LNG FOR ALL TRANSPORTATION: READY, WILLING AND ABLE

Since the turn of the 21st century, LNG as a vehicle propulsion fuel of choice has been gaining popularity worldwide as IGU affiliated organisation NGV Global reports. **By Dr Jeffrey Seisler and David Perry**

Commercial trading of LNG began in 1964 and, for the next three decades, different visionary engineers created some innovative LNG proof-of-concept vehicles for on- and off-road applications.

But it wasn't until the dawn of the new century that LNG took hold as a legitimate fuel. NGV and LNG stakeholders became enthusiastic that LNG had a role to play as a cleaner, economical and viable fuel substitute for diesel. Today, there are new dedicated LNG gas engines for trucks with improved performance and drivability, an increasing number of LNG-powered and LNG-ready marine vessels, more and more small-scale LNG operations to support the fuelling infrastructure for on-road, off-road and marine transport, and more truck-loading facilities at LNG terminals.

Marc Buttler, Director of Application Innovation for Oil and Gas for Emerson, a supplier of LNG metering, and NGV Global Board Member sees the momentum continuing and extending further into rail applications. He also points out that China is experiencing extraordinary growth; Europe's LNG truck fleet and infrastructure is expanding; India's major oil companies are planning LNG corridors; and China and Russia are building a Pan-Eurasia LNG refuelling network.

Lars Mårtensson, Director Environment and Innovation at Volvo Trucks agrees with Buttler: "Our vision for gas is that it will be the major fuel alternative to diesel. We see globally a shift from diesel/oil towards gas not only for road transport but in many transport and industry sectors. There is also a very positive momentum from the energy sector with investments in production and filling stations. And, in the end, a great interest from customers who look for alternatives to diesel and think LNG is the best solution."

LNG-fuelled trucks, such as Volvo's FM, allow transport operators to take big steps towards sustainable transport.

On the road with LNG

The heavy-duty transportation sector is expected to play an increasing role in the global economy. In Europe, natural gas fuelled trucks are being adopted as competitive alternatives to diesel, evidenced by growth from near zero four-to-five years ago to a fleet of nearly 4,000 LNG trucks today, reports NGV Global-affiliated association NGVA Europe.

LNG trucks are able to travel more than 1,600 km before refuelling from a network of 155 filling stations. Continued European Commission involvement and the greater availability of LNG through an expanding terminal infrastructure will, according to EU stakeholders, by 2030 lead to 2,000 LNG stations and 280,000 LNG trucks plying the roads of the EU.

Volvo's FH LNG and FM LNG heavy-duty trucks came onto the market in 2018. Their CO_2 emissions are 20-100% lower compared with diesel, depending on choice of fuel, allowing transport operators to take big steps towards sustainable transport. Powered by either a 420 or 460 hp engine the FH LNG and FM LNG deliver performance and productivity on a par with equivalent diesel Volvos. These LNG trucks join similar truck offerings from Daimler, IVECO and Scania, providing expanded choice, durability and range for freight movement across Europe.

Meanwhile, China is the hottest market for LNG with more stringent environmental policies providing increased motivation for acquiring NGVs. Some 350,000 LNG vehicles were operating in China by the end of 2017, refuelled from 3,100 stations. By the end of the 13th Five-Year Plan (2020) it is anticipated that the number of LNG-fuelled vehicles will reach about 700,000 units.

The major push for cleaner transportation in China has given rise to container trucks, in-transit cement mixers, dump trucks and buses as major applications in city environments, with port-related vehicles benefiting from ready access to LNG refuelling facilities.

Westport Fuel System's Nadège Leclercq, Director for Market Development in Europe, observes that even though China has the fastest growth of LNG as a fuel for the transport sector, Europe is also showing a number of positive growth signals: increased original equipment manufacturer (OEM) participation, expansion of the LNG refuelling network in many countries (e.g. Spain 39 stations, France 27, Netherlands 26, UK 13) and increased end-user demand, primarily driven by the retail sector, which is shifting to alternative fuels for sustainability and reduced emissions. It has been estimated that at least 40 LNG filling stations will be required to enable domestic transport of goods in Germany, up from the present four.

Leclercq is excited about the future for natural gas engine and associated

This Ural Next truck was one of the participants in the Gas Into Motors NGV rally which covered 9,887 km between Rudong in China and St Petersburg in Russia, September 4 to October 4, 2018.

Europe's LNG refuelling network is expanding – a station in Rotterdam.

technologies, which she says can be improved. Preliminary analysis indicates the Westport high pressure direct injection (HPDI) technology (the HPDI 2.0™ fuel system was launched in Europe in 2017) has the potential to achieve even greater CO_2 reduction by 2030 compared to current diesel powertrains, thanks to engine efficiency improvements. This progress will be enhanced by vehicle technology developments related to driveline efficiency, aerodynamics, tyres and other advances, in the same way as for a diesel truck.

Erik Postma, NGVA Europe's Technical and Regulatory Affairs Manager, draws attention to future developments in heavy-duty CNG/LNG engines that have been demonstrated in the Horizon 2020 HDGAS project (www.hdgas.eu). They show the potential to increase engine efficiencies by 10% compared to current state-of-the-art technologies. Integration of natural and renewable gas technologies in hybrid powertrain architectures on heavy-duty applications also has great potential.

Across the Atlantic, Todd Sloan, Senior Vice President, Innovation and Business Development at Agility Fuel Solutions (100% owned by Hexagon Composites), says the viability of LNG as a transport fuel in the North American heavy-duty market is dependent on several factors including commodity price (affected by the form of source gas in a particular region), vehicle architecture limitations, the status of infrastructure development and OEM product availability. Sloan does not see the pace of demand for LNG trucking in the US ramping up as in Europe and China. In the US, he says, the market appears to have stabilised on a preference for CNG as the optimal alternative to diesel.

Cummins Westport's range of 2018 natural gas engines includes the L9N and ISX12N which are the lowest certified NOx emission engines in North America. Suitable for regional haul truck/tractor, vocational and refuse applications, they are certified to EPA and CARB low NOx emissions standards of 0.02 g/bhp-hr, a 90% reduction from engines operating at the current EPA NOx limit of 0.2 g/bhp-hr.

As of 2018, the US had 140 LNG stations and 4,034 vehicles running on LNG. The LNG vehicle market is dominated by heavy-duty, refuse, transit and Class 8 trucks. The heaviest concentration of LNG stations is in southern California and along the major auto routes to/from adjacent states. There are also off-road mining and construction vehicles running on LNG.

On the seas with LNG

The regulatory shot across the bow for the maritime industry that opened the door for LNG came in 1997 with a new Annex (VI) to the International Convention on the Prevention of Pollution from Ships (MARPOL) adopted by the International Maritime Organisation (IMO). Annex VI came into force in 2005 and as regards NOx and SOx emission limits:

- Tier I NOx emission regulations were retroactively applied to ships built after January 1, 2000; Tier II came into effect in 2011; and Tier III in 2016, with limits

categorised by diesel engine power output.

- IMO regulations for SOx emissions from ships first came into force in 2005. From January 1, 2020, the sulphur cap for diesel fuel oil used on board ships operating outside designated Emission Control Areas (ECAs) will be reduced to 0.5% m/m (mass by mass).
- Even more stringent requirements apply in Sulphur Emissions Control Areas (SECAs) in the Baltic, North Sea and on the coasts of the US and Canada, where vessels operate within a sulphur limit of 0.1%. A Mediterranean ECA/SECA is proposed for 2020 and coastal areas in other parts of the world (e.g. Japan, Central America) could follow in future.

IMO has also targeted a 50% reduction of CO_2 emissions by 2050, all good news for LNG in the maritime sector.

In 1999, the Norwegian company Marintek designed and launched the Glutra, the first passenger and car ferry to run on LNG. Since then, embracing LNG as a marine fuel has led to vigorous economic activity for shipbuilders, ship owners and operators, bunker suppliers and port authorities. DNV GL's Alternative Fuels Insight (AFI) platform reports that as of January 2019 there were 144 LNG-fuelled vessels in operation and 138 on order; 282 in total. Additionally, there are 139 LNG-ready vessels, designed to accommodate LNG retrofit systems.

Car/passenger ferries and offshore supply vessels dominate the LNG shipping fleet with 37 and 22 vessels in operation respectively.

Given that ships take years to plan and build and will be in service for decades, the growth for LNG in ships is dramatic. Despite other fuel and technology options, LNG will play a significant if not dominant role in the worldwide shipping industry into the future.

As of August 2018, DNV GL reported 69 locations worldwide that supply LNG for seagoing vessels. "Building approvals" and "under discussion facilities" each equated to about the same number, thereby potentially tripling bunkering infrastructure sites. The count includes local storages, bunker ship loading facilities and truck loading facilities (locations with multiple bunkering modes/facilities are counted as one).

Europe

In Europe, LNG was prohibited by the Central Commission for Navigation on the Rhine (CCNR) from being used on inland waterways until 2012 when Shell received an exemption to operate one of the first inland waterway LNG ships, the *Argonon*. CCNR regulations for truck-to-ship bunkering came into force in 2016 so more LNG ships are sure to follow as the fuelling infrastructure expands.

The French liner service operator CMA CGM has specified dual-fuel engines for nine new 22,000 TEU container ships, which will be propelled by the largest gas-burning engines ever built and fitted with 18,600 m^3 bunker tanks. They will be delivered between the turn of the year and the end of 2020, and will be the largest ships that are not LNG carriers to be powered by LNG. Their size means the loss of cargo

Kairos is currently the largest (7,500m³) in a growing fleet of LNG bunker vessels and commenced operations in the Baltic Sea in December 2018.

AIDAnova entered service in December 2018 and is the first cruise ship to use LNG at sea.

space for LNG tanks is minimised to a 1% penalty. They will be served by a purpose-built LNG bunker vessel (operated by Total Marine Fuels Global Solutions) with a capacity of 18,600 m³ – three times the size of the largest LNG bunker vessel currently in service.

China

Unconfirmed reports suggest more than 280 LNG vessels traverse China's rivers, and more are coming. China's first LNG-powered passenger ship began sailing out of Zixing City in Hunan Province in late 2017.

The Chinese Ministry of Transport has extended Domestic Emission Control Areas (DECAs) to include all coastal waters and inland waterways. A new regulation, issued on November 30, 2018, states that:

- From January 1, 2019, the sulphur cap for sea-going vessels operating in the DECAs should not exceed 0.5% m/m.
- From January 1, 2020, the sulphur cap for sea-going vessels reduces to 0.1% m/m when operating in the inland river emission control area.
- From January 1, 2022, for sea-going vessels the sulphur cap is set at 0.1% m/m when operating in the coastal emission control area in Hainan waters.
- The sulphur cap for sea-going vessels when operating in the coastal emission control area on and after January 1, 2025 is the subject of a feasibility study but is likely to be set a 0.1% m/m.

India

The Indian Register of Shipping (IRClass) expanded its Rules in 2017 to embrace LNG-fuelled coastal and inland vessels, anticipating the introduction of cleaner transportation on India's inland waterways as part of the government's push toward a gas-based economy.

Germany

Carnival Corporation's AIDA Cruises, based in Germany, introduced its $1.1 billion LNG-fuelled *AIDAnova* into service in December 2018. Some of AIDA's other ships have dual-fuel engines allowing them to use LNG in port, but *AIDAnova* is the world's first cruise ship to use LNG at sea. The 183,900 GRT vessel will soon be joined by 31 more ships, elevating cruise ships to the second largest of DNV GL's tracked vessel categories.

Russia

Sovcomflot, Russia's largest shipping company, is gradually switching its tanker fleet from heavy fuel oil to LNG. The first of six to be ordered, Gagarin

Prospect is the world's first operational LNG-fuelled Aframax crude oil tanker, completing her maiden voyage in October 2018.

Standards promote safety and legitimacy

ISO standards for marine applications and bunkering have been published or are under development. In January 2016, the DNV GL "Gas Fuelled Ship Installation" rules came into force as well as a DNV classification for "Gas Ready" ships; those that can be retrofitted to run on LNG/dual-fuel. The Society of International Gas Carrier and Terminal Operators (SIGTTO), the Society for Gas as a Marine Fuel (SGMF) and other international and national organisations are also preparing a variety of LNG safety standards, guidelines and best practices related to ships, storage and fuelling. This will provide the additional legitimacy that LNG at sea is a safe, economical and environmentally friendly option to dirty marine fuel oil.

LNG on the rails

Railway industry visionaries in various parts of the world have also been looking at the potential for LNG to replace diesel since the 1990s. But there is no regulatory framework in any region globally that formally and specifically allows LNG-fuelled engines, transport and fuelling infrastructures outside of experimental testing, demonstrations or exemptions. Currently, regulatory authorities in various countries – the US and India being two – are evaluating the development of regulations that could open the sector for LNG.

Gagarin Prospect is the first LNG-fuelled Aframax crude oil tanker.

- Russia has been very active in this sector over the past few years. In 2018, Russian Railways announced plans to increase the fleet of gas turbine locomotives and shunters powered by LNG from three to 22 units by 2023. The locomotives will operate on the Sverdlovsk Railway. Gazprom and Sinara-Transport Machines (STM) have entered into a contract whereby Gazpromtrans (a subsidiary of PJSC Gazprom) will acquire 24 LNG-fuelled shunting locomotives.
- The European Commission Connecting Europe Facility (CEF) approved funding for *LNGHIVE2: Infrastructure and Logistics Solutions* – a project coordinated by Enagás, which aims to boost the use of LNG as a fuel for maritime and rail transport.
- The first tests in the EU of a train powered by LNG got underway in the province of Asturias in Spain in January 2018. The aim of the project is to analyse the potential environmental and economic advantages that natural gas can provide in rail transport using non-electrified lines.
- Canadian National Railway Company (CN) tested dual-fuel LNG trains in 2015 with EMD locomotives and tender cars supplied by Westport.
- Florida East Coast Railway has been operating on LNG since late 2015 and completed the conversion of its entire mainline thru-haul fleet to run on LNG in 2017.
- Indonesia's oil and gas corporation PT Pertamina (Persero) and railway company PT Kereta Api Indonesia (KAI), both state-owned, began testing LNG in late 2016.

Spain's LNG rail trial is led by national operator Renfe working with Naturgy, Enagás and Alstom Ventos.

A completely new fuel delivery infrastructure for LNG will have to be created to serve the railway sector. This will represent similar challenges as the railway industry experienced when making the transformation from steam engines to diesel. But the economic rewards for the gas and railway industries would be enormous, as would the clean air and climate benefits.

LNG with wings

In 1983, a Russian helicopter demonstrated the first airborne potential for LNG. In January 1989, following its maiden flight on hydrogen in April 1988, the Tupolev Tu-155 became an airborne LNG "laboratory", making a total of 70 European flights in its lifetime. Its range was 2,600 km. Since the turn of the 21st century other LNG airborne concepts have been envisioned by respected companies and institutions such as Boeing, the US National Aeronautics and Space Administration (NASA) and the Russian Space Agency, Roscosmos.

LNG-fuelled air transport could be a commercial reality but not in the near future. When LNG in the other transportation sectors achieves the status of a "fuel alternative" and not just an "alternative fuel", and the safety realities and perceptions are resolved in a regulatory framework, there should not be technical barriers to seeing commercially available LNG-fuelled aircraft. In the meantime, LNG aircraft technology roadmaps are on the radar screen of some governments and aircraft industries.

LNG policy drivers

The EU proposed its first CO_2 regulations for heavy-duty vehicles in May 2018, with ambitious targets for 2025 and 2030. The new regulation, which employs a calculation tool to declare CO_2 and fuel consumption, is likely to boost the deployment of all solutions that can reduce CO_2 emissions from trucks, including natural gas.

Volvo welcomes the new legislation. "Heavy-duty trucks account for roughly 5% of CO_2 emissions in Europe. This will need to be reduced if the EU is to meet its climate goal of reducing greenhouse gas emissions from transport by 30% by 2030 (compared to 2005 levels)," Mårtensson, looking to his end-users, states. "It will make it easier for our customers to select a fuel-efficient vehicle with lower CO_2."

NGVA Europe is working with its members and European partners to underline the importance of natural and renewable gas as viable solutions that can make an immediate contribution to decarbonisation and improve overall air quality. While the initial CO_2 emissions regulation proposal considered only exhaust emissions, NGVA Europe is also lobbying for the implementation of a specific methodology to account for the benefits of renewable fuels, which it views as a pragmatic, transparent contribution to a Well-to-Wheel (WTW) approach rather than just measuring exhaust emissions. This more holistic approach also tends to highlight the potential contribution of renewable methane, something that needs greater visibility.

From Emerson's perspective, one of the challenges to expanding LNG as a vehicle fuel has been legal metrology, since the composition and, thus, the energy content is variable. Methods to accurately measure quantities that can

be trusted by both parties in any transaction are essential for confidence in the market place. This need for trust becomes ever greater as the market grows to encompass more and more participants and transactions of all sizes. Emerson's Coriolis flow meters offer the ideal solution for metering LNG because they can measure mass directly and accurately at cryogenic temperatures. Pairs of meters are used to measure both the liquid LNG sold and the LNG vapour returned to the system.

Legal metrology standards continue to be developed globally to address point-of-sale issues (e.g. the International Organisation of Legal Metrology (OIML) is adding an annex on LNG to its recommendation for dynamic measuring systems for liquids other than water (R-117).

Despite all the positive developments, challenges remain. LNG tends to be considered as a bridge fuel rather than a long-term solution to decarbonise the transport sector. The viability of a large transition to renewable gas in this sector needs to be made more visible, particularly with regards to economics and feedstock availability, but also the related environmental and social benefits of this "circular economy option" compared to other "clean mobility" solutions.

The May 2016 industry report "Game Changer: Next Generation Heavy-Duty Natural Gas Engines Fuelled by Renewable Natural Gas" by Gladstein, Neandross and Associates notes that while the potential for renewable gas is large, there are still significant barriers to overcome. A combination of incentives, public and private investments, and new or amended regulations will be needed to materially increase the use of organic waste streams to produce the large volumes of renewable gas fuel needed in the transport sector.

Leclercq observes that despite this lack of clarity on the long-term relevance of LNG and bio-LNG as a vehicle fuel, the number of European users who believe and invest in this solution keeps increasing.

In addition to the need for a WTW approach, NGVA Europe's Postma also finds the uncertainty associated with excise duty among EU countries to be a deterrent to market growth. One European country increased excise duty on LNG recently without warning. Permit handling for LNG infrastructure deployment should also become more streamlined, he adds.

Conclusion

There is little doubt that LNG will command an increasingly important role as a transport fuel. Despite challenges associated with overcoming the "chicken and egg" syndrome – simultaneously providing fuelling infrastructures compatible with the growth of new LNG vehicles – the favourable economics coupled with its environmental advantages will help lead the renaissance in the use of natural gas as a fuel alternative to petroleum.

"Today, LNG is an effective and available partner in the drive toward cleaner mobility. Tomorrow's possibilities are extraordinary," says Brandon Grote, Chairman of the Board for NGV Global and Transportation Market Manager at Swagelok. "The abundance of natural gas, the rising tide of renewable natural gas and the continued technological advancements that further improve the already positive environmental benefits are helping to set LNG apart as a market leader in transportation fuel use for the future.

"NGV Global acknowledges all leaders of growth in this increasingly diverse industry. The continued investments into the world's LNG infrastructure and technology are pivotal in growing the future downstream demand for LNG as a transportation fuel. For all industry stakeholders – OEMs, suppliers of equipment or gas and end-users – now is a great time to be involved in the natural gas industry," Grote concludes.

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