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Rail transportation of liquid methane in Sweden and Finland

(Järnvägstransport av flytande metan i Sverige och Finland)

Martin Ragnar

"Catalyzing energygas development for sustainable solutions"

Svenskt Gastekniskt Center AB

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Malmö 2014

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Summary

Methane is an interesting energy carrier for the future. Traditionally, methane has been distributed in gaseous form at high pressure in grids and in tanks. Liquifying methane enables cost-effective transports on longer distances. Such liquified methane comes in two different qualities – (imported) liquified natural gas (LNG) and liquified biogas (LBG), which currently is transported on shorter domestic routes, but for the future could also be exported using the infrastructure built up for LNG. The first LNG terminal in Sweden and Finland was inaugurated in 2009 in Nynäshamn southeast of Stockholm. Currently a number of projects are either ongoing or upcoming, where new import terminals are to be built. With terminals in place the next issue is how the LNG could be transported further from the terminals and to customers at other locations, be it inland or on the coast off from the terminal. For smaller customers transport by truck is likely to be the first hand choice. For bigger customers a more efficient transport is desirable. Against this background a number of actors with interest in gas in Sweden and Finland decided to conduct the current investigation on the transportation of liquid methane on rail. The study involves a summary of the locations of possible customers and discusses aspects of system design and safety. Two planned railcar concepts for the transportation of liquid methane are presented and discussed; one container-based system and one freight railcar. The former is likely to be particularly suited for shorter term transports, where heavy investments in infrastructure should be avoided, whereas the latter is likely to be particularly suited for longer term transports. Both railcars could be realised in less than two years. Finally, operating experiences from containerbased railcar systems for LNG in Japan are discussed.

Contents

1. Background

1.1 Background

As climate change attracts an ever increasing interest, reductions of carbon dioxide emissions become prioritized in all sectors of the society. Means of phasing out the use of coal and oil are given high priority. Although the ultimate goal is to turn to renewables only, it is of great importance that any change could take place in such a way that competitiveness could be kept in relation to the rest of the world. For many applications this leads to methane in the form of natural gas being an interesting alternative to coal and oil since carbon dioxide emissions could be heavily reduced due to the higher hydrogen content of methane in comparison to the alternatives. Compared to oil the carbon dioxide emissions could *e.g.* be cut by some 25 % for a certain energy production. However, introducing methane as a new fuel means that an infrastructure for the methane must be at hand. In continental Europe it is, in the form of an extensive grid of gas pipelines that stretches across the continent. However, in Sweden and Finland (and Norway) this is for most parts of the countries not the case. To a port, methane could easily be transported in liquefied state by big tankers. However, should the methane be used inland, a rational transportation system to bring it there from the port is required.

Inland production units for liquid methane made from renewable materials have also begun to be built. Also here land transports are required.

Although transports of liquid methane already take place on road there are a lot of good arguments as to why it would be desirable to think of rail as the first hand choice for such transports onwards. Such arguments include the high transportation capacity of the railway, the energy efficiency and low climate emissions from such transports, the safety of railway transports and the rapidness of the transports.

1.2 Limitations

In the current study two modes of railway transportation of liquid methane are discussed and evaluated with the emphasis on making such transportations a reality in Sweden and Finland in 2015. In the discussions possible clients are surveyed, the available rail concepts discussed, safety aspects of rail transports specifically studied and an attempt made at evaluating costs. The focus is on Sweden, but for most aspects the results are believed to be valid also for Finland. The issue of how to run rail transports between Sweden and Finland, having different gauges, is given special attention. A more in-depth market analysis including volumes is not found in this report as this has been the focus in recent studies for the liquid methane market as such (SGC Rapport 236). For general aspects on the manufacture and characteristics of liquid methane the reader is advised to look elsewhere in the literature.

1.3 Method

The work has been carried out by means of literature studies combined with interviews with important actors, mainly in Sweden. In order to get hold of operating experiences and solutions to various details of the transportation system a technical visit to Japan was made as a part of the project with Japan Petroleum Exploration Company as the host. Another journey was made to Tornio to take a closer look at the existing rail network and its location in relation to the planned LNG terminal. Finally, a visit to Kiruna Wagon was also included.

2. Liquid methane

2.1 Definitions

Liquefaction of methane is a means to increase the energy density of methane. Doing so the transportation costs could be reduced and the methane allowed to be transported longer distances in an economically sustainable manner. LNG is an abbreviation for Liquefied Natural Gas, meaning methane of fossil origin, whereas LBG is an abbreviation for Liquefied BioGas, meaning methane of renewable origin. At atmospheric conditions methane condenses at –162 °C. Compared to CNG (compressed natural gas) at 200 bar, liquid methane typically occupies only about 42 % as big space for the same amount of energy.

2.2 Liquefaction of gaseous methane

Liquefaction of methane was first practiced in 1917. On some markets it appeared in greater scale in the 1960’s and 1970’s, but it is only in recent years that the real boom for LNG has occurred. LNG is usually transported from an export terminal close to the well on a big LNG tanker. The transport usually reaches a big import terminal (having a volume of the magnitude 100 000 m³ and more) from which it is further distributed on smaller vessels to smaller distribution terminals (having a volume of the magnitude 10 000 m³ and more). Terminals of this latter type are currently being built and planned in Sweden and Finland, whereas the closest big import terminal is the Gate terminal located in Rotterdam, The Netherlands, and owned by VOPAK and Gasunie.

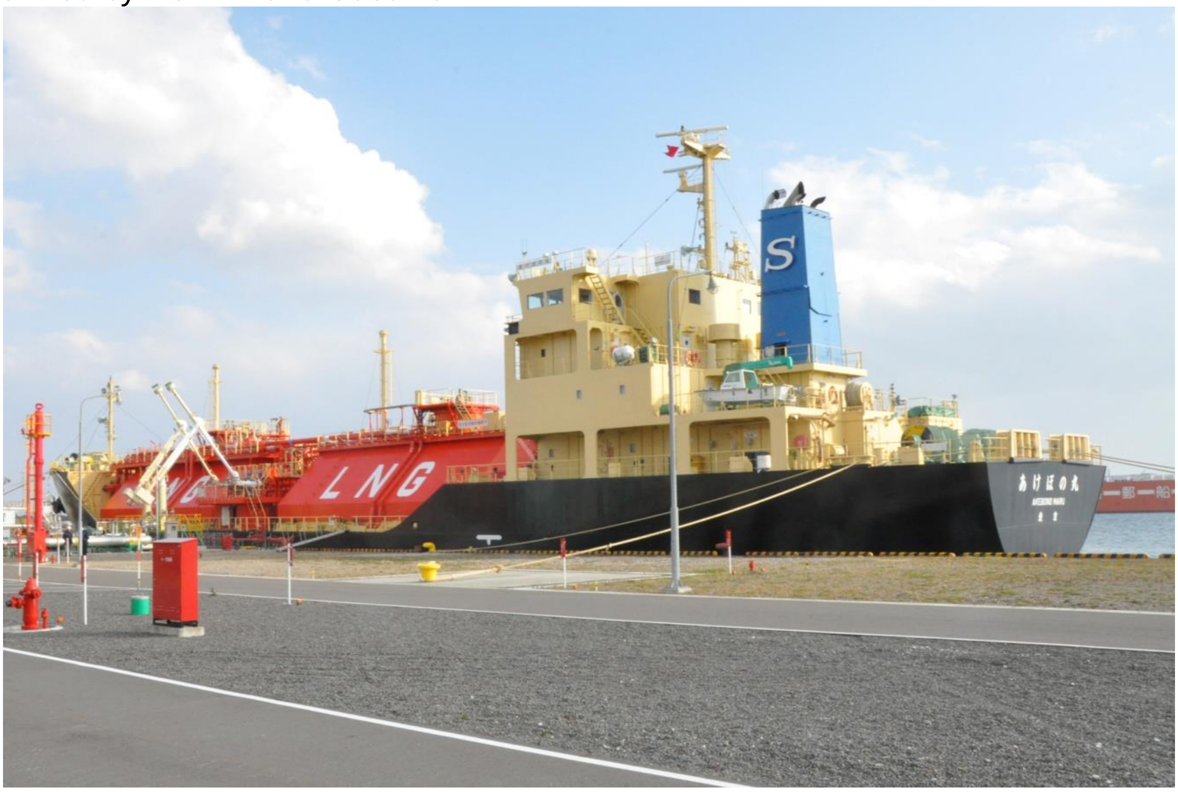


Figure 1. Coastal LNG tanker used for LNG local transports around Hokkaido island in Japan.

The Gate terminal opened in 2011 and has three storage tanks with a capacity of 180 000 m³ each, meaning 540 000 m³ together.

LBG (also referred to as liquefied bio-methane, LBM) is a recent development with the very first production unit staring up by Gasrec in Surrey, UK in 2007, using landfill gas as the raw material (www.gasrec.co.uk).

2.3 Characteristics

Methane is a colourless, odourless, non-corrosive and non-toxic gas at room temperature. It has a significant climate effect, about 24 times that of carbon dioxide. Methane could be condensed to liquid state. Liquid methane is cryogenic. The density of LNG is in the span from 0.41–0.50 ton/m³ and the energy density varies between 5.7–6.3 GWh/m³. Above –110 °C methane is lighter than air and thus tends to move upwards into the atmosphere.

3. Demand for liquefied methane transports in Sweden and Finland

3.1 Relations of interest

Methane is supplied via transmission grids in limited areas of Sweden and Finland. However, an existing connection to the national gas grid is not per se an argument for a non-existing interest in LNG. As some interviewed persons tell, the pricing of gas transmission in the grid is such that a competition by other means of gas transportation is welcomed. Having noted this, the main idea of introducing rail transports of liquefied methane in Sweden and Finland could basically be divided into four different categories, being transports of:

- LBG from production unit to end-user
- LBG from production unit to (export) terminal or national gas grid
- LNG from (import) terminal to end-user
- LNG from (import) terminal to regional gas grid

The first LBG production unit in Sweden was started up in 2012, being the Lidköping biogas AB Lidköping plant, with a production capacity of 29 m³ LBG/24 h (60 GWh/år). There should be good reason to believe that many more LBG production units will come onwards, in particular if and when biomass gasification is introduced on a broader scale.

The first LNG (import) terminal in Sweden was started up in Nynäshamn in 2011. Additional terminals are currently being built in Lysekil and a number of others are being commissioned and or planned, e.g. in Göteborg and Gävle.

3.2 Extension of the national gas grids

The national gas grids in both Sweden and Finland are limited to their extension. The Swedish grid covers most of the west coast from Trelleborg to Stenungsund plus a branch line to Gnosjö. The Finnish grid covers most of the southern part from Imatra to Ikaalinen, including the big cities of Helsinki and Tampere.

Figure 2. The Swedish gas grid. Malmberget, indicated on the map, is located very close to Gällivare, discussed in the text. Svappavaara, discussed in the text, is located some 100 km east of Kiruna. Source: Swedegas AB.

Figure 3. The Finnish gas grid. Source: Gasum Oy.

3.3 Existing and planned terminals

In Table 1 the existing and planned terminals are given.

Table 1. Existing and planned terminals for liquid methane in Sweden and Finland.

Location	Owner	start-up	volume/m³	Type	Details
Nynäshamn	AGA	2011-03	20 000	Import	
Lysekil	Skangass	2014 Q1	30 000	Import	
Göteborg	Swedegas +VOPAK	2016 Q1	20 000 +7 000	Import	
Gävle			30 000	Import	Skangass or Swede-gas
Helsingborg	Öresunds-kraft et al.	2016?		Import/ Storage	
Turku	Gasum	2015 Q4	30 000	Import	
Tornio	ManGaLNG	2016		Import	Industrial group of Finnish companies

In the case of the Lysekil terminal the problematic fact should be noted that the existing railway line connecting Lysekil with the Swedish rail network recently has been proposed to be shut down permanently by the Swedish Transport Administration (Trafikverket) (http://www.lysekilsposten.se/cms/index.php?mact=News,cntnt01,detail,0&cntnt01articleid=5705&cntnt01returnid=52). Should there be a true interest in transporting LNG by rail from Lysekil, Green Cargo believes it would be easy to restart traffic again provided the plans are made public in the coming months.

3.4 Existing and planned LBG production units

In Table 2 the existing and planned LBG production units are given. A further discussion on ongoing LBG projects is given in SGC Rapport 270 *Biogas upgrading – Review of commercial technologies*.

Table 2. Existing and planned LBG production units in Norway and Sweden.

Location	Owner	start-up	capacity [GWh/year]
Moss		2012-10	15
Lidköping	AGA	2012-12	60
Oslo	Oslo kommune	2014-02	50
Borås	Borås Energi & Miljö	2014 Q1	small
Helsingborg	LBG AB	2015	80
Sjöbo	Biogas Sydöstra Skåne AB	2016	120

3.5 Industrial branches with a potential interest in liquid methane

3.5.1 Background

Industry branches with a potential interest in liquid methane are likely to be found among big net energy users – big since some infrastructure at the end-user is necessary meaning a sufficient amount of liquid methane per time is required to motivate such investments. This indicates that industries of particular interest should be found among the following groups:

- Forest industries
- Mining industries
- Steel industries
- Aluminum industries
- Foundries
- (Chemical) process industries
- Ports
- Filling stations for heavy duty trucks
- Grid injection points

In the following we take a closer look on each of these groups.

3.5.2 Forest industries

Forest industries are numerous in both Sweden and Finland. Being large-scale process industries they use large amounts of energy. However, many industries are self-sufficient in energy since they make use of wood residues as fuel. Generally speaking the forest industries could be divided into the following groups:

1. Saw mills
2. Unintegrated chemical pulp mills
3. Integrated chemical pulp and paper/board mills

4. Unintegrated (chemi-)mechanical pulp mills
5. Integrated (chemi-)mechanical pulp and paper/board mills
6. Unintegrated tissue, paper and board mills
7. Paper converting industries (*e.g.* manufacturers of corrugated board)

Out of these it is primarily categories 4–6 which could have a potential interest in LNG, due to their enormous energy requirement as well as the big size. Such mills in Sweden, yet not having access to gas in any other form include:
Katrinefors (Metsä Tissue)
Pauliström (Metsä Tissue)
Nyboholm (Metsä Tissue)
Grycksbo (Arctic Paper)
Munkedal (Arctic Paper)
Åmotfors (Arctic Paper)
Hallstavik (Holmen)
Braviken (Holmen)
Fors (StoraEnso)
Kvarnsveden (StoraEnso)
Kisa (Swedish Tissue)
Jönköping (Munksjö)
Dals Långed (Rexell)
Fiskeby (Fiskeby)
Rottneros (Rottneros)
Djupafors (Cascades)
Vaggeryd (Waggeryd Cell)

The energy utilization of these mills could be found in the environmental database on the website of the Swedish Forest Industries Federation (Skogsindustrierna), www.skogsindustrierna.org and a general discussion on the energy consumption as such in the report *Energiförbrukning i massa- och pappersindustrin 2011*.

3.5.3 Mining industries

Mining is an important industry in both Sweden and Finland. It could roughly be categorized considering either the ore, either the construction of the mine (open-pit or underground) or the function (primary ore extraction or secondary processing to commodities *e.g.* iron pellets). In Sweden it is primarily plants for secondary processing that has a particular interest in LNG to replace oil and coal. In addition big open-pit mines use a lot of diesel fuel for the propulsion of the trucks used in the mining. The size of mines varies dramatically and in the below lists only those really big open-pit mines have been included in addition to the processing plants:
Kiruna, 3 iron pellets plants (LKAB)
Malmberget, 2 iron pellets plants (LKAB)
Svappavaara, 3 iron pellets plants (LKAB)
Rönnskärsverken/Skellefteå, processing plant (Boliden)
Aitik, open-pit mine (Boliden)
Leveäniemi/Svappavaara – open-pit mine under planning (LKAB)
Märtäinen/Svappavaara – open-pit mine under planning (LKAB)
Figures from SveMin tell that the six pellets plants currently use about 2 TWh fossil fuel per year.

3.5.4 Steel industries

Sweden and Finland are home to a great number of steelworks. The two countries host three blast furnaces each (located in Oxelösund, Luleå, Brahestad and Hangö) in addition to a number of mills for metalworking. Blast furnaces today utilize cokes as fuel, but also as reduction agent. Development of the reduction processes is ongoing and technologies for direct reduction of finely ground iron ore with methane as a reduction agent are available. However, although a company like Swedish mining giant LKAB is interested in the technology it takes time from idea to reality and it requires a lot of money and confidence to replace a process known to work in a reliable manner by a new process. Hence, mills including blast furnaces are so far not to be considered as potential clients for LNG in Sweden or Finland.

The metal working mills utilize a lot of energy to heat up the raw steel to enable it to be handled in the working processes. For this latter purpose oil or LPG so far dominates in Sweden and Finland. However, some metal working mills have already converted (Hagfors (Uddeholm)) or are in the process of converting (Borlänge (SSAB)) to LNG. Turning from oil to LNG usually calls for an investment in new burners. Current figures for Sweden tell that 1 TWh of oil is used for metal working and 2 TWh of LPG, according to Jernkontoret – The Swedish Steel producers' association.

Metal working industries in Sweden with a potential interest in LNG include:
Boxholm (Boxholm Stål)
Munkfors (Böhler-Uddeholm)
Halmstad (Celsa)
Långshyttan (Erasteel Kloster)
Söderfors (Erasteel Kloster)
Vikmanshyttan (Erasteel Kloster)
Fagersta (Fagersta Stainless)
Avesta (Outokumpu)
Degerfors (Outokumpu)
Långshyttan (Outokumpu)
Torshälla (Outokumpu)
Smedjebacken (Ovako)
Boxholm (Ovako)
Hofors (Ovako)
Hällefors (Ovako)
Forsbacka (Ovako)
Hallstahammar (Ovako)
Sandviken (Sandvik)
Hallstahammar (Sandvik)
Björneborg (Scana Steel)
Karlskoga (Scana Steel)
Söderfors (Scana Steel)
Borlänge (SSAB)
Surahammar (Surahammar)
Rönnskär (Boliden)
Ramnäs (Ramnäs)
Vargön (Vargön)

3.5.5 Aluminum industries

Aluminum industries could be divided into primary aluminum manufacturers, aluminum pressworks and aluminum foundries. Although the primary manufacturers are giant energy consumers, the energy used for process technical reasons has to be in the form of electricity. The foundries are on the other hand usually small and therefore likely not to be the main target of the LNG supply by rail. This leaves the aluminum pressworks, which are big units using a fair deal of energy. In Sweden two such facilities prevail being
Vetlanda (Sapa)
Åseda (Profilgruppen)

3.5.6 Foundries

In a foundry metal is melted to be given the shapes and forms desired. In Sweden both steel, aluminum and brass are handled in big foundries. The steel foundries have all but one turned from the use of fuel-based furnaces to electrical ones, using inductive heating. The remaining steel foundry using a fuel for heating is the Volvo plant in Skövde. It is unlikely that this Volvo would invest in this furnace rather than replacing it with a new induction heated one. In the aluminum branch two bigger foundries are active, being
Hultsfred (Finnveden)
Vimmerby (Metallfabriken Ljunghäll), which buy the aluminum in liquid state from Älmhult (Stena)
In addition to these, there are a also a number of brass foundries, *e.g.* making products for the fresh water side. Generally speaking the foundry sector seems to be on its way to take further steps towards an increased dependency on electricity for melting, meaning taking steps away from fuel based melting. However, there is also a serious interest in methods for drying of metal waste and preheating, before melting. In this segment there might be room for LNG in some bigger foundries.

3.5.7 Chemical industries

The chemical industry is a much more diverse group of industries than most of the here otherwise discussed sectors. Both in Sweden and Finland clusters of chemical industries prevail. Unlike most of the other sectors, the chemical industry has an interest in LNG not only as a potential fuel, but first and foremost as a chemical to be used in various processes. In Sweden the dominant cluster is located in Stenungsund, but important nodes are also to be found in
Bohus (Eka Nobel)
Helsingborg (*e.g.* Kemira)
Perstorp (*e.g.* Perstorp)
Sundsvall (*e.g.* Akzo Nobel)
Örnsköldsvik (*e.g.* Akzo Nobel)

3.5.8 Filling stations for heavy duty vehicles

Heavy duty vehicles could use LBG/LNG as a fuel directly in methane diesel motors, filling the liquid methane rather than gaseous methane. A few such filling stations have already appeared in southern Sweden and in Stockholm. However, the European Union has a clear vision to develop a pan-European infrastructure for such filling station, in such a way that stations should be located every 200 km all over the continent. In order to turn this vision into reality a great number of filling stations would need to be built both in Sweden and in Finland. In Figure 4 a map of Sweden with existing, planned and strategic filling stations for LNG is shown.

Figure 4. Heavy traffic relations including existing, planned and strategic filling stations for LNG. Source: SGC Report 236. By the end of 2013 five filling stations for LNG are in operation. These are, in addition to the one in Göteborg, two in Stockholm and one in Malmö and one in Jönköping. A new filling station in Örebro is being commissioned.

3.5.9 Ports

When new regulations come into force concerning the emissions from ships LNG should be one interesting option. It is evident that ports in which receiving terminals for LNG are built will be able to supply LNG for the bunkering of visiting ships. However, big receiving terminals will not be built in every port. This could potentially also open up a market for LNG transports in smaller scale to such ports. The association Ports of Sweden (Sveriges Hamnar) claims that so far discussions on this matter have mainly anticipated that such transports would be made be small scale bunkering ships along the coastline from the nearest receiving terminal. However, rail transports on such relations is of course another possible option. Ports unlikely to get a full scale receiving terminal for LNG, but never-the-less believed to have a serious interest in being able to offer LNG for bunkering include (apart from Visby, which has no rail connection):
Halmstad
Malmö
Trelleborg
Ystad
Karlshamn
Oskarshamn
Oxelösund
Sundsvall
Skellefteå

3.5.10 Grid injection points

Injection of vaporized LBG/LNG into the national transmission grid could in principle be made at any location along the extension of the grid. From an economical point of view it would be less costly to inject methane into the grid in the northern part, where the pressure is lower (today around 35 bar) than further south. In order to be able to inject methane into the grid a place to put the LNG car/trailer is needed along with a vaporizer, some meters and a compressor. The transmission grid owner, in Sweden Swedegas, would be responsible for and invest in the compression for injection, the connection to the grid and for metering and control.

In the future it is possible to consider transports of liquid methane going both ways between existing regional grids and/or the national grid, having the connection to the continent. From future regional grids, LBG could be transported for injection in the national grid for further export to Denmark and Germany, although the opposite direction is of course also possible.

4. Rail networks

4.1 Sweden

The rail network in Sweden is given in Figure 5.

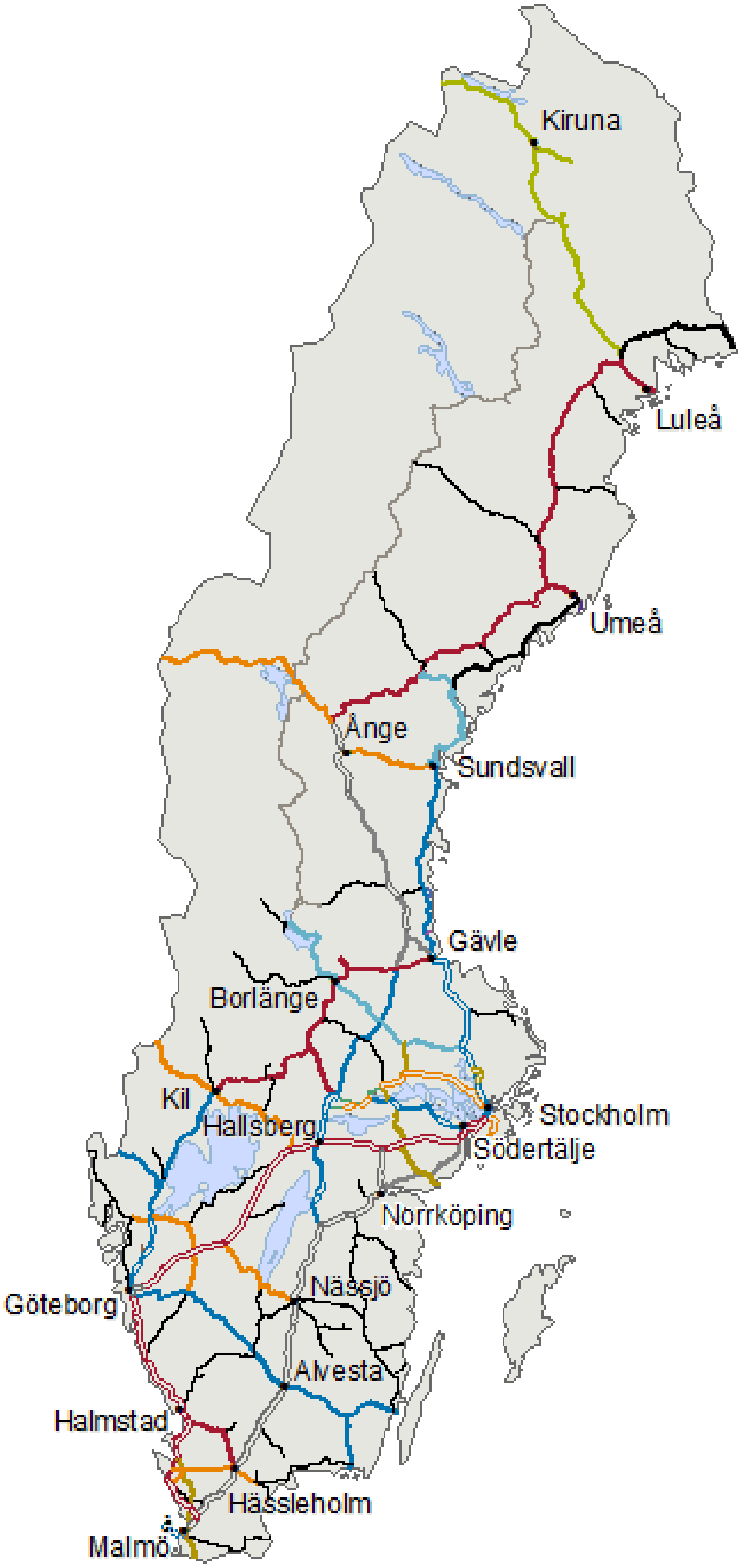


Figure 5. The Swedish rail network. Source: Swedish Transport Administration

The network covers most of the territory and include branches to most of the industries with actual or potential interest in LNG. One exception is the steelworks in Hagfors, Munkfors and Söderfors which since the early 1990’s lack rail connection. The Swedish rail network has European standard gauge – 1435 mm.

4.2 Finland

The rail network in Finland is given in Figure 6.

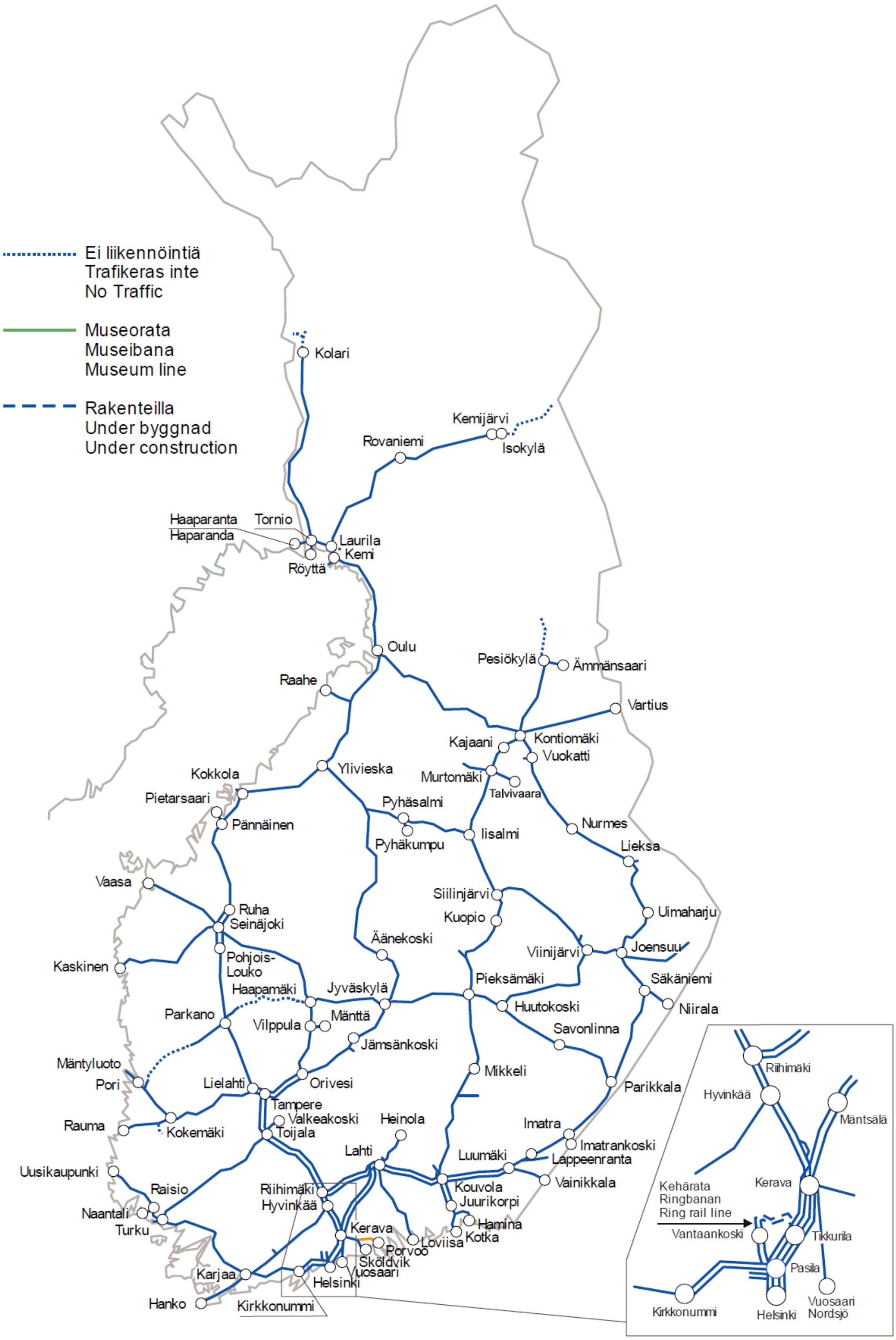


Figure 6. The Finnish rail network. Source: Finnish Transport Agency.

Most of the territory of the country is covered by the rail network. In contrast to Sweden and most parts of Europe outside former Soviet union, Finland has a broad gauge rail system of 1524 mm. This means that railcars cannot roll between Sweden and Finland without either changing bogies at the border or doing something else, to be discussed more in detail onwards in this report. The railway line between the border towns Haparanda and Tornio has double gauges – 1435 mm as well as 1524 mm.

5. System design

5.1 Loading

Loading of LNG onto a railcar and/or a container is carried out by connecting the terminal with the tank on the railcar. Connections could be made up of either adjustable mobile arms or of flexible pipes. The former has the advantage of a reduced risk for being run over by accident, whereas the latter is likely to be the less expensive and in most cases preferred concept.

In the case of a container this could be lifted onto the railcar before or after loading of the LNG.

5.2 Transport

Since the tank of the railcar does not have any cooling capacity of its own it is important that the transport takes place in a well planned way and in such a way that all railcars reach their destinations within three days. There is currently no system for real time tracking of individual railcars in operation in Sweden, but the operator has a good knowledge of the location of each railcar even without such a system.

5.3 Unloading

The customer needs to have a certain storage capacity on site to receive the supplied LNG. Such a tank should have a certain cooling capacity in order to enable a long term storage. From the user point of view it is usually desired to keep the storage capacity as low as possible, to minimize costs. However, a smaller storage capacity also means a bigger vulnerability as variations in the local demand could be hard to cover-up. The same goes for a sudden stop in the supply chain. Another aspect of the storage capacity is the frequency of the LNG transports. If it is considered desirable *e.g.* from economical point of view, to run system trains with LNG railcars only such trains are likely not to run every day to a certain customer, but has to take place with certain regular intervals. The larger the system train, the larger the intervals – but also the larger the local storage tank, and vice versa.

In the case of a container there are two options. Either the container is emptied analogous with above – or, else the container is lifted off and the LNG kept in the container at the customer's site. This concept of using the container in such a flexible way has been designed and developed by Norwegian company Liquiline, who could of course also supply solutions where the LNG is pumped from one mobile container to another stationary one.

5.4 Minimizing slips and spills

It is important to minimize slips and spills of methane for a number of good reasons.

- Obviously slips and spills mean a reduced transmission efficiency and loss of money for either supplier or customer.
- Methane is a strong climate gas and any spill to the atmosphere is an argument against the use of methane instead of other fossil fuels.
- Methane slips make up a potential risk for fires and explosion, although small, so still existent.
- Liquid methane is very cold and cryogenic liquids could cause damages including embrittlement effects on materials.

The biggest risk for slips and spills is obviously connected to the transfer of the methane from the receiving terminal to the railcar and opposite from the railcar to the client's storage. The Swedish company ManTek has developed a fitting with extraordinary features making it close to dropless. This technology means that also the connecting pipes are cleaned after usage so that any methane present in the pipes is removed before the pipe is opened to the atmosphere. The technology has so far been used in the fueling of the passenger ship Viking Grace in Stockholm. It is strongly recommended that the dropless fittings by ManTek should be employed as a standard for railcars.

5.5 The gauge issue

5.5.1 Railcar solutions

The Swedish railways have the European standard gauge of 1435 mm, whereas Finland has a broader gauge of 1524 mm, equal to that used in former Soviet union, *i.e.* today's Russia, Estonia, Latvia and Lithuania. This means that railcars cannot travel over the Swedish–Finnish boarder without taking certain measures. Historically the measure taken was simply reloading of the cargo from a Swedish railcar to a Finnish and vice versa. This method is labor intense and therefore costly. In addition it does not work for certain types of cargo, such as dangerous goods, which should be handled as little as possible. In order to transport such goods over the boarder a special crane was built in Tornio, enabling a change of the bogies of the railcar. However, this also proves a complicated and expensive technology. Although it has been proposed to scrap the crane in Tornio, it is still there and possible to use.

Figure 7. The crane in Tornio. Photo: Martin Ragnar.

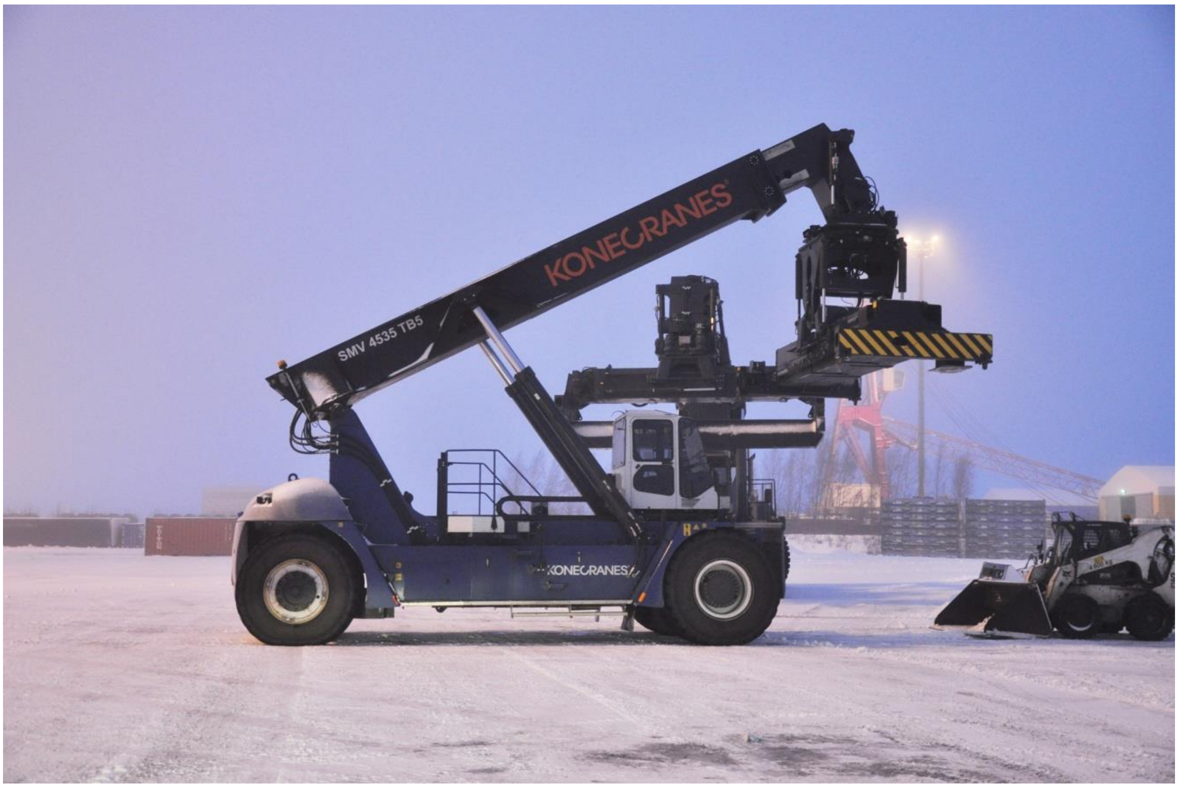


Figure 8. Top lifter in Outokumpu harbor in Tornio. Photo: Martin Ragnar.

However, change of bogies is still regularly practiced on the boarders between former Soviet union and EU countries, *e.g.* Poland–Belarus, Poland–Ukraine,

Ukraine–Slovakia and Moldova–Romania as well as between Mongolia/Kazakhstan and China.

Spain and Portugal also have broad gauge railways, in fact even broader gauge than Finland – 1668 mm. Trains running between France and Spain thus have to change gauge. For the purpose of transferring passenger trains between the two countries the TALGO system for gauge change was developed. This system has also been evaluated by the Swedish Transport Administration (Trafikverket) in the early 2000's in Haparanda. The evaluation clearly showed that the TALGO system was not suitable for northern conditions and *e.g.* required deicing to function.

Another system for gauge change of the railcars was developed in Germany and practiced into the 1960's on some of the above-mentioned crossings between Soviet union and other eastern countries. However, as it seems that the technology ceased to be used until the Swedish Transport Administration awoke the interest once again some years back in time. A trial was carried out in Tornio for a few years ending in 2010 using the German system, based on bogie frames from ELH (www.elh.de) and wheels by Bochumer Verein Verkehrstechnik GmbH (www.rafil-gmbh.de).

Figure 9. The German gauge changer in Tornio is very simple and works well also in winter conditions – here partly covered in snow. Photo: Martin Ragnar.

The Swedish experiences of the system were that most difficulties could be overcome and that the system was not sensitive towards a northern climate. However, following some 110 000–120 000 km the wear on the axis suddenly became problematic since the locks for the elongation of the axis no longer always got stuck in the correct position. Therefore the trials were stopped. Unfortunately, the German manufacturers at this time did not pay too much attention to the issue, but this attitude is now about to change. A meeting was held with the Swedish Transport Administration in late September 2013 and serious bench trials will be performed in Germany during the autumn of 2013, meaning that a solution might again be under way. It is, however, reasonable to believe that additional full-scale trials are required before large scale commercial operation is to count upon. Should this technology be used, the railcars must have a special kind of axis to function.

5.5.2 Rollbocks/Transporter wagons

A rollbock looks like a small bogie which could be carrying one axis or a bogie of a differently gauged railcar. The system was invented already in the late 19th century and was significantly improved in themed 1970’s. The technology is nowadays owned by Bombardier and currently in use *e.g.* in Switzerland.

On a transporter wagon an entire railcar of a different gauge is rolled on and transported. Also this technology emanates from the late 19th century central Europe. Unlike the rollbock system, transporter wagons have been frequently used in Sweden for several decades and up til the early 1990’s.

Both rollbocks and transporter wagons require a ramp for loading and unloading of the railcars transported.

5.5.3 Infrastructure solutions

Instead of changing the gauge of the railcars upon transporting cargo over the border it is of course also possible to find other solutions to the problem including the construction of new infrastructure. The distance from the planned LNG terminal and to the nearest rail track with Swedish standard gauge (located at the Tornio rail yard) is 8.5 km. Four options are then at hand, namely

1. To use a container-based system including reloading of the containers
2. To rebuild the current 1524 mm rail track to a 3-rail dual gauge track including also 1435 mm
3. To rebuild the current 1524 mm rail track to a 4-rail dual gauge track including also 1435 mm
4. Take the LNG from another terminal

Reloading of containers from truck to rail and again from rail to truck is standard procedure in the JAPEX LNG satellite system, although for different reasons than here. The system requires a top loader at the reloading site. In the Tornio context containers could be carried either on rail or on trailer from the harbor up to Tornio rail yard where loading of standard gauge railcars could be made.

The second option with a 3-rail dual gauge track might sound complicated, but has been practiced for many years in Sweden when railways of 1435 mm, 1067 mm and 891 mm met in different locations in southern Sweden. Still today a 3-rail dual gauge line is in operation between Västervik and Jenny in the southeast of Sweden. In Växjö all three different gauges were once combined in a triple gauge (4-rail) track, which stayed in operation until 1970. However, the difference between 1435 mm and 1524 mm is usually considered too small to allow a 3-rail solution, although such a solution has been demonstrated to work in Kaliningrad and in a rail yard by a manufacturer outside Berlin.

The third option with a 4-rail dual gauge track (where 1435 mm uses rail 1 and 3, whereas 1524 mm uses rail 2 and 4) is the way the railways between Sweden and Finland are combined today. Finnish trains could thus go all the way to Haparanda today and Swedish trains could go all the way to Tornio.

Figure 10. The Swedish and Finnish tracks come together when passing the bridges over Torne river. Photo: Martin Ragnar.

The rail yards on each side of the boarder are separated between the different gauges. To rebuild an existing rail track of 1524 mm to include also 1435 mm is possible. However, the bank is likely to have to be broadened and some other challenges will also be at hand. InfraNord makes a very rough estimate that the rebuild would cost around 60 MSEK for the missing kilometers to Tornio harbor.

The fourth alternative is not to use the Tornio terminal for the supplies to Sweden, but to push for a rapid establishment of LNG terminals in Narvik and Trondheim respectively and use the railway for transports from there to *e.g.* Kiruna, Gällivare, Östersund and Sundsvall. Yet other alternatives of course include utilizing the LNG terminals now existing, being built or seriously planned in Nynäshamn, Lysekil, Göteborg and Gävle for train supplies all over Sweden including destinations in the far north.

6. Safety aspects

6.1 Hazards

Methane is a fuel and could thus burn. It is explosive in a mixture with air in the range 4.2–16 % if a source of ignition is present. The hazards concerning LNG are mostly the same whether the transport takes place by truck or by rail. The obvious difference is the bigger risk for sparks to occur as a result steel wheels rolling on steel rails. On the other hand, it is likely that the engine is further away from a possible leak, meaning a reduced risk here as compared to the trailer case.

A serious summary of potential hazards concerning LNG is given in the BP Process Safety Series: LNG Fire Protection & Emergency Response. Here a few of the most important aspects are summarized:

- If no cooling takes place, which usually is the case during transportation of methane, the temperature tend to increase slowly. This means that the pressure slowly increases during storage in the transport vessel. Movements of the liquid as a result of the transports also contribute to an increased temperature and pressure.
- There is a phenomenon called rollover, meaning that the LNG could layer in different layers. The phenomenon should be counteracted by an appropriately designed container. Should it occur it could cause a rapid evaporation and the pressure increases.
- A large LNG release in water could physically explode due to rapid phase transition (RPT). This explosion is not caused by a fire, but is an explosion taking place for other reasons.
- Liquid methane is cryogenic, which means it could cool down materials in its surroundings such that the characteristics of the material get entirely changed. One such risk is the embrittlement of materials, including also carbon steel.
- Leakage of any kind is a fire hazard. Only the evaporated gas would ignite, but this would cause a more rapid evaporation and the result would most likely be a pool fire. In facilities handling LNG, regulations require safety zones where fluid is collected in the case of leakage, as well as large setback distances. The risk that vapor gathers in a certain spot is small since methane having a temperature above –110 °C is lighter than air at STP and hence rapidly will disperse into the air.

6.2 Laws and regulations in general

6.2.1 Transporter

The company responsible for the transportation, the transporter, needs to have a license and a safety certificate to be allowed to transport LBG/LNG. These documents are issued by the Swedish Transport Agency (Transportstyrelsen). In addition, companies previously not engaged in the transportation of hazardous goods need to show that they fulfill the education requirements concerning RID put up by the Swedish Civil Contingencies Agency (Myndigheten för Samhällsskydd och Beredskap, MSB) and published in the MSB FS 2012:7.

6.2.2 The pressure vessel

No absolute state requirement for the pressure at which the security valve should open has been identified in this study. However, a general discussion on the matter is of interest. First of all the LNG tank could never be filled more than to 95 % of its volume. Second, the higher the pressure, the warmer the liquid would be and the bigger the volume it would make up. This is equal to say that the density of the liquid methane is temperature dependent. At atmospheric pressure the density is 424 kg/m³ and the methane has a temperature of –161 °C, at 4 bar 392 kg/m³ and –142 °C and at 7 bar 372 kg/m³ and –131 °C. This means that the higher the security valve setting the lower the maximum load allowed in the tank. Accordingly, increasing the pressure setting from 4 bar to 7 bar would reduce the maximum load of the car by 5 %.

The formal requirements on the pressure vessel are published by MSB, in terms of MSBFS 2012:6 and 2012:7.

6.2.3 Restricted lines

Almost all lines of the Swedish rail network are open for traffic with *e.g.* LNG. However, for safety reasons no such railcars are allowed to pass through Helsingborg C.

6.3 Training

Whereas a truck driver needs to have a special education for the load she is carrying, this is not the case for the locomotive driver. However, locomotive drivers are regularly trained in the transportation of dangerous goods in general. Moreover, should a true accident really occur it is highly unlikely that any kind of driver would play a major role in the following events. In practice there should thus be no reason to claim a road transport to be less hazardous than a railway transport – quite a lot the opposite.

6.4 Climate and environment

The climate and environmental effects of the choice of rail transport instead of truck transport is giant. Electrically propelled locomotives using electricity generated in Sweden have marginal impact on the environment, whereas diesel fuelled trucks cause pollution *e.g.* my means of carcinogenic particles.

In terms of climate effect Green Cargo calculates an electrical train in Sweden to cause emissions of 0.003 g CO_2/net ton*km, to be compared with 48 g CO_2/net ton*km for a truck. The train thereby proves 16 000 times more climate efficient than the truck.

7. Existing and planned railcars

7.1 Experiences of rail transports

Liquid methane has been transported on railway since the early 1970's. By far most experience in this field has been gathered in Japan where both specially designed freight railcars and container railcars have been used. In USA railcars for carrying LNG as locomotive fuel exist since a few years. In Norway, container manufacturer Liquiline has carried out a few commercial rail transports of LNG during 2012.

7.2 Concepts and Manufacturers

Two different technical solutions could be considered upon transportation of LNG on rail – a specially designed freight railcar or a more multipurpose container railcar complemented by LNG containers.

Figure 11. Specially designed LNG railcar for Tokyo gas, courtesy of JAPEX.

Figure 12. Container transport on rail in Japan, courtesy of JAPEX.

Standard containers exist in 20, 30 and 40 feet length. It is generally claimed that in order to optimize capacity on a railcar, two 30 feet containers should be the given choice.

The specially designed LNG freight car by definition is specially designed. However, when it comes to container railcars many different options prevail. Moreover, many different manufacturers of the containers suitable for the transportation of liquid methane also exist. In Japan Air Water and J-Trec respectively manufacture containers. In Sweden Cryo would do the same and in Norway Liquiline is a company already having done so.

7.3 Freight railcar versus Container railcar

There are some obvious differences between the two systems as clarified in Table 3.

Table 3. Comparison of railcar concepts.

Freight railcar	**Container railcar**
Bigger capacity	Smaller capacity
Requires special permit from transport authorities, since it is a new railcar	Standardized flat railcar could be used
Requires access rail track to terminals	No access rail track required
No back-up in case of rail accident	Could use the same terminal as trucks
	Trucks could transport the containers should a bigger rail accident (track failure) occur
	The container could be used as a storage at the customer's site
	Is designed to be lifted on and off a railcar, which means some sort of increased risk
	Likely to be easier to handle in cross-border traffic between Sweden and Finland

The freight railcar concept has been practiced in Japan by Tokyo Gas for rail transportation of LNG in the 1970's.

As always no system has only benefits. The reasonable conclusion is that a container based system could be useful in a start-up phase when the transportation is evaluated and for smaller end-users, whereas the freight railcar option should be the first hand choice for long-term transports between a terminal and a big end-user.

A new and modern freight railcar concept is under development by VTG in co-operation with railcar manufacturer Chart Ferox in Czech republic.

7.4 Container railcars

Railcars designed for carrying containers in general exist since many years in both Sweden and Finland. Leading freight train operator in Sweden, Green Cargo, *e.g.* has a standard railcar for two 30 feet containers which is 19.64 m in length (Green Cargo type Sgnss). This car is able to carry close to 20 ton LNG.

Figure 13. Green Cargo railcar type Sgnss here loaded with three 20 feet containers. This railcar could also handle two 30 feet LNG containers. Courtesy: Green Cargo.

7.5 Kiruna Wagon container railcar

Apart from the Japanese container railcar concept Swedish railcar manufacturer Kiruna Wagon develops a railcar concept suitable *e.g.* for LNG containers. The patented system has a high degree of flexibility in terms of allowed axis load, line load (ton/m), coupling type, load carrier etc. According to the manufacturer (e-mail from Fredrik Kangas, Kiruna Wagon, 131009) the concept is designed for clients interested in beginning with smaller volumes and a possibility to expand. This also means that no heavy investment is required day one. The standardized railcar carrying the LNG container is already approved by the authorities and the containers could be put on top of each other at the client and be used for storage there. The Kiruna Wagon railcar is a light-weight steel construction, having low environmental impact as compared to *e.g.* cars built in aluminum. Each car hosts one container, but in case two containers should be transported on a regular basis a short-coupled two-unit car is utilised having a total length of 24 m (each single car is 12.5 m in length). The basic idea of the railcar concept is that it should provide a high degree of flexibility for the car owner, so that following a period of LNG transports it should be possible to use the same car for other purposes instead – simply a modularized system where the railcar is one and the same and owned by a railcar company, whereas the top of the car is owned by the customer and could easily be moved away. The Kiruna Wagon railcar is ready for production, but so far no orders have been laid. From the day of order Kiruna Wagon estimates that the railcar could be in operation in 12 months.

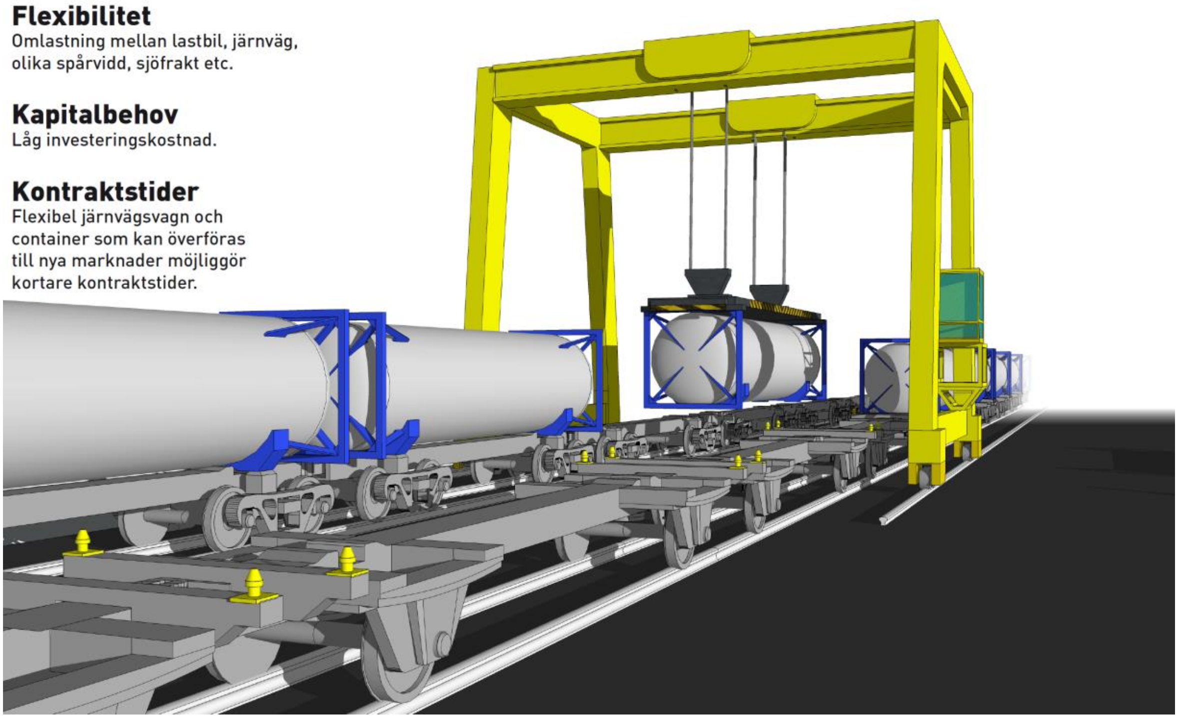


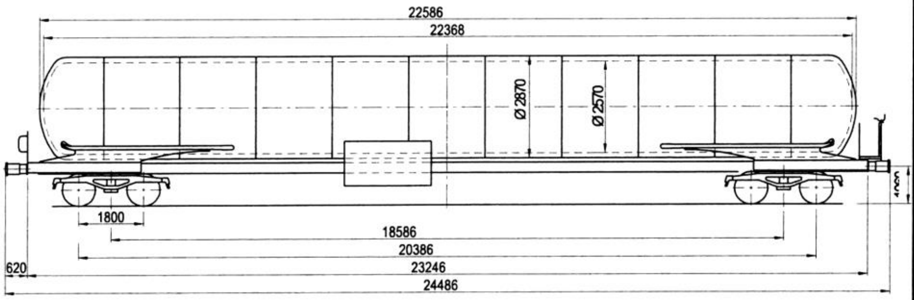
Figure 14. Principle scheme for safe reloading of an LNG containers onto the Kiruna Wagon standard railcar. Courtesy of Kiruna Wagon.

7.6 VTG freight railcar

German freight car owner VTG currently develops a new freight railcar for LNG. The car includes two separate vacuum-insulated tanks together containing 112.5 m^3 which corresponds to about 2.5 lorries, although the car does not extend more than 24.5 m in length. On most railway lines in Sweden this railcar would allow a load of 43.7 ton LNG. Current expectation is that the first railcars of this type will be built during 2014 and also get a formal approval the same year so that they will be available to customers starting mid-2015.

PROJECT DATA SHEET

VTG	**112,5 m³ - GAS TANK WAGON**	TANK WAGON TYPE **7899.ac**



TECHNICAL DATA

1. GENERAL DATA

Loading material	LNG (methane) refrigerated liquid
Tare weight	appr. 44,9 t
Axle load	22,5 t
Temperature range (TSI)	T_{RIV} -25 / +45°C

Pay loads

	A	B	C	D
S	~18,0 t	~26,0 t	~36,0 t	~43,7 t
120	00,0 t			

First year of construction	2014
Brake	KE-GP-(K)-12"
Designed for fitting of automatic coupler	Plan 14
min. curve radius	55 m
RIV - Running gauge	G1
Crash Buffer IP 400 CX	400 kJ

2. RUNNING GEAR

Bogie	Y 25 Ls 1-K	Helical springs
Whell sets	25 t	

3. TANK

Capacity	appr. 112,5 m³	Double shell tank
Design pressure (RID)	10,4 bar	
Test overpressure	7,0 bar	
Working overpressure	-1 / +7,0 bar	
Design temperature	-196 / +50°C	

1. Issue from 24.04.2013

Figure 15. Technical type sheet for the VTG liquid methane railcar.

The safety valve is planned to be located in one of the cabinets on the left side of the car, as shown in Figure 16.

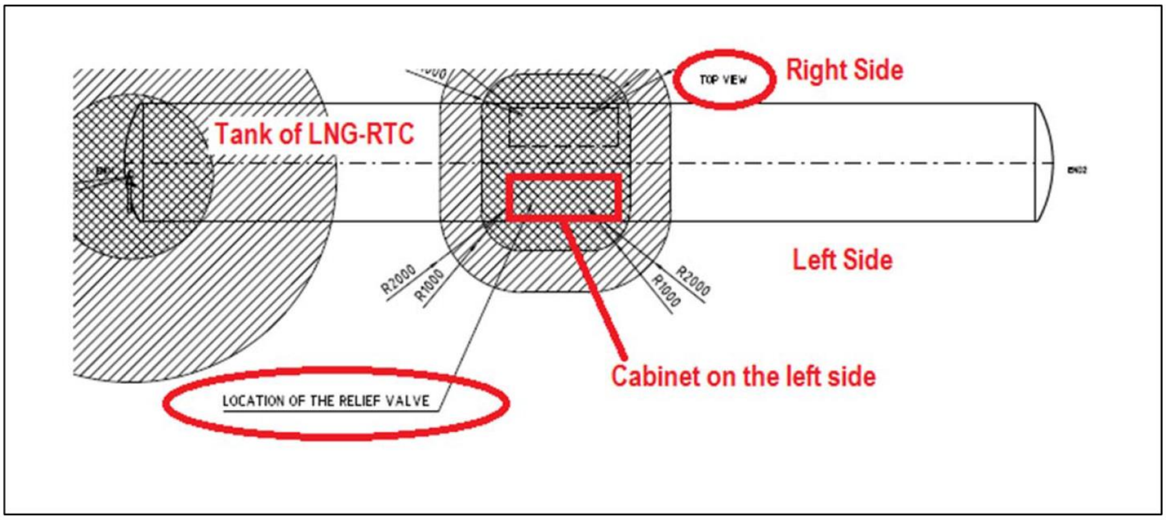


Figure 16. Detail of the planned VTG LNG railcar. Source: Chart Ferox.

The LNG could be released from either side of the car at the cabinets mid way on the length of the car through the couplings for filling and discharge, the pressure relief valves as well as other valves. In addition, LNG could be released through vent and outlet from pressure relief devices at one of the short ends of the car, as shown in Figure 17.

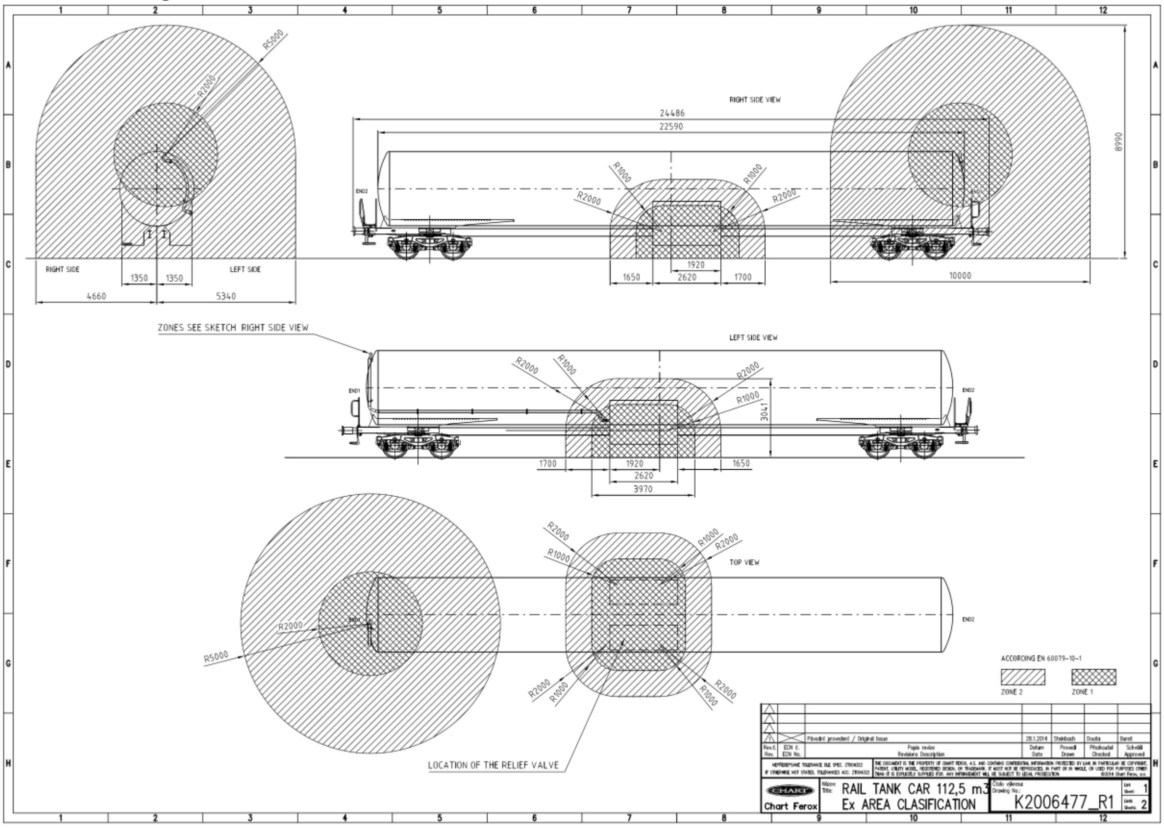


Figure 17. Possible release points and zones from the planned VTG LNG railcar.

Release could be of two different grades – zone 1 and zone 2, as indicated in Figure 17. The zones were determined by manufacturer Chart Ferox according to the standard EN 60079-10-1 for normal operation on places for filling and/or discharging of LNG.

When it comes to special techniques to prevent the safety valves from opening during transport the railcar as such does not have any special equipment for this. Instead railcars could be equipped with a telematics system, by which *e.g.* the pressure of the tank could be monitored in real time.

7.7 Transportation capacity

7.7.1 Maximum capacity

Currently the maximum allowed train length in Sweden is 630 m. Today's train length would allow 24 VTG railcars, equaling a total LNG transportation capacity of 2 700 m³ or close to 1 050 ton LNG per full train. A 30 000 m³ terminal could thus be emptied by eleven full length freight trains.

In a recent article written by researcher Oskar Fröidh at KTH, it is proposed that freight trains of 2 km length should be allowed in the future in order to make freight trains more efficient and more competitive. Such a 2 km train would allow close to 3 500 ton LNG per full train.

7.7.2 A realistic near-future scenario

Sandvik steelworks in Sandviken close to Gävle in the Mideast of Sweden is one big potential consumer of LBG/LNG. With an annual demand for 362 GWh fuel for heating and up to 500 GWh should the electricity price increase, this corresponds to some 1000–1400 m³ LBG/LNG to be transported every week *e.g.* from the harbor in Gävle to the steel works. Considering the VTG railcar this would call for 9–13 railcars should the transports take place once a week. However, to not require too heavy investments in on-site storage capacity in Sandviken a more realistic scenario should rather be biweekly transports of 5–6 railcars, which would then also be more efficiently utilized.

7.8 Indicative costs

7.8.1 Background

When it comes to cost estimates for the different concepts these could be divided into different categories.

7.8.2 Transportation

There is a transportation cost charged by the transportation company, *e.g.* Green Cargo, RushRail, Hector Rail or Tågåkeriet i Bergslagen – or in Finland VR. This cost will also depend on if the transportation takes place in a separate system train or if it takes place in the form of sending one or several cars on an existing standard train. At least Green Cargo run trains of the second type on a great number of relations in Sweden. In order to consider a system train it is obvious that the transportation need be fairly big. The bigger the transport, the higher the likelihood is for a low price. Thus, if one train with seven cars could be sent once a week this would probably be more economical transportation-wise, than if one car is sent every day, seven days a week. On the other hand – the fewer the trains, the higher the vulnerability of the customer is, in case of sudden cuts in the supply chain. The fewer and bigger the trains the bigger also the demand on the client to build a big receiving tank to be able to store the LNG on site. Having said all this, Green Cargo has given an indicative price for the transportation back and forth of one

VTG railcar from Göteborg to Borlänge of 7.7 kSEK, indicating that the transport back and forth would require two days.

7.8.3 Rental of railcar

VTG plans to own the railcars and lend them out to clients. The company has an indicative rate of 200 EUR per day for a one year rental.

Kiruna Wagon estimates that the cost for renting one of its cars would be 400-450 SEK per day once it has been delivered.

7.8.4 Rental of container

In case of the container based solution not only the railcar, but also the container needs to be rented. Liquiline gives a price indication of 2 kNOK per day for the container rental.

8. Operating experiences – the Japan example

8.1 LNG in Japan

Although Japan since the 1950's extracts both oil and gas in its territories, the volumes are far too small in comparison to the consumption. Today only 4 % of the total gas consumption is supplied through domestic extraction. The rest is imported in the form of LNG.

The history of LNG started in Japan in 1969 with the inauguration of the first import terminal in Tokyo. As of today 31 terminals are in use ranging in volume from 35 000 m^3 to 2 660 000 m^3. The largest number of terminals is situated in Tokyo, Osaka and Nagoya respectively. The terminals are situated all over the country from Hokkaido in the north to Okinawa in the south. Japanese law tells that terminal owners could choose among three different regulations for the terminals. These are the gas regulations, the electricity regulations and the high pressure regulations. 15 of the terminals follow the gas regulations, whereas the rest are divided equally between the two remaining options.

Although transmission pipes connect Tokyo on the east coast with Niigata on the west coast and extend back to Sendai on the north east coast, there is no nationwide transmission grid for gas. The two megacities Tokyo and Osaka *e.g.* so far lack a connecting grid.

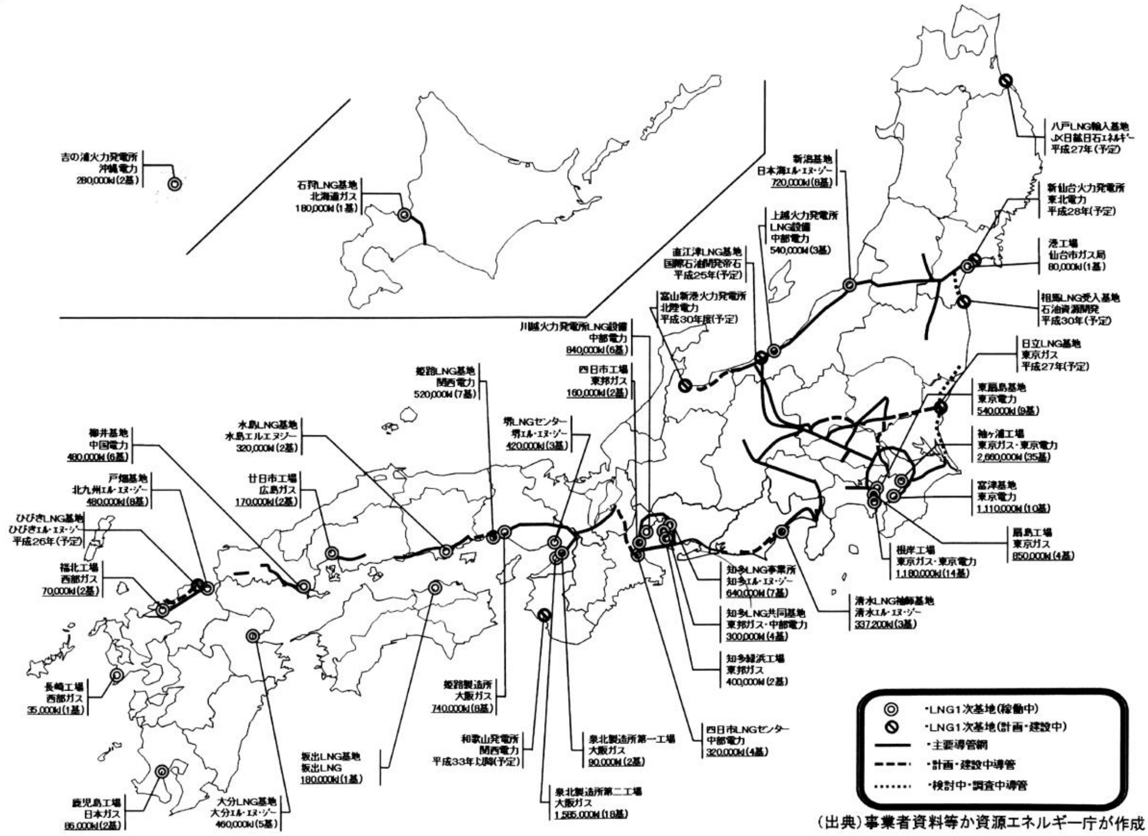


Figure 18. Gas transmission pipelines and proposed such (dotted lines) in Japan. Courtesy of JAPEX.

However, gas is widely used in Japan and in particular for heating and cooking in towns. Old town gas production facilities have been phased out. Today most of them rely on a continuous supply of LNG either directly through an import terminal or a grid, but in many cases also through land based transports of LNG. The distribution companies normally have a local monopoly on gas distribution including that to industrial customers. Transports of LNG on truck are frequent all over Japan. In some locations LNG transports also occur on rail. Tokyo gas was the first company to try such transports during the 1970's on the line between Yokohama and Hitach. Following the extension of the gas grid in the late 1970's these transports stopped. In more recent time three companies have employed container-based rail transportation of LNG, namely JAPEX (more about this company onwards), Osaka gas (on the relation Osaka–Toyama between 2003 and 2012) and Saibu gas (on the relation Fukuoka–Kumamoto starting in 2012). In the following the JAPEX transportation system for rail is discussed more in detail. All companies use the same size and type of container and the container has been built in about 100 copies. 74 of these have been supplied by the company Air Water (http://www.awi.co.jp/english) and the rest from J-Trec (http://www.j-trec.co.jp/eng).

Figure 19. Empty LNG containers stored on the railway station in Tomakomai, Japan. The lighter blue containers on the top are of the J-Trec type and the bottom ones of the Air Water type. Photo: Martin Ragnar.

8.2 The transportation system

Japan Petroleum Exploration Company, JAPEX, is one of Japan's leading energy companies operating a number of oil and gas fields in Japan and supplies natural gas to power plants, local gas distribution companies and industries through a pipeline system of some 1 000 km. JAPEX has been involved in the LNG business since the late 1970's starting in Niigata on the western shores of the main island, Honshu. LNG is mainly purchased from Indonesia and re-gasified by JAPEX for use in the grid. JAPEX also runs one liquefaction plant of its own, situated in Tomakomai on the northern island, Hokkaido, and taking care of gas from the Yufutsu oil and gas field owned by JAPEX. A small portion of the LNG is transported to clients outside of the grid, in what JAPEX refers to as its *LNG satellite system*. The idea of the system is to transport LNG to remote consumption areas where the LNG could be stored and sold to a local market. Originally the satellite system used trucks only for the transports to the satellite terminals with transports reaching up to 190 km at the most and utilizing trucks with an LNG transport capacity of 9.8 tons each since the late 1990's. For distances longer than 200 km the Japanese regulations call for two persons to operate a truck, making such transports expensive and commercially uninteresting. The regulations apply to all fuels, thus being equal for petrol, LPG, diesel – and LNG. However, business opportunities with LNG exist also on greater distances, which was why JAPEX developed LNG transports on rail starting March 15th 2000. Also the harsh climate on parts of Hokkaido was a driving force for JAPEX to go for rail transports on some relations rather than truck transports.

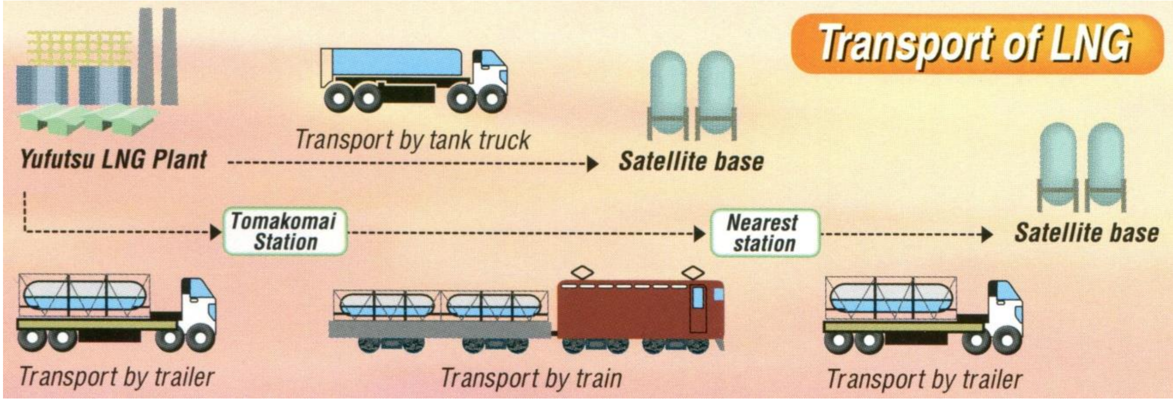


Figure 20. Principle of the JAPEX satellite system for LNG transportation on Hokkaido.

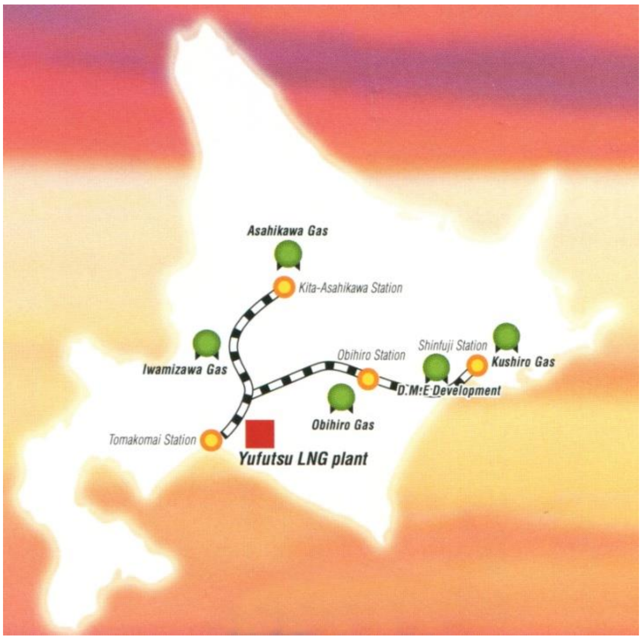


Figure 21. JAPEX rail based satellite system on Hokkaido.

The Japanese regulations have changed somewhat over the years and new and more efficient tank trucks have also been developed from a loading capacity of 13.5 ton in 2002 up to 15.7 ton by 2012. This means that the economically feasible range of trucks has been extended. However, Japanese law sets an upper limit of 17 m length of trailers, setting an upper limit to the possible loading capacity of a truck.

8.3 Details of the system

8.3.1 Containers

The LNG transports use the existing and extensive rail network in Japan. For the transports a special LNG container was developed with the standard 30 feet length having a capacity of close to 10 ton LNG each and as such weighing 10 ton, meaning a loaded container has a weight of 20 ton. An up-to-date budget prize for such an LNG container from Air Water is 1.6 MSEK free from the manufacturing site in Ishikari close to Sapporo.

Figure 22. Air Water's LNG containers for trailers and railcars illustrated in a brochure by Air Water.

Loading one container takes about 45 min including start and stop routines. Two containers could typically be loaded as well as unloaded at the same time.

The pressure vessels have a design pressure of 0.96 MPa and the safety valve opens at 0.8 MPa. The valve is mounted to the right of the back corner of the container. This means that methane released through the valve will be spilled away from rails and electric lines. The container is designed to withstand being dropped fully loaded from 3 m height, which is the typical height to which the top loader lifts it to.

8.3.2 A reliable system

JAPEX argues that its LNG satellite system is a particularly reliable one, especially since many of the customers are located in the far north, including on the isle of Hokkaido, where the climate resembles that in northern parts of Sweden and Finland. In such a climate the railway is more reliable and the risks for accidents small compared to other means of land based transports. However, should something unexpected yet happen, the container based system still allows delivery by truck.

8.3.3 Current system

Currently, the LNG satellite system on Hokkaido includes transports from Tomakomai to Asahikawa (179 km by rail), Obihiro (195 km by rail) and Kushiro (320 km by rail), respectively. Neither the liquefaction plant in Tomakomai, nor any of the customers' receiving terminals are connected to the rail network. This means that each container has to be loaded while carried by a truck, the reloaded onto the railcar and again reloaded onto a truck at the destination. Loading and unloading is carried out using a mobile top-lifter. Finally the container is delivered to the customer and the LNG fed to a storage tank for re-gasification and utilization. The on- and off-loading operations come at a big cost, typically some 30 % of the total transportation cost.

8.3.4 The transport

The containers are owned by Japan Oil Transportation company, which also keep track of the position of each container in real time. Loading of LNG into the container is typically carried out in Tomakomai at around 10 am and by 10 pm the train leaves. At 8 am the following morning the containers are reloaded onto trucks in Kushiro. The empty container leaves back for Tomakomai at around 5 pm. The longest standard times from loading in Tomakomai til empty container in Kushiro is thus 36 h. This time presents no safety problem, since the LNG could easily be kept safe in the container for 3–4 days until the pressure gets too high. Unlike the truck driver the engine driver at Japan Railways (JR) does not have any specific education on LNG, but in practice this is not considered any problem since there are lots of ways to communicate with the central rail control should any problem arise. Each railcar takes two containers and trains of up to 20 cars are possible.

Figure 23. Loading of an LNG container at the JAPEX Yufutsu LNG plant using flexible arms. The container is located on top of a trailer. Photo: Martin Ragnar.

Figure 24. The loaded container on the truck is weighed and then carried away to the railway station. Photo: Martin Ragnar.

Figure 25. The loaded LNG container is lifted off from the trailer, which drives away. The top lifter holds the container in a steady grip and transfers it onto the waiting railcar. Photo: Martin Ragnar.

Figure 26. The loaded LNG container is fitted into its right position on the railcar by the top lifter. Photo: Martin Ragnar.

Figure 27. Loaded LNG containers on top of a railcar awaiting further transportation from Tomakomai to the destination Kushiro. Photo: Martin Ragnar.

8.4 Safety – and incidents

Although each container is lifted twice on its way from the loading terminal to the client, during 15 years of operation only one incident has occurred. One container – although empty – fell off from the top-loader. It was concluded that the reason behind this incident was a malfunction in the control system of the top-lifter which showed a green light, when a red light in fact should have been shown, indicating that the container was not properly fastened in the grip of the loader.

Figure 28. The top lifter has several security points to ensure the container is kept in a steady grip. When all points are correctly fitted a red light turns green and the driver could safely lift the container. Photo: Martin Ragnar.

8.5 Concluding impressions

The JAPEX LNG satellite system appeared to be a very well thought through system, with the only exception of the lack of rail connections in either side. Routines seemed well functioning and safety awareness high. The fact that the transportation capacity of trucks have grown steadily since the railcar set up first was launched presents a long-term threat to the economical sustainability of the rail transports should no new rail connections be built and no further development of bigger and more efficient rail containers take place.

9. Conclusions

Liquid methane in the form of either LNG or LBG could be transported on rail. Such transport should have a potential to be safer than other land-based transports. It would also have a significantly lower environmental impact. LNG has been transported on rail since the early 1970's and experiences have been gained mainly in Japan, but also in the USA and in Norway. Two different set ups are possible – either using a specially designed freight railcar – or using LNG containers which are put on top of a standard railcar. Both systems have been tried in practice. The freight railcar concept has a potential to be more cost-effective when large volumes of LNG should be transported from A to B during a long period of time. The container-based system has an advantage in terms of its flexibility. This flexibility *e.g.* allows the use of rail even when direct connections between the railway system and the LNG terminal lacks. The flexibility could also be utilised such that the container is used as the storage at the site of the customer, who then does not have to invest in a receiving tank. Both systems are likely to find their markets in the Nordic countries in a few years time.

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Torbjörn Larsson, Svenskt Aluminium
Jan Pettersson, Green Cargo
Urban Lavén, Tågåkeriet i Bergslagen
Mikael Eriksson, Trafikverket
Susanne Lindqvist, Sandvik

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Anna Brynås, Swedegas
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Appendices

Appendix 1: Main conclusions of SGC Rapport 236

The conversion potential to replace oil in the energy intensive industries and diesel in heavy transport is estimated in the study to 6.8 TWh and 10 TWh per year, respectively. Several alternative fuels compete for this conversion potential. What fuels will take market share depends on several factors such as price, availability of fuel, availability of process technology and vehicles, technology development and possible future technological advances. For liquid methane to compete a new infrastructure is required that in a cost effective manner makes it possible to distribute the liquid methane to the regions where the need is the greatest. With today's distribution system, including truck delivery from import terminals in Nynäshamn and Fredrikstad, virtually the entire southern Sweden is within reach of LNG deliveries. The study points out three nodes, Gävle, Sundsvall and Luleå, which is suitable for distribution of liquid methane to the central and northern Sweden. The three hubs are suitable for freight transfer to trucks as well as rail and shipping. A strategic nationwide network of refueling stations is also proposed, with a total of 18 new stations, in addition to the filling stations in southern and central Sweden that are already planned or in operation.

Appendix 2: Excerpt rom SGC Rapport 270

4.3.1 Existing plants

In the early 1990s, Prometheus Energy developed a cryogenic process for the upgrading of landfill gas. First, a pilot plant in Canada was build in 2000; later, in 2006, a larger plant with a capacity of 280 Nm³/h (4 800 kg/day) was erected at the Bowerman Landfill in the USA. The energy consumption of the process is 1.54 kWh/Nm³ product gas (N. Johansson 2008).Since then and until today, there have been no updates or other news whatsoever on the plans of Prometheus Energy to further develop the technology. At the moment, Gastreatment Services (GtS) from The Netherlands is the only supplier of cryogenic upgrading technology. GtS have a pilot plant in the Netherlands, consisting of a unit for CGB production and another unit with higher capacity for liquefaction. Therefore, the two units are linked via a buffer and the liquefaction unit must be operated semi-batchwise. Apart from the pilot plant, GtS have built commercial cryogenic upgrading plants in Loudden and Sundsvall in Sweden. Another plant was originally planned in Varberg but will not be built. GtS does not give any statements on the state of the existing plants. Therefore, the following information is collected from different persons involved in the operation of the plants. The Loudden plant at Tivoliverket is owned by Scandinavian Biogas Fuels AB and has been built since 2009 with a planned capacity of 400 Nm³/h of raw biogas. Since then, the plant has had several severe operational problems ranging from programming issues to leakages and design flaws for heat exchangers and cooling machines. Also, the gas entering the liquefaction step contained too high concentrations of carbon dioxide, c.f. Table 11. This should have been corrected by the addition of a polishing step using a molecular sieve, which never has been implemented. In late 2011, the first LBG was produced, however, the production never exceeded very limited flows. Most of the problems have been solved in the meantime, but there is no more activity from GtS at the moment. After having cancelled all contracts with

GtS, Scandinavian Biogas Fuels will require the removal of the plant and is looking at other, conventional solutions for upgrading and distribution. The situation in Sundsvall is similar. According to Mittsverige Vatten, the supplier of the raw gas, the plant is almost finished but is not able to produce noteworthy amounts of liquid biogas on a continuous basis. The gas supply contract as well as the building license have expired in autumn 2012. In the meantime, GtS have announced the delivery of a new plant for LBG production to the Schoteroog landfill in Haarlem in the northern part of the Netherlands. This is near the headquarter of GtS, which should give much better conditions to work with the plant optimization and handle and solve practical problems. The plant is to treat gas from the nearby WWTP with a total raw gas flow of 280 Nm³/h equivalent to approx. 122 kg/h of LBG. The upgrading part of the plant is in operation since mid 2012 and is reported to work as expected. The liquefaction step has been commissioned in autumn 2012, but without any information on its operability at the hour of writing. Methane losses are specified by GtS to be less than 2 %, and can be expected to be below 0.5 % in an optimized plant (K. Andersson et al. 2009). Electricity consumption is expected by GtS to be approx. 0.45 kWh/Nm³ raw gas for LBG production. Almost 100 % of the CO_2 can be recovered as LCO_2; however, this will increase the energy demand of the process. The LBG is normally produced at an elevated pressure of 17 bar(a), which implies that it can be stored at temperatures much higher than -160 °C. This can be an inconvenience for distribution purposes since the margin to the pressure where the boil-off of the LBG must be released to the atmosphere becomes quite small. If the LBG was produced at lower pressure (and hence lower temperature), it could be stored for a longer time without the need to release boiled-off gas.

Apart from GtS, a small startup company in Gothenburg called BioFriGas is aiming at developing a small scale, low budget cryogenic biogas upgrading and liquefaction process. Work has begun and a first pilot plant has been built at Sobacken, the waste treatment plant in Borås in Sweden. At the moment, the only information available on the planned process available is that it is supposed to be based on standard equipment and shall have a capacity of 25 Nm³/h.