blue Sky Program" at the end of 1980s, which consisted in the implementation of 30 CNG stations across the country (driven by Petramina, Indonesia's state owned Oil & Gas Company). The program failed due to lack of incentives for users (fuel was subsided) and high costs of operating stations. Later, in 2005, the private sector increased their investments in NGV and industrial CNG business. This time the Government supported the initiative with new NGV policies (2007-2011). In addition, the Government boosted the deployment of CNG Stations through the implementation of the regulation 64/2012 on Supply, Distribution and Pricing of Gas for Transport. As a result, in 2012 Petramina launched the first CNG station. Ministry of Industry and Mineral Resources are currently working on new incentives to CNG use.

Regarding the supply, Envogas (CNG subsidiary of Petramina) and several private companies offer CNG supply across the country. Based on Pertamina, the company had 13 CNG stations deployed along Java and Sumatra in 2014, and it has targeted to build 150 CNG stations annually for 5 years, starting in 2015. This plan includes extending the supply to other islands, such as Balikpapan and Sengkang. Also, the private sector has several CNG stations deployed in Java and Sumatra. Several of these stations are on the grid area, thus, are supplied by the pipeline network; however, many of them, called "daughter" stations are supplied by virtual pipeline (trucks) from "mother" stations. Based on the Association Perusahaan CNG Indonesia (APCNGI) there were 22 CNG mother stations established (plus 5 planned) and 6 daughter stations among its member companies in 2012.

According to NGV Global, in 2015, PT Pertamina and PGN signed a memorandum of understanding (MOU) in order to cooperate to facilitate natural gas to refuelling stations. PGN has already identified 73 fuel stations in Greater Jakarta, which intersect the gas pipeline network and, as a result, could be converted to multi fuel suppliers (LNG/CNG).

Regarding the demand, the conversion to NGV by users depends on 2 main factors: a perdurable gap between petrol and gas prices (which is hindered by current subsidies on gasoline and diesel fuels) and a spread availability of CNG filling stations. Recently, the Ministry of Transportation launched a program to promote the CNG use. According to manufacture experts this policy remains unclear and needs time to have significant impact.

8.4.3. Experience of Jakarta

Jakarta implemented a pilot project in 1980s, which consisted of installing CNG converter kits in 200 local taxis. The project failed due to the lack of availability of supply. This issue was explained by the gap of oil and gas prices, which did not incentivise the private sector to invest in CNG stations.

In 2007, Jakarta retook the conversion plan, and started a transition of local government fleet and public transportation vehicles to CNG technology. According to International Council on Clean Transportation, Jakarta Transportation Agency has committed to a full conversion of three-wheeled taxis by the end of 2016, and TransJakarta BRT system, which operates 600 CNG buses, has plans to introduce a 1,000 more. Finally, DKI Jakarta will add 3,000 CNG powered mini buses.

Regarding the supply, the city had 8 CNG stations in 2012 and had ambitious plans to quadruple the number. However, the expectations are not being met, since only 6 stations were operational from the 10 built in 2014. In addition, Jakarta Department of Industry and Energy and a recent MOU between Jakarta Propertindo and TransJakarta announced to build 50 and 20 new stations, respectively.

As it can be noted, Indonesia has decided to progress with the NGV technology and, taking into consideration the geography of the country (an archipelago with deficient gas transportation network), a significant growth of mother/daughter stations is expected in the following years, in order to comply with targets. In this case, trucks and vessels carriers would be developed to supply the rest of the islands. It is important to note than Jakarta´s stimulus in the NGV field is a main driver for Indonesia´s progress on NGV developments.

8.4.4. CNG as fuel for industrial sector

CNG has a potential market in the industrial sector, which had contracted 13 MMscf/d from mother stations supply in North Java by 2012.

According to CNG-NGV Forum, the industrial sector, and especially the mining sector, would be economically benefited by the conversion of conventional fuel to CNG. The transportation proposed to these areas is by pipeline or virtual network (trucks) in the cases which are not reached by the grid. Several mining companies in Sumatra and Kalimantan islands have already switched to CNG/LNG fuel in order to reduce their fuel costs.

Based on the success of these experiences, several industrial clusters could implement the conversion of oil to gas fuel in order to make significant savings.

9. POTENTIAL BARRIERS AND INCENTIVES

It has been found that the development of CNG is slowed down by several barriers such as:

- "The coordination problem" for investment decisions (in terms of infrastructure development).
- The minimum required scale (demand/ supply) in order to assure economic viability.
- The prices that the demand is willing to pay for the new equipment.

Besides those facing these experiences, there are other countries which have been developing interesting and successful projects with CNG technology. Some of these practices should be taken into account in future CNG developments in order to capitalize on the already acquired knowledge related to the field. In this regard, a study of Yeh (2007) has underlined the following policies[4]:

- Demand side market creation programs: mandatory conversion of government fleets and urban buses procurement.
- supply side market creation programs: governmental investments in refueling stations, pipelines and conversion kits.
- financial incentive programs offered to consumers and equipment suppliers: subsidies and tax breaks to reduce prices of natural gas specifically for transportation, rebates and loans to lower or eliminate consumers' vehicle conversion costs, exemptions from import duties and the lowering or elimination of import tariffs on machinery, equipment, and kits, and exemption from sales taxes for the construction and operation of refueling stations.
- Regulation-based policy: industry standards, regulations, and certification programs; liberal licensing for CNG retailing; expedited approvals for the installation of CNG refueling stations; forced early retirement of old fleet vehicles, city buses, and taxis; penalties for operating city buses on ''dirty'' fuels such as diesel; and traffic restrictions for which NGVs are exempt.
- Information - or coalition - type policies: government/industry/non-governmental organization (NGO) coalitions and government-funded research and development programs.
- Interactions between stakeholder groups, such as incentives provided by equipment suppliers to consumers: the voucher scheme developed in New Zealand.

10. CONCLUSIONS

CNG is an already proved technology and it has been boosted in several aspects since the 1990s.

[4] Yeh, Sonia (2007), "An empirical analysis on the adoption of alternative fuel vehicles: The case of natural gas vehicles", Energy Policy 35, pp. 5865–5875.

There are economic and environmental reasons to develop CNG in the different countries. Regarding the economic aspect, CNG technology is a cost effective solution to supply gas to areas which are not reached by the grid and do not reach the minimum required volume to invest in a traditional infrastructure.

Regarding the environmental aspect, crucial in several cities for instance in China, emission reduction policies are the main factor to develop this technology, aiming to reduce gas flaring and also vehicular emissions.

The following projects are examples of the main small scale CNG solutions in countries like USA and China.

In order to supply areas that are not reached by the grid, currently, there are several projects being developed in USA, such as a virtual pipeline to supply NGV stations by mother/daughter system in New York and “CNG in a box” in North Dakota to fuel engines on drilling rigs. Also, it should be noted that CNG transportation system by vessel has significant advantages over LNG (smaller fixed capital asset), and the technology could be sturdily developed to monetize stranded gas. However, it is necessary to design a convenient ship that supplies economic and technical requirements.

Additionally, in China there has already been implemented a mother/daughter system which has been successful.

Regarding the flared reduction, an oil company in USA is developing a low-cost “CNG Box” in order to supply gas to engines in drilling rigs.

It is important to note that marine CNG transportation has some benefits compared to LNG in terms of costs, due to its lower investment in fixed facilities (regasification, liquefaction plants).

CNG development has to cope with several barriers that slow down its popularization as the “coordination problem” or non-competitive prices. In order to tackle these issues, tgovernment action by means of incentive programs has been proven as an effective solution.

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