2012 – 2015 Triennium Work Report

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PROGRAMME COMMITTEE D3: SMALL SCALE LNG

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Executive summary

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Introduction

Scope of Study Group 3

The small scale LNG business is becoming a more and more relevant sector throughout the world. Whereas the sector of LNG as a transport fuel has been so far populated by small players, the recent growth is determining the ingress of some of the big LNG players into this slice of the market.

LNG as transport fuel is provided via the small LNG scale value chain, whose details and mechanisms are illustrated below. In the 2012-2015 IGU triennium had to capture this new application of gas resources in all its complexity. To this aim, two dedicated groups worked through the triennium: PGC-D3 focussing on Small Scale LNG production chain, and PCG-D2 focussing on the LNG as transport fuel.

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ADD DESCRIPTION OF FOCUS AREAS OF THE REPORT AND METHODOLOGY

Definition (Value Network, boundaries, overview)

The small scale LNG value network is illustrated in Figure 1. Producing LNG in small scale so that it can be used for transport purposes (trucks, vessels) and small industrial applications require a deep change with respect to the conventional large scale LNG chain.

EXPAND ABOUT VALUE CHAIN

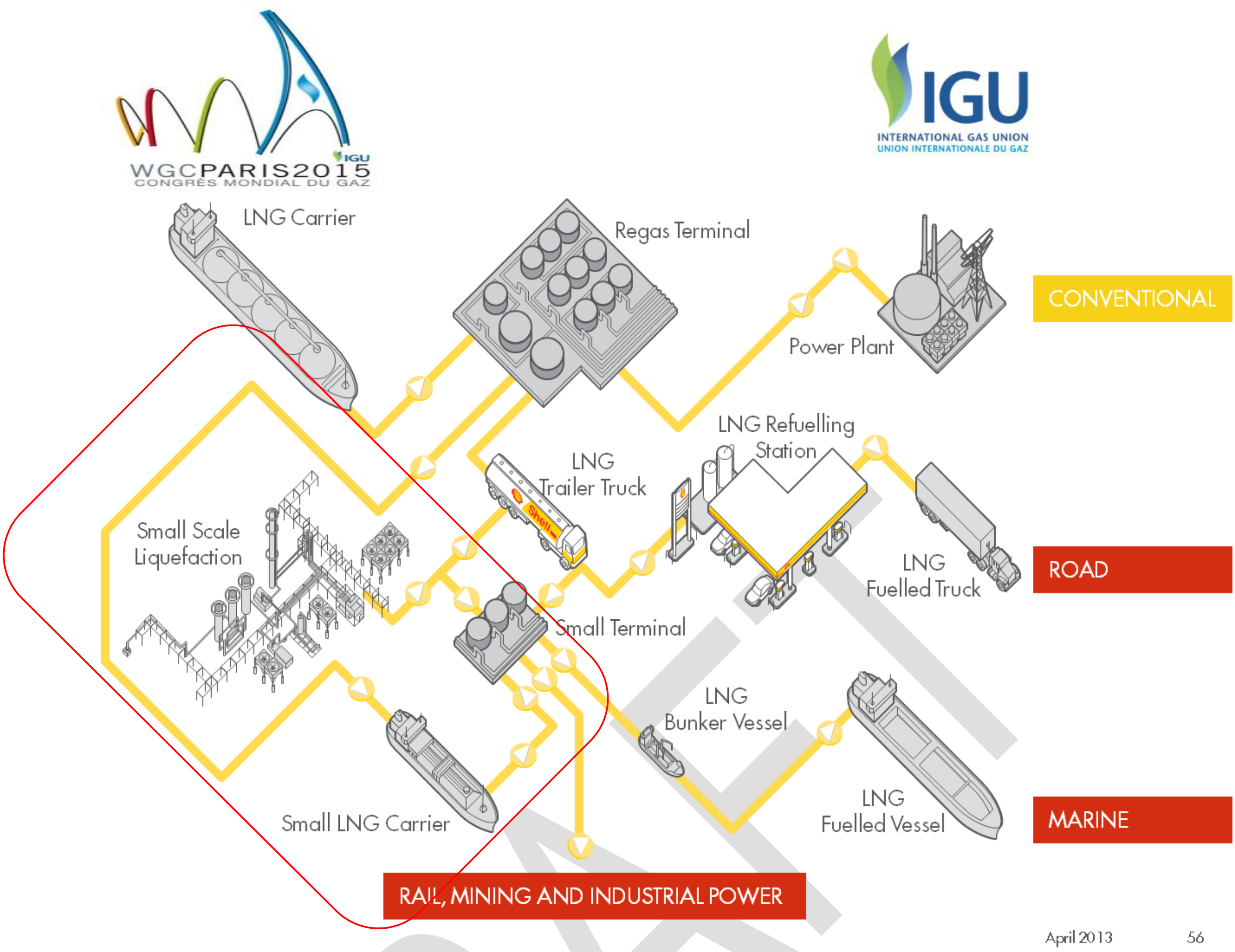
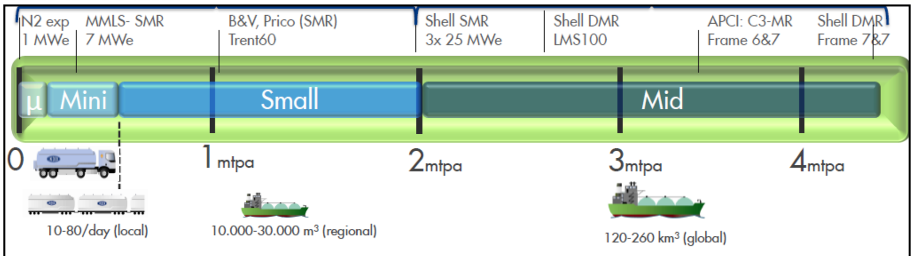


Figure 1 Small Scale LNG Value Network - Comparison with conventional LNG Chain

The small scale LNG sector has been defined as LNG chain dealing with a capacity between 0.1 and 1 mtpa. The production and transportation of LNG at such lower scale imposes application of different technologies in order to meet efficiency and cost requirements.

The scope of PGC-D3 is limited to the production and distribution elements of the value network up to the point where the LNG is distributed to its end users.

Also, even below the 1 mtpa threshold, it is possible to differentiate between different value chains, where with the capacity, the liquefaction and transportation methods and end customers also vary (see Figure 2).



	Concept	Technology	Transport	Purpose
Micro 0-0.1 mtpa	Simple	N_2	Truck	Enabler of oil production, flare gas Peak shaver LNG
Mini 0.1-0.5 mtpa	Movable & Modular	N_2 or SMR	Truck/container	Premium markets Replace marine gasoil, road diesel, naphtha, LPG
Small 0.5-2 mtpa	Minimum equipment	SMR	Small LNG carriers	Phased deployment Supply gas grid /power plants
Mid 2-5 mtpa	Economy of scale	DMR or C3-MR	Ship to terminal	Traditional base-load Supply gas grid /power plants

Figure 2 Small Scale LNG Definitions

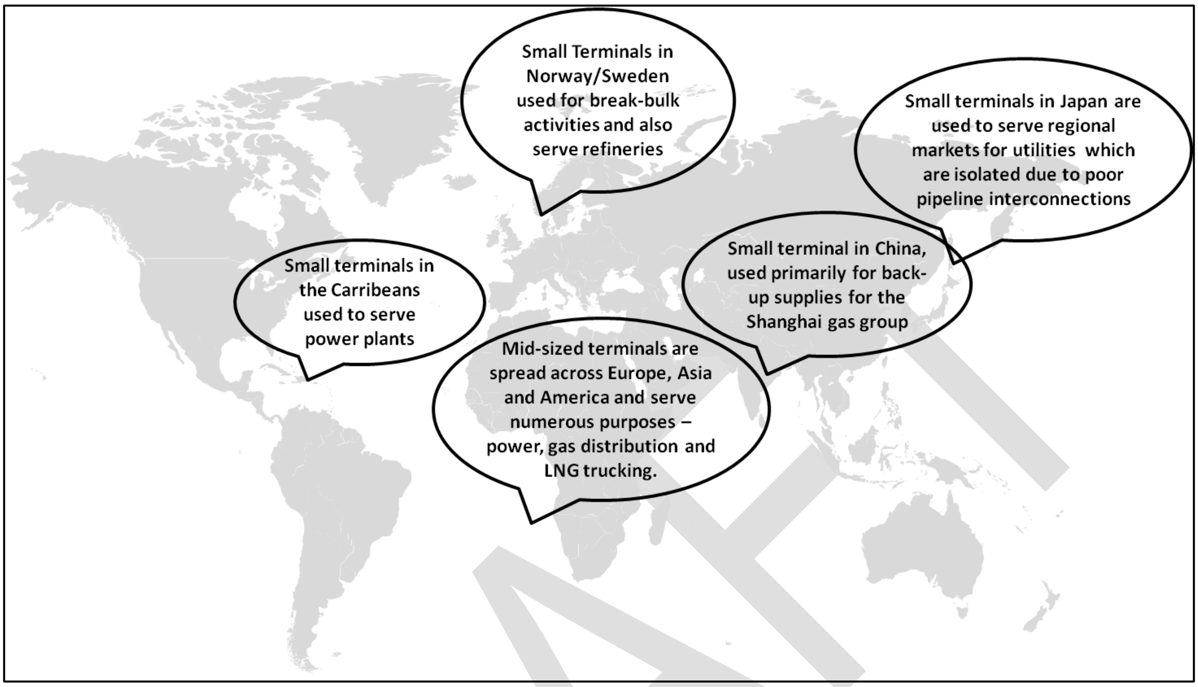
Logistics

Drivers and Business Model (intro followed by regional analysis of ongoing and future projects, assets and businesses, characteristics,)

A number of factors is pushing towards the application of LNG as transport fuel:

- In the transport sector, high oil prices are emphasizing the need to broaden the transport fuel mix
- Improved air-quality from reduced emission, both of sulphur and of particulates. This is particularly important in urban areas, not least in the growing cities in emerging economics.
- Reduced sulphur and particulate emissions are also an important advantage for marine transport where operators are facing increasingly stringent emissions regulations.
- Due to its higher energy storage density, it can offer the range that commercial and heavy duty operators need.
- Due to the current price differential between gas and oil products in some markets, there can be a cost advantage in using gas. This can be an especially important factor for owners of fleets of heavy duty vehicles and can reduce the payback time for any investment in infrastructure.
- Natural gas used in road transport can in some cases deliver lower ``Well to Wheel'' (WTW) CO_2 emissions - up to 20% for LNG in heavy duty applications under the right conditions – but it is important to consider performance over the full supply chain as this is not always the case.

In Europe, increasingly stringent emissions regulations are forcing customers to reconsider their fuel options and LNG can offer an attractive alternative. In North America, the current wide price gap between gas and liquid fuels is providing a powerful incentive to develop more natural gas vehicles. Meanwhile in Asia, the growth in long-term demand for transport fuel is such that all viable options, including LNG, are under active consideration. An overview of the different drivers for small scale LNG facilities across the world is given in



Yet, several obstacles must be overcome in developing a global market for LNG as a transport fuel. Those challenges include significant infrastructure investment, technical innovation and focused effort across the whole supply chain to ensure the safety and sustainability of gas in transport. In order to build the market, a supportive broader policy and regulatory context that can ensure the highest standards of safety and environmental protection are required. To overcome such difficulties, a cooperative approach might be the key: one example of this approach is the joint industry project in Rotterdam and Singapore that Shell is participating in. Partners from across the whole value chain, public authorities and classification bodies are all working together to develop the safety and legal assessment process for the introduction of small scale LNG as a marine fuel in these very busy ports. The main focus of this work is to ensure safe bunkering procedures to deliver the LNG to shipping customers.

The industry must continue to work with governments and regulators around the world to develop clear, robust and consistent regulations and safety standards for LNG in the transport sector.

Players (across the value chain, categories)

Technology (overview across the value chain, incl. shipping)

Such elements have been identified as:

- Liquefaction
- Transportation
- Small Regasification Terminal
- Storage

In the remainder of this section, a functional description and technology options applicable to each section of the value chain are described.

Liquefaction

As in the conventional scale LNG chain, the natural gas will have to be liquefied in order to reduce its volume for an efficient transportation.

The liquefaction facility then will comprise a treating section, where impurities such as CO_2, H_2S, H_2O, Hg and heavier components will be removed, and the liquefaction section itself which will bring the gas to its liquid form at around -163 degC and atmospheric pressure.

Three main liquefaction processes are currently employed for liquefaction at this scale: Single mixed Refrigerant, Nitrogen Expansion cycles, Mixed Refrigerant Process.

The Nitrogen Expansion process utilises a closed loop, multiple pressure level nitrogen expansion system. The nitrogen is expanded to lower pressure to provide the necessary cooling duty to liquefy the natural gas.

Single mixed refrigerant (SMR) processes use a mixture of light hydrocarbons (methane through pentane) and nitrogen that is partly condensed at ambient conditions and then used to cool the natural gas feed stream.

The process typically chosen for capacities above 0.5 mtpA is a mixed refrigerant process. For the majority of the plants this is a single mixed refrigerant process with no pre-cool. For some of the floating LNG applications nitrogen expansion processes have been proposed due to safety concerns and plot space limitations but for onshore plants they have not yet been selected in the Small Scale range. Any Small Scale trains, onshore or offshore, using an expansion process would provide a large step out from previous experience and would probably require parallel units due to the equipment sizing limits.

As the trains/plants become larger the impact of efficiency becomes more important which is why the mixed refrigerant is the prevalent process choice in this range.

A pre-cooling loop can be incorporated in any of the above processes. The advantage for the expansion processes is a higher efficiency at the cost of higher Capex and equipment count.

The pre-cooled MR process using propane as the pre-cool refrigerant is the most commonly installed process in base load LNG plants reflecting that at higher capacities the pre-cool system is advantageous. For small capacities there are very few pre-cooled processes installed. (DETAILS AND SCHEMATIC IN APPENDIX?)

Below, a list of active technology providers for each of these methodologies (TO REVIEW):

- Single Mixed Refrigerant (SMR) processes:
  - Black and Veatch PRICOTM;
  - Linde SMR;
  - Shell SMR;
  - Kryopack SCMR.
- Nitrogen Double Cycle Expansion Refrigerant processes:
  - APCI APXTM – Double N2 Expansion process;
  - APCI APXTM – Double N2 Expansion cycle with C3 or CO2 Pre-cooling cycle;
  - Kanfa Aragon;
  - Hamworthy with Gear-Box (Kollsnes II);
  - Hamworthy Improved (new process August 2008);
  - Mustang NDX-1.
- Mixed Cycle Refrigerant processes:
  - CB&I (C1 and N2 independent cycles);
  - Mustang OC-R (feed gas, open, refrigerant cycle).

While N2 cycles are preferred for lower capacity, they are not viably efficient for production higher than 20 t/d. The SMR options, instead, should only be considered for throughput higher than 400 t/d.

The main technologies are available for the cryogenic exchanger are the plate-fin heat exchanger and the coil wound heat exchanger. The pro’s and con’s of each of them are illustrated in Table 1.

Table 1 Cryogenic Heat Exchangers

Cryogenic Heat Exchanger	Pro’s	Con’s	Capacity Range (t/d)	Manufacturers
Plate-fin heat exchanger	• low cost per unit area • complex stream arrangement possible • readily available from many qualified suppliers	• expensive manifolding for larger pant capacities • limited acceptable temperature gradients	20 - 800	
Coil wound heat exchanger	• large heating surface per shell • tolerant against thermal shocks • good part load behaviour • fixing of single tube leakages within moderate	• proprietary equipment • only one shell side stream possible	> 400	

	down time			

Three main types of compressors can be considered within the small scale liquefaction plant: reciprocating, screw type and centrifugal. The main characteristics and capacity range are illustrated in

Table 2 Compressors types for small scale applications

Compressor Type	Characteristics	Capacity Range (t/d)
Reciprocating	• Inexpensive • Small capacity • Reduced availability	<20
Screw Type	• Insensitive to composition • Medium capacity • High reliability	20-100
Centrifugal	• Optionally integrally geared • Medium to large capacity • High reliability	20-3000

In terms of compressor drivers, the alternatives are electric motors, steam turbines and gas turbines. They differ mainly in terms of optimal capacity range, but also in terms of availability, tolerance to nitrogen content in the fuel gas. The main characteristics of each of these drivers are illustrated in

Table 3 Compressor Drivers Alternatives

Driver Type	Characteristics	Capacity Range (t/d)
Electric motor	• Requires stable grid • May require NRU • High availability	20-3000
Steam turbine	• Good match in (coal) chemical plants with HRSGs • May require NRU • High availability	100-3000
Gas turbine	• First choice in remote areas • Sink for N2 rich fuel (max. 20-30 vol-% N2) • Reduced on-stream time (maintenance)	400-3000

Transportation

Small Regasification Terminals

Storage

BOG Management

Safety, standards and regulations

Outlook and Conclusions (challenges and way forward)

Conclusions and Trends

Acronyms

FLNG	Floating Liquefied Natural Gas
GHG	Green House Gas
IOC	International Oil Company
LCA	Life Cycle Analysis
LCNG	Liquefied to Compressed Natural Gas
LNG	Liquefied Natural Gas
LNGC	LNG Carrier
LPG	Liquefied Petroleum Gas
MR	Mixed Refrigerant
MTPA	Million Ton Per Annum
NGL	Natural Gas Liquids
ORV	Open Rack Vaporizer
PFHE	Plate Fin Heat Exchangers

Bibliography

Appendix 1. Study Group Members and Contributors