# MEDIUM SIZE LNG TECHNOLOGY ON PROGRESS

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## ABSTRACT

Large natural gas liquefiers and LNG (liquefied natural gas) tankers have been in service for decades, but most LNG is being evaporated and compressed into long distance pipelines.
Recently, we have witnessed growing trends of LNG applications directly at customer sites.
LNG has been widely used at off-pipeline energetic bases. A more advanced technological application is use of LNG directly as automotive fuel at LNG or LCNG stations. Both the technologies bring economic as well as environmental benefits.
Examples of this technology, like small liquefiers, road and railway tankers, large vacuum insulated storage tanks, off pipeline bases, car refueling stations, and car on-board cryogenic fuel tanks are presented in this paper, as well as regions, where this technology is being utilized.

## INTRODUCTION

Natural gas is one of the most important energy resources of the world economy. Unfortunately, most gas fields are located in regions other than those with the most concentrated energy consumption. Certain parts of the gas from the fields can be transported by gas pipelines under pressures of 50 bar or higher. Ocean transport technology for transporting liquefied gas between continents has been developed. Taleb (2002) recently published an overview of the current state of this technology. Since the first natural gas liquefaction plant was put in operation in Algeria in 1964, world LNG production has grown to 125 MMTPA in 2001, with an expected growth to 165 MMTPA by 2004. The LNG is being purified and liquefied at the gas fields, stored, transported by ocean tankers, and offloaded into huge storage tanks with capacities of one hundred millions liters or more. Currently, nearly all this LNG is being compressed by pumps to pipeline pressures, vaporized, and transported inland by transit pipelines. Steep growth of this technology continues as result of oil shortages, increased gas use, and environmental concerns. It is not our aim to further discuss this technology, but it must be mentioned to illustrate interrelations to this subject, medium sized LNG technology.
Medium sized LNG technology is based on direct use of LNG by the final customer or local distributor. Typical storage volumes at final user site are 10 to 1000 tons. There are several factors influencing the direct use of LNG:
Independence on pipeline using road tankers, local storage, vaporization, and distribution by customer or municipal pipeline network make gasification of living areas (small resorts, individual house, hotels, etc…) possible.
Gasification of geographically difficult to access consumption regions, can be accomplished by LNG sea barges.
Back-up for case of pipeline fallout for continuous processes in industrial plants.
Peak shaving installations can cover pipeline supply shortages during most cold winters.
LNG tanks are placed on board LNG powered vehicles.

## 1 LNG MEDIUM SIZE SOURCES AND USE

### 1.1 LNG sourcing directly from seashore terminals

There are few gas companies directly selling liquid from seashore terminals. The reason may be that direct sale LNG volume is minute when compared to the everyday business of supplying transit pipelines. But we are witnessing good progress in Spain, e.g., for energy and vehicle transport use. Energy conservation and market stagnation can make large gas companies diversify and enlarge their market to include direct sales of LNG.

### 1.2 Liquefiers at local gas sources

As the world's supply of fuel becomes depleted, use of small local sources becomes more potential. A closed cycle mixed refrigerant compressor and throttling cycle is typical of current liquefaction technology for these cases. An interesting attempt on the part of several U.S. companies was a liquefier project using heat from combustion of 30% of the gas to be liquefied and generating thermo-acoustic waves in helium filled volumes to generate liquefaction cold on the other end of a resonance tube. Liquefaction is the only method in which to extract gas from stranded wells, with potential capacity of tens to hundreds tons per day.

### 1.3 Liquefiers of gas from transit pipelines

For large liquefiers of this kind the mixed refrigerant cycle is also useable since the direct stream of reasonably pure gas is already compressed to a suitable pressure.

### 1.4 Liquefiers as part of gas pressure reduction stations

Reasonable quantities of LNG can be withdrawn, if the liquefier is combined with gas reduction station. This method may be used for production of LNG by just using the pressure energy of the gas to eliminate energy consumption. Using a simple Joule-Thompson cycle with liquefaction of 3 to 5% of the reduced gas e.g. and returning the rest to the lower pressure regional pipeline is the simplest and lowest investment option. This process, further upgraded by using vortex tube, is being used in Russia as referred to by Ryazanov (2002). Larger LNG recovery, 12% e.g., can be achieved by using expansion turbines. Prototype stations are being tested in California, where approximately 600 potential locations exist.

### 1.5 Liquefiers using available high-pressure compressors at CNG car refueling stations, e.g.

The system was presented by Ryazanov (2002) as well as Peredelskiy (2002). There are many existing CNG stations not fully used in Russia. Combining the existing compressor equipment with an additional Freon refrigerating system and liquefaction box allows 24 ton/day of LNG to be recovered with 28% liquefaction coefficient. Relatively high-energy consumption 0.7 to 0.8 kWh/kg LNG is compensated by lower investment cost, which is important when starting pilot projects.

### 1.6 Liquefier using Stirling cycle

The widely used Stirling cycle liquefiers, using helium as a working gas, were developed in Holland in the middle 20$^{th}$ century. Davydenko (2002) referred to a Russian modification for small scale LNG liquefaction with production of 0,24 to 3,6 ton/day of LNG, as a suitable source for vehicle fleets of up to 15 trucks. Without indicating energy consumption, the author claims excellent profitability of operation.

### 1.7 Liquefaction of LNG using cold of liquid nitrogen vaporization

This process links natural gas liquefaction closer to classic air gases cryogenics. This is advantageous for small liquefiers because of equipment simplicity. A further advantage is that it can operate intermittently on demand, producing LNG in as little as 15 minutes after startup. This is most effective at sites where liquid nitrogen is delivered for continuous vaporization to be used by certain nitrogen-application processes. Recently, this liquefier was customized as packaged unit for standard design.

## 2 TYPICAL MEDIUM SIZE LNG USE

### 2.1 Municipal heating and electricity companies

Both environmental and fiscal factors are encouraging towns to convert their energy systems from oil or propane to natural gas. If such a town is distant from gas pipelines, and especially if there are geographical limitations not permitting building of such a pipeline, the only economic solution is liquefied natural gas. Combined production of heat and electricity is the most economical way of use of gas. As example, Jackson Hole, Wyoming, is using 15 million liters of LNG per year.

LNG back-up systems can be used in areas supplied normally by a pipeline, if the pipeline capacity is not sufficient to supply peak demands or to prevent penalties for excess gas consumption.

### 2.2 Industrial process companies

Some process plants depend on continuous supply of gas to keep glass or metallic bulk process in liquid state, e.g. Not only does the full LNG supply finds its use there, but LNG back-up systems can be combined with pipeline delivery to allow reasonable shut down time of production process if there is a pipeline failure. Similarly, LNG back-up can be used for emergency electric power generation if environmental regulations mandate a low emission generating system. Paul *at all*, 2000, reported on such a system at Greenville, NC, where two 200,000 liter LNG storage tanks supply natural gas for a 13 150 Nm3/hr send out system.

### 2.3 Transport companies

There are several benefits supporting use of natural gas for transport. Engine emissions and noise reduction are the most important. Economy of the use depends on government tax policies, so the economical benefits vary between countries. Compressed natural gas technology (CNG), based on 200 to 300 bar fuel cylinders achieved quite successful range of use. Relatively younger direct **LNG on board technology**, with approximately 4000 vehicles world wide , recognized steep growth after the year 2000 thanks to tested technology and the benefits of smaller weight and volume fuel tanks. LNG availability has limited the progress, but many new projects are being considered. Some companies are going to convert their existing CNG fleets to LNG, as done in El Paso, or LCNG (a relatively easy change). Municipal fleets and fixed route fleets are typical for this period of developing infrastructure. The next period will be characterized by building gas-refueling stations along various motorways (Green Corridors in USA and Blue Corridors in Europe).
Not only road, but also sea is an area of LNG application. Sea shuttle-barges operating on fixed routes (ferries, supply boats) covering their needs from a single re-fueling station are the first step. The second one would be, after more re-fueling stations would be built in larger regions.
**LCNG stations** are a transitional step in situation, when LNG is already available for vehicle fueling, while fleets of CNG vehicles are still in operation. LNG is compressed by low energy low maintenance high-pressure liquid pumps, vaporized, and dispensed into vehicle high-pressure cylinders.

## 3 ENERGY RELATIONS IN THE LNG SOURCE TO GAS USER CHAIN

There is lot of confusion concerning energy demands in the various steps of natural gas handling between the gas field source and the final gas user. Energy for liquefaction, gas compression, transport by vehicles or for pipeline, re-compression, vaporization, and other process steps must be addressed. It is impossible to understand total energy losses without analyzing the entire chain. Some examples are presented in the Table 1. The particular energy loss calculations are based on generally known engineering or typical references. All the energy needed is unified to methane consumption. If electricity is needed, methane consumption for production of that electricity was considered with 40% efficiency.
Thicker lines divide the table into three sections corresponding to long distance transport, middle distance transport, and vehicle fueling respectively.
When sub-totaling first two thirds, we get energy losses up to heating and similar stationary applications. It shows, that direct LNG distribution from sea shore terminals would save energy by avoiding losses of big vaporizers, while on consumer site, ambient air vaporizers are typically used with no energy penalty. But, this is not a rule and heated vaporizers may be preferred in cold climate regions.
Long-distance transports need nearly the same energy as the pipelines and ship systems for the indicated distance 4000 km. For longer distances ships require less energy than pipelines and vice versa.
Energy consumption at vaporization terminals can be reduced by liquid gas exergy utilization systems, as already in operation in Japan (Baudino *at all*, 2000).
Bold framed numbers deserve special attention as proof of effectiveness of LNG technology. These represent:
*Column C:* Liquid distributed from seashore terminal directly to LNG car re-fueling stations.
*Column G:* Liquid, distributed from reduction station liquefier directly to LNG car re-fueling stations.
All these conclusions can be challenged regarding specific site conditions. Because the differences are not large, investment, existing infrastructure, and logistical aspects may impact the final solution considerably. Regarding CNG stations: their locations are bound to pipelines, making it difficult to install them at the motorways. Longer fueling methods require more energy even when not considering operational comfort and lost time.

Table 1. Energy losses at the gas path from gas field to vehicle fueling

| **Process step** | **Energy (gas) consumption** | **Energy losses as part of the transported methane** | (Gas heat of combustion = 13,9 kWh/kg =100%) Losses of methane as primary energy needed for each process step. Abbreviations represent the value of relative losses of methane from the column in the left. They are totaled at the bottom line, then. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **kWh/kg** | **%** | ***A*** | ***B*** | ***C*** | ***D*** | ***E*** | ***F*** | ***G*** | ***H*** | ***J*** | ***K*** |
| Gas field LNG liquefaction | 1,370 | **9,86** | f. liq. | f. liq. | f. liq. | f. liq. | | | | | | |
| ship transport 4000 km distance | 0,156 | **1,13** | ship | | ship | ship | | | | | | |
| Gas field compression to transit pipeline | 0,581 | **4,18** | | | | | f.com. | f.com. | f.com. | f.com. | f.com. | f.com. |
| pipeline transport 4000 km | 0,951 | **6,85** | | | | | pipel. | pipel. | pipel. | pipel. | pipel. | pipel. |
| pump compr. & vaporiz. at a sea shore terminal | 0,292 | **2,10** | vapor. | | | | | | | | | |
| pipeline transport 500 km | 0,119 | **0,86** | pipel. | | | | | | | | | |
| road trailer 500 km | 0,233 | **1,68** | | road 5 | road 5 | road 5 | | | | | | |
| reduction | 0,008 | **0,06** | red. | | | | red. | red. | | | | |
| local liquefaction | 1,130 | **8,14** | | | | | | | | | loc.LNG | loc.LNG |
| LNG liquefaction at reduction station | 0,000 | **0,00** | | | | | | | LNG re. | LNG re. | | |
| road tanker 100 km | 0,050 | **0,36** | | | | | | | road 1 | road 1 | road 1 | road 1 |
| **SUBTOTAL ENERGY LOSSES FOR HEATING APPLICATIONS** | | | **14,0** | **11,5** | **12, 7** | **12, 7** | **11,1** | **11,1** | **11,4** | **11,4** | **19,5** | **19,5** |
| LNG station | 0,004 | **0,03** | | LNG | LNG | | | | LNG | | LNG | |
| CNG station from 3 bar pipel. | 0,748 | **5,39** | CNG | | | | CNG | CNG | | | | |
| LCNG station | 0,115 | **0,83** | | | | LCNG | | | | LCNG | | LCNG |
| travel to CNG station 5 km | | **1,00** | | | | | | travel | | | | |
| **TOTAL ENERGY LOSSES UP TO VEHICLES** | | **%** | **19,4** | **11,6** | **12,7** | **13,5** | **16,5** | **17,5** | **11,4** | **12,2** | **19,6** | **20,4** |

# 4 LNG MEDIUM SIZED APPLICATIONS AND POTENTIAL ACTIVITY REGIONS

## 4.1 Asia

Largest liquefaction capacity of all the continents (Middle East 21% and the rest 41% of world production in 2004 (Taleb, 2002)). Japan owns 23 LNG terminals (largest number per country). The Japanese overseas trade of LNG is more than half of the world total (Baudino *at all*, 2000). Other LNG importers are Korea and Taiwan. Densely populated Asian cities with big environmental problems have future potential for LNG vehicle transport. Ten large terminals to be built around the Indian shore will make possible gasification of interior not only by pipelines, but by off pipeline LNG installations and use of LNG and CNG vehicles. The Chinese government decided to put 20 000 natural gas buses, (probably LNG) until the Olympic games in 2008.

## 4.2 Europe:

**Using LNG directly from their LNG terminals:** Spain, both vehicle transport and energy centers. (Potentially: Portugal, Italy, France, Belgium, Greece, Turkey)
**Using LNG from their middle sized regional liquefiers:** Norway, Poland, Russia (all for energy centers, but planning vehicle transport projects, LNG driven ships operate in Norway)
**In the reach of LNG liquefiers existing and planned:** Finland (potentially: Sweden, Denmark, Holland),
**Countries with availability of clean, easy to liquefy gas:** Russia and all countries supplied by Russian natural gas (Ukraine, Byelorussia, Baltic states, Czech Rep., Poland, Hungary, Austria, northern Italy, Germany (partly)) and countries or regions, which use exclusively the gas, evaporated from seashore terminals.
**Countries with availability of high pressure gas wells:** (low or no energy consumption for liquefaction, if there is consumer of low pressure gas.**)**

## 4.3 USA:

California and Arizona: Government environmental protection policies are driving LNG application for transport. Long distances in both the municipal transport and long distance transport make LNG the preferred choice of alternative fuel.

Midlands: Local gas wells can improve national energy balance if used thanks to liquefaction technology.

### 4.4 South and Central America:

Argentina has the largest CNG vehicle population in the world. This and domestic sources of natural gas makes the conditions for starting use of LNG technology.
Mexico City has dramatic air pollution problems, which can be solved by use of natural gas for transport.

### 4.5 Australia:

LNG from Perth liquefier, one of the largest in the world, used for export only, will be used for fueling inland towns for both economical and environmental reasons. Flat country and long distances make conditions for use of trains of road tankers. Also smaller liquefiers are planned or operating.

### 4.6 Africa

Is the second largest liquefaction continent, but with no receiving terminal, so purely exporter. Export of LNG from Nigeria started in 2000. Great future in the transportation industry though.

## 5 TECHNOLOGY FOR MEDIUM SIZED LNG APPLICATIONS

### 5.1 Technology in general

LNG technology is very similar to that used for air gases, but low density of LNG and big volumes needed require specific approach for development of dedicated equipment. Although less flammable than Propane, LNG’s flammability and volatility may require special safety measures. The public sale of smaller LNG quantities requires safe and easy to use equipment and precise measurement dispensers. This brings new challenges to engineering and manufacturing of LNG technology. For traditional cryogenic equipment manufacturers it brings at the same time new opportunities of growth. The U.S. manufacturers have taken an active role developing small-scale consumer level technology for the past 10 years or more.

### 5.2 Storage of LNG

Middle size liquefiers of the range 100 ton/day, e.g, require storage sized 2 million liters (80 ton) for reasonable retention with expectations of later enlargement. This size of equipment was traditionally projected as low-pressure (500 mm water head, e.g.) **flat bottom tanks** with atmospheric pressure perlite insulation. Their operation is very sensitive to atmospheric pressure changes and with a danger of “roll-over”. This means that when the liquid is stored for longer time, the lower layers of liquid can become warmer than the upper, resulting in lower density. The same can be caused by filling the tank by various charges of liquid of different composition (ethane content, e.g.). Lighter lower layers cause instability of the tank content which can move the liquid into instant circulation. Mixing layers of various enthalpies would produce heat of mixing, resulting in sudden evaporation and consequent pressure increases, leading to possible destruction of the tanks. This, and breathing of the tank due to atmospheric pressure changes require sophisticated pressure control and continuous measurement of liquid concentration and temperature by samples traveling up and down inside the tank. This is required by EN 1473. Another disadvantage of flat bottom tanks is long lead-time of on site assembly and field mechanical testing. These tanks have cylindrical shells sensitive to earthquake and other ground movements like settlement, which require thick concrete basements with vented corridors between two layers of basement.
Progress of mechanical technology resulted in manufacturing of large shop manufactured **vacuum insulated tanks** of up to half million liters. Four such tanks can substitute one two million flat bottom tank for comparable or lower investment cost. Roll over is impossible in these tanks, which can be easily sized to 8 barg pressure (e.g.). This means, that any generation of heat mixing is compensated by small pressure increases inside the tank pressure vessel, which stops further evaporation. Two shells, inner pressure vessel and outer relatively thick vacuum sized vessel with evacuated insulation between both the vessels makes these tanks resistant to fire and other hazards. One fixed saddle and one slice saddle make the tank relatively independent from soil movement, thus well resistant to earthquake. High operating pressure makes possible large liquid discharge rates without any pump, while the tank pressure is maintained by a pressure build-up vaporizer (PBU). Recently, an LNG receiving terminal was contracted for Sunndalsora, Norway (operation scheduled for fourth quarter 2003) consisting of three vacuum insulated tanks of total capacity 1.5 million liters, to serve as gas source for an aluminum foundry. LNG will be delivered by an LNG carrier ship with capacity of one million liters and transferred to these storage tanks by pump.

Fig.1. Vacuum insulated tank 403 m3

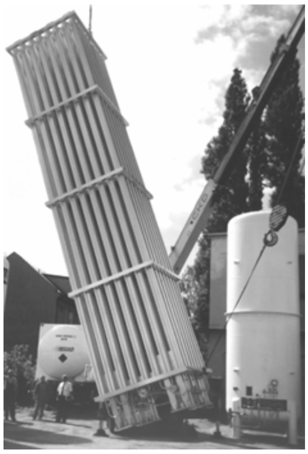

Fig.2. Ambient vaporizer of LNG 40t/d.

## 5.3 Vaporizers

Function of the vaporization can be best explained on the example of the above-described project. Liquid will be discharged to switching sets of ambient air vaporizers, which can provide long time service without any energy consumption, if the weather conditions are sufficient to prevent their loading up by ice, or a water bath vaporizer, which can work independently from weather, but 2% of the vaporized gas gets consumed by burners heating the water bath. Other means of vaporization – direct fired, steam, seawater etc. can be used as site conditions permit.

## 5.4 Transport means of LNG


Fig. 3. LNG road semitrailer


Fig 4. LNG delivery unit


Fig. 5. LNG rail car 76 000 liters


Fig.6. LNG driven locomotive

**Rail cars:** Can be sized up to 100 m3 and combined into trains, representing the largest ground transport capacity after the pipelines

**Road tankers:** Thanks to LNG density, which makes half of density of liquid nitrogen, the semitrailer volume can be much larger and is limited more by maximum allowed assembly length and width than by weight. Maximum capacity vacuum super-insulated semitrailer with gross volume of 56 000 liters was manufactured for operation in Norway.

**ISO containers:** This is another lower volume and lower cost means of transporting LNG. A 20 feet container has a 20 m3 gross volume. After several years of experience in USA, the manufacturing was started in Europe. Application of European norms ADR and TPED makes it possible to increase pressure of the same product from 10 bar to 18 bar.

**Delivery units:** Various kinds of smaller transport containers can be mounted onto frames of trucks. Typical truck tankers have a rigid vacuum-insulated tank with a volume of 13 000 liters. These units are generally equipped with an incorporated submerged pump for rapid offloading and delivery.

# 6 LNG VEHICLE SYSTEMS

## 6.1 Car re-fueling stations

**LNG stations:** The main principle of the LNG re-fueling station is similar to that of a petrol station, but cryogenic nature of the fuel sets several challenges to the design and operation. Most frequently LNG is distributed at a temperature close to saturation at atmospheric pressure (normal boiling point). The liquid has to be heated so that the engine regulator required pressure would be maintained in the vehicle tank. Warming can be done in the storage tank or during fueling by “saturation-on-the-fly” sophisticated computer controls. The liquid is warmed up to temperatures, corresponding to saturation pressure 3 to 8 bar, depending on the engines of the fleet served. Re-fueling pump has a typical capacity of 190 liters/min (50 gal/min). This makes the speed of truck fueling equivalent or higher to petrol car fueling. The dispenser contains a composition analyzer and a cryogenic flowmeter that are immersed in the cryogenic liquid, ensuring constant conditions of measurement. These dispensers are tested and certified for public sale of LNG in the USA.

**LCNG stations:** Because there are many CNG vehicles in operation, LCNG stations were developed to support their operation by lower cost technology, more flexible possibilities of installation, and lower operating costs. The assembly of LCNG station consists of the LNG storage tank, the content of which in this case does not have to be saturated. A high-pressure piston pump delivers the liquid to a pressure up to 300 barg with minimum energy consumption compared to CNG compressor. The LNG is vaporized in a vaporizer to the ambient temperature and stored in buffer cylinder storage for quick dispensing to car fuel cylinders. Odorizers are used to inject odorant into the vaporized gas, complying with safety requirements on board. In some cases, odorizers are not used when vehicles have on board methane detection.

**Box designs:** For smaller sizes of both the LNG and LCNG station “Black Box” and “Gas Box” compact designs were developed with all the station equipment including the storage tank located inside a standard ISO container box. This makes these stations easy to install and move.

**Underground designs:** In urban areas, underground placing of station tanks may be required for space economy and architectural requirements. Such tanks are designed to be buried in the sand. The outer vacuum shell of these tanks must withstand higher overpressure than normal cryogenic tanks and a proper water and cold resistant protection layer is needed.

Fig. 7. Car refueling station


Fig. 8. LNG driven truck

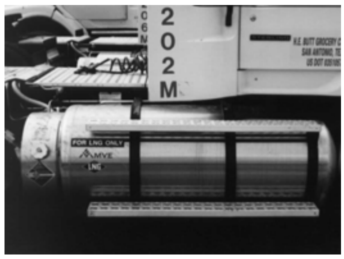


Fig. 9. LNG fuel tank

## 6.2 On-board fuel tanks and accessories

LNG from the fuel tank is drawn through a vaporizer, where it is warmed up by the engine coolant. Then it flows through a regulator to the engine. If the pressure in the fuel tank gets elevated by heat leak through insulation, gas from the vapor space is withdrawn preferably by the economizer regulator and injected into the liquid flow in front of the vaporizer. Vehicle fuel tanks are manufactured in standard sizes from 60 to 750 liters. One liter LNG corresponds to approximately 0.6 liters of diesel. Double wall superinsulated fuel tanks with both the inner and outer austenitic steel shells are extremely resistant to damage due to accidents.

## 6.3 Types of vehicles

**Heavy trucks, coaches and busses** are best candidates for conversion to LNG because of their nearly continuous operation, which brings maximum economical and environmental effect. **Municipal utility vehicles**, especially waste compactors and cleaning cars, bring double effect when converted to LNG, because their fuel consumption is increased by the work done during traveling and they operate in the most populated living areas. **Vans, personal cars** of continuous service such as taxis, police and other single location bound service vehicles may also create prospective market for LNG powered vehicles. There are other types of vehicles powered by LNG. Besides ships, **airplanes** are interesting means of transport where LNG may be a very economical alternative. Kunis (2002) referred to a Russian project to build 50 airplanes TU 204 (132 to 210 passengers) to be set for operation in the period between 2007 and 2017. Every plane will have a 23-ton LNG fuel charge and a 5-ton emergency kerosene back up. **Rail and station servicing locomotives** may potentially create another market for LNG use since they also consume large amounts of fuel. LNG driven **ships** are in operation and under construction in Norway.

### 6.4 Size of future operation

In the year 2002 natural gas vehicle fueling got new dimensions by the USA Clean Act. The European Commission announced their intention to implement directive for substituting of 20% of oil borne fuels with alternative fuels, half of it presumed to be natural gas. 23 million vehicles are expected to operate in the year 2020 on gas in Europe. Additional 50 billions of Nm3/year of natural gas will be needed in Europe, which corresponds to the full capacity of the transit pipeline Russia-Czech Rep.-Germany, or to full operation of fifty ocean tankers size Methania 50 000 ton LNG. Because of advantages of LNG as described above, it can be presumed, that a large number of gas vehicles would be LNG powered.

## CONCLUSIONS

Middle size applications of LNG require specific equipment, which is currently available in a variety of scales and brands to support the upcoming boom of use. Critical point is starting organizational measures for the development of a LNG sourcing infrastructure, while the LNG itself is already available in quantities, incomparably larger than the middle size application would require in the near future.

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