



FINAL RESULTS
CRITICAL ISSUES STRATEGIC PLAN

LNG IS HOT:
OPPORTUNITIES, CHALLENGES & STRATEGIES AS A VEHICLE FUEL
3-4 December 2009
Brussels, Belgium

Sixty-six experts and specialists representing the interests of liquefied natural gas (LNG) and liquefied natural gas vehicles (L-NGVs) from 18 countries and four continents met in Brussels at the Clean Fuels Consulting Critical Issues Workshop, *LNG is HOT* on 3-4 December 2009 to discuss critical issues and strategies to improve the market opportunities for LNG as a vehicle fuel. Participants from the natural gas industry, government, equipment suppliers, consultants and related stakeholders engaged in two-half days of active dialogue that resulted in substantive findings, conclusions and strategic recommendations about worldwide L-NGV markets, technologies and politics.

L-NGV Benefits are clear

- *Economics: Generally LNG is at least 30-35% cheaper than diesel.*
 - The competitive price of oil most strongly influences LNG economics. Higher priced oil makes LNG increasingly competitive.
 - Low natural gas prices make LNG less competitive and can drive customers to compressed natural gas (CNG) vehicle applications.
- *Environment: LNG enjoys the same low emission advantages as CNG and biomethane.*
 - No particulates in dedicated NG engines; dual fuel systems will improve upon existing diesel emissions clean-up technologies;
 - Very low CO and significant NOx reductions;
 - Greenhouse gas reductions of 5-85%.
- *Security of supply will strengthen because of LNG trading.*
 - Worldwide trade in liquefied natural gas (LNG) is anticipated to triple from its 2002 levels to 2030, to over 700 billion cubic meters (bcm).
- *L-NGV technology is increasingly available with factory-built and retrofit (dual fuel) options.* Though not yet as prevalent as NGVs running on CNG, a wider range of vehicle types running on LNG are available in different worldwide markets.
- *LNG provides better range for vehicles than CNG.* LNG contains about 60% of the energy value of diesel in the same volume tank whereas CNG is only 30% of diesel's energy

content. Range is an issue for both fuels so LNG has an advantage over CNG, especially for heavy duty vehicles and vehicles with large fuel capacities (like ships and trains).

LNG Fuel Markets: Differs by region but the supply will be strong

- About one-quarter-to-one-third of the possible 700 billion cubic meter (bcm) world trade and LNG demand will be attributed to the broad Asia-Pacific region. Nearly 100% of natural gas consumed in Korea and Japan arrives as LNG. Production capability in Australia and other countries in the region is growing.
- In Europe there are 11 new LNG terminals under construction across the region, which will double the existing number of terminals over the next decade. As countries build more receiving terminals and re-gasification plants, an increasing portion of the LNG demand will be from the vehicle sector, particularly for larger, over-the-road transport vehicles in areas where the fuel is readily available.
- Existing terminals in North America currently are under-utilized due to the low price of natural gas.
- South American NGV activity should benefit as LNG becomes more widely available.
- Liquefied, renewable biomethane offers a local fuel distribution option but is likely to remain a “niche within a niche within a niche” (NGVs are a niche in the petroleum vehicle market; LNG is a niche inside NGVs/CNG; liquefied biomethane is a niche within that niche.)

L-NGV Availability: OEMs and retrofits in search of customers

- In North America two heavy duty engines principally are available in a wide range of vehicles and vehicle body configurations. The varied range of vehicle options provides almost too wide a choice for customers and presents a greater challenge to enlist new OEMs to create increasingly differentiated products.
- The Asia-Pacific region has abundant new models of L-NGVs, especially in China, Korea and Japan.
- European OEMs must be convinced by LNG stakeholders who reach out to customers that LNG products are viable for specific heavy duty engine & vehicle markets (on-road & off-road).
- Dual fuel LNG engines will provide a distinctive option, particularly for long-haul trucks that can take advantage of greater steady-state drive-cycle operation that lends itself to improved diesel fuel replacement, better economics for the customers, and less harm to the environment.
- Different LNG engines function more effectively when the LNG is delivered to on-board storage tanks at slightly different temperatures and pressures. Harmonization of the fuel requirements for L-NGVs and LNG engines will continue to be an issue. (See below: Fuelling Infrastructure)

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Fuelling Infrastructure: Keep options open (large & small) but keep it simple

Creating the ideal LNG fuelling station is complex, expensive, and requires relatively long lead time to construct and to have approved. Large stations can serve hundreds of vehicles. Small stations, including those that deliver liquefied and/or compressed natural gas (L-CNG) add to the versatility of using the fuel. But the physical properties of LNG pose a number of special challenges.

- Gaseous methane liquefies at atmospheric pressure when it is cooled to -162° (C) [-259.6° (F)]. LNG is stored in specially designed vacuum insulated tanks in order to keep it cold when in transit, stored at the fuelling station, or on-board the vehicle. But at each step LNG absorbs a certain amount of heat, which causes the temperature and pressure to increase over time. This may require some gas to be vented or re-liquefied in order to remain within the pressure limits of the storage tank. At -130° (C) it is stored at 8 bar (120 psi), which is typical for an LNG vehicle fuel tank. At this temperature and pressure the gas and liquid phases are in equilibrium.
- At its lowest temperature (-162° C) LNG has more energy density than warmer LNG, therefore, if it can be stored on-board the vehicle at lower temperatures and pressures, the range of the vehicle will be greater.
- On the other hand, many LNG engines require gas at higher pressures in order to increase efficiency and performance. Thus, it is a challenge to store the fuel on-board the vehicle at the optimum conditions to maximize range.

Stakeholders at the workshop (and in subsequent correspondence) debated the costs and benefits of using the coldest possible, lower pressure LNG versus warmer, higher pressure LNG but with little final resolution.

"It will be very difficult to agree on uniform conditions in station tanks, fill pressures, filling techniques or even on holding times. Thus, more intelligent fuel dispensers must be designed that can recognize the type of on-board tank, the required condition of the LNG, measure the pressure in the tank before refuelling, determine venting requirements and then fill the tank with liquid that is conditioned during or prior to the filling process to meet the required post-fill conditions on-board the vehicle.

Dispensing uniform "cold" LNG from the station could have benefits, but is it realistically achievable given the various sources of LNG, the different transport modes, the various stages of handling prior to it arriving at the fuelling station and the handling in the station itself? Additional refrigeration may be needed and this adds unnecessarily to the cost and complication of the system.

There is a cost involved in having LNG in the station tank at 3 bar rather than, for example, 8 bar. This cost can be incurred at the liquefaction plant or somewhere else along the delivery chain in the form of either additional refrigeration (which increases energy consumption) or through vaporization of some of the LNG. Tank costs can be less by keeping the pressure to 3 bar

but these savings are offset by the cost of producing the colder liquid.” (Brenda Smith, Gas Advisers)

Many issues need attention & resolution

Some gas industry stakeholders stressed the need for simplification of LNG systems: two pressures and temperatures; two fuelling connectors; too expensive; too complicated. Many of the issues relate to standardization and harmonization of existing standards and, in the longer run, regulations.

- International, harmonized standards and ultimately regulations are needed for LNG fuelling stations and fuel storage. National ‘models’ are available but worldwide harmonization must be the ultimate goal (to the best extent possible and sooner than later!)
- A standard LNG temperature and pressure requirement for the vehicles should be established.
- Define a standard vehicle tank whether it is single nozzle (no vapor recovery) or a dual nozzle (vapor recovery possible).
- Standardize and harmonize the fuelling nozzles (on the dispenser) and receptacles (on the vehicle). Currently there are two principal models of connectors.
- Define standard fuel quality requirements for LNG.
- Harmonize fuel measurement units (kilograms vs. cubic meters, standard cubic feet, etc.)
- Liquefaction of natural gas removes any odorant, thus methane detectors are needed to monitor possible gas leakage.

A Strategic Roadmap for LNG: Actions required to move the sector forward

Developed from a synthesis of the presentations, comments and discussion at the LNG is HOT workshop (including subsequent email correspondence on specific issues), the following conclusions and recommendations have been identified by the L-NGV stakeholders as the most critical elements to move the L-NGV market forward.

- *International standards are moving forward but need more expert stakeholder involvement.* LNG stakeholders and companies need to support their experts to participate in critical International Standards Organization (ISO) standards efforts for vehicles, fuelling connectors, fuel storage, fuel quality, and fuelling station development, among others. Worldwide harmonization of standards and regulations must be achieved.
- *Support from fuel suppliers remains fragmented and should be harnessed.* Traditional gas suppliers focus on re-gasification of LNG into the pipeline network. They like the ‘big pipe’ customers --gaseous and liquefied—such as power plants and large industry-sector consumers. But if there is an adequate and sustainable source (or storage) of LNG, natural gas companies should be encouraging customers in the vicinity of the LNG facilities to consider the L-NGV option (the ‘low hanging fruit’ of the marketing tree). Industrial gas suppliers are more accustomed to distributing LNG via over-the-road

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- haulage and they could gain advantage from supplying LNG to even a limited number of LNG and L-CNG fuel stations.
- *Over-the-road trucks and heavy duty urban vehicles are the priority L-NGV markets.* When the OEMs understand there is a market for L-NGVs and LNG engines the products can come to the market fairly rapidly, as they are in some regions.
 - Along with heavy duty over-the-road transport trucking, important L-NGV markets also can be found in urban buses and garbage/refuse vehicles.
 - Marine applications are a very 'interesting' potential second market due to the huge amount of fuel consumed and a need for much cleaner diesel (especially after new UN rules on marine fuel quality enter into effect). Multiple partnerships with LNG providers, shippers, terminals and port authorities should become a prime marketing opportunity.
 - Railway applications should not be overlooked as a third tier market but saturation of electric locomotive engines in some markets (i.e. Europe) will be more challenging whereas diesel-driven railway markets (US/Asia) could see major market breakthroughs for these very fuel-intensive vehicles.
 - *Government support, particularly R&D, is needed to address things such as fuelling issues, dual fuel engine technologies and expansion of off-road applications.*
 - Governments tend to view LNG as a security of supply option but generally are not focused on the specific L-NGV market or technologies.
 - Government R&D for L-NGVs generally does not exist, suffering from the tendency to support longer-range technologies and not focusing on what fuels and technologies are needed to bridge the gap between today and future visions of fuel use in the transportation sector.
 - The European Commission has supported through specific funded projects the development of marine applications and may be interested in doing more.
 - The US market for LNG will benefit from incentives for alternative fuels.
 - More focused NGV industry advocacy is required at national, regional and international levels to bring attention to the environmental, climate and energy security benefits of replacing heavy diesel fuel with clean LNG. This includes activities with the International Maritime Organization (IMO), part of the United Nations, to advocate LNG as a maritime fuel serving ships, which will be required to use cleaner fuels, and to look at opportunities in seaport operations, including trucks that serve these facilities.
 - *Communications – to government, the gas industry, but particularly to key customers – will be critical in the uptake of L-NGVs.* The benefits of LNG should be linked with CNG and biomethane to demonstrate the diversity of natural gas applications across the full gamut of the transportation sector including, at some future time, the aviation sector. What is unknown is disliked; what is known will be liked.

The proceedings from **LNG is HOT** are available to anyone not attending the workshop by visiting the IANGV website at: <http://www.iangv.org/shop/142-lng-is-hot-critical-issues-workshop.html>. (€ 155). Participants at the workshop receive the proceedings as part of their registration fee, which can be downloaded by visiting www.LNGisHOT.org and going to 'proceedings.'

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