Consider Mid-Scale LNG to Monetize Natural Gas

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Introduction/Background

Today, about 80 large LNG trains worldwide produce LNG for the world market. Plants currently under construction typically have train sizes in excess of 4.0 million tons of LNG per year (World-Scale LNG). Qatargas' trains 4 to 7 and Rasgas' trains 6 and 7 each have production rates of 7.8 million tons LNG per year continuing the industry's trend towards even bigger trains.

At the same time, the number of reservoirs supporting such large trains is limited. Additionally, such reservoirs may be difficult to access for various reasons such as remoteness, geological or political obstacles. Accessing those reservoirs requires more resources, capabilities and balance sheet strength than ever before. The above mentioned circumstances have prompted some market players to evaluate Mid-Scale LNG technologies and opportunities.

For the purpose of this paper Mid-Scale LNG shall mean LNG plants with a train capacity *between 300,000 and 1,000,000 tons of LNG per year*. The high end represents the capacity which comfortably can be implemented with a single flow mixed refrigerant cycle using one compressor train as well as current compressor and driver technology. The low end represents a threshold below which the diseconomies of scale in jetty, tank and infrastructure tend to become too dominant. The paper focuses on single mixed refrigerant processes which are considered the most appropriate process technologies for a base load LNG service of significant size. Other processes available, such as single or double nitrogen expander processes, require up to 80% more power and towards the upper end of the above-mentioned range have significant higher equipment count and have therefore not been considered for this paper.

Objectives of the paper

The objective of the paper is to evaluate the differences between World-Scale LNG plants and Mid-Scale LNG plants and also to identify conditions under which building a Mid-Scale LNG plant should be considered as an alternative to investing in a World-Scale LNG project.

Discussion & Methods

For the purposes of this paper World-Scale and Mid-Scale LNG plants are compared on the basis of project set-up, technology, plot space, infrastructure requirements, schedule, and cost. LNG production costs are estimated for typical Mid-Scale project scenarios.

(a) Project Set-up

Looking at World-Scale and Mid-Size LNG projects, some important differences can be noted. While World-Scale LNG projects are typically fed from one or several dedicated non-associated gas reservoirs, Mid-Scale LNG projects typically take-off pre-treated feed gas from an existing pipeline system. In other cases Mid-Scale LNG Projects utilize associated gas from nearby oil reservoirs.

The necessity of developing dedicated gas reservoirs for a World-Scale LNG Project largely impacts schedule and capital requirements. Exploration, appraisal and environmental approval activities influence the schedule and decision process. These activities together with development of field infrastructure and pre-treatment facilities require significant upfront capital which often exceeds the capital required for the LNG facility itself. Mega trains or multiple train developments are often seen as an adequate strategy to better amortize such significant upfront investment. However, this adds more capital requirements to the project. Only a limited number of national and international oil and gas companies worldwide have sufficient expertise and financial strength to lead a World-Scale

LNG development. This situation is further amplified by the fact that large reservoirs, sufficient in size to support a World-Scale LNG development, are becoming increasingly scarce and are increasingly associated with political or technical challenges. In addition, World-Scale LNG Projects typically involve multiple equity partners whereby reservoir owners often take a leading role and LNG off-takers often hold minor stakes.

While one needs to be cautious in making general statements about how economics of Mid-Scale LNG projects compare to World-Scale LNG projects given the large number of variables, a few observations can be made. Mid-Scale LNG projects fed from pipeline are significantly less capital intensive than World-Scale LNG Projects. They make use of existing field and pre-treatment infrastructure upstream of the pipeline system which normally is of a reasonable size. This equally applies to Mid-Scale LNG projects fed with associated gas. Even though they may, in some cases, require a dedicated pre-treatment section, upstream development is driven by oil production and associated gas is considered a by-product which needs to be taken care of in a beneficial way.

The above-mentioned differences result in lower capital requirements, shorter schedule and potentially higher feed gas prices for Mid-Scale LNG Projects compared to World-Scale LNG Projects. World-Scale LNG Projects normally can benefit from LPG and condensate production to help amortize the upstream development costs. Pipeline based Mid-Scale LNG Projects do not enjoy any significant benefits from natural gas liquids. Pipeline transportation capacities need to be committed and paid for on a long term basis. Natural gas liquids sales from associated gas may help to carry the dedicated investment in pipeline and somewhat subsidize the pre-treatment section of a Mid-Scale LNG Project.

(b) Technology

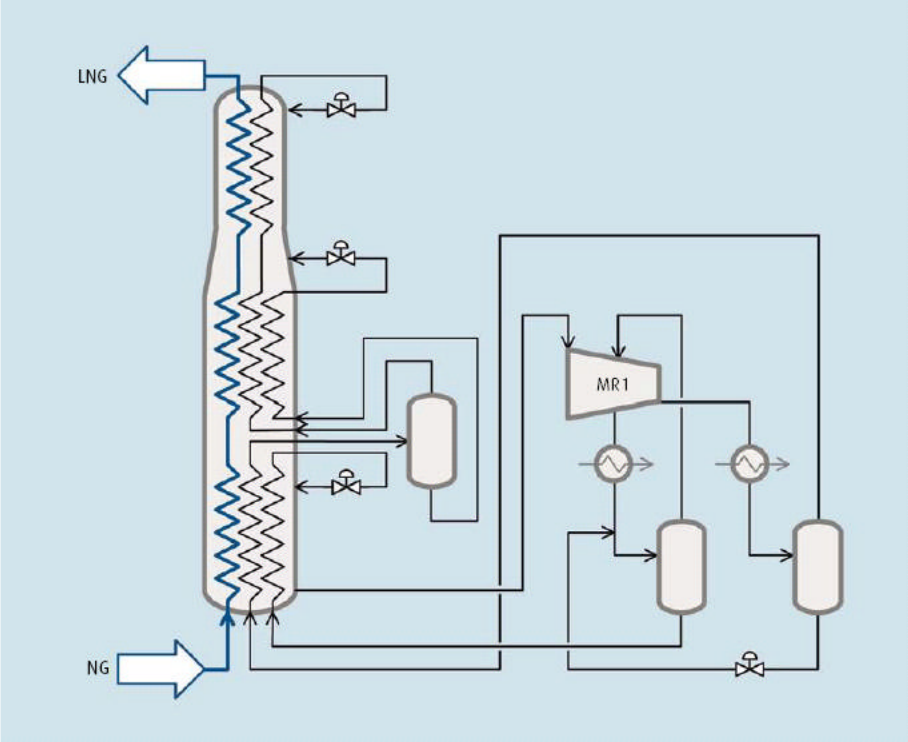
World-Scale as well as Mid-Scale LNG plants, with few exceptions, use mixed refrigerant processes. The rationale of using gas mixtures of hydrocarbons and nitrogen as a refrigerant is to create a wide temperature range of evaporation which allows close alignment of the temperature profile of the refrigerant during evaporation to the temperature profile of the feed gas during pre-cooling, liquefaction and sub-cooling. The bulk of the cold service utilises the latent energy of the refrigerant at a temperature level allowing minimum temperature differences in the main heat exchangers resulting in energy efficient liquefaction.

The first LNG plants based on the Prico process used multiple plate fin heat exchangers in liquefaction service. Later, coil wound heat exchanger design was modified for LNG service and became a standard in World-Scale LNG liquefaction. In a coil wound heat exchanger, the liquid mixed refrigerant enters at the top of the coil wound bundles inside the heat exchanger shell and evaporates on its way down. Feed gas enters the pipes of the bundle at the bottom and liquefies on its way to the top. Coil wound heat exchangers have some characteristics which make them intrinsically robust and safe. Firstly, pipes of a bundle are not welded or joined but wound to a bundle allowing relative movement to accommodate uneven contraction and expansion induced by temperature differences. Secondly, in the very rare event of a pipe leakage, hydrocarbons are contained in the outer shell thereby preventing leakage to the atmosphere. Despite leakage, the LNG plant will normally be able to maintain production until the next revision stop by monitoring the refrigerant composition. Plugging of defective pipes can be completed in a few days and does not result in a noticeable loss of production.

Since the development of the original Prico process, numerous mixed refrigerant processes have been developed. In Word Scale LNG, AP's C3MR process which uses propane as a pre-cooling refrigerant and a mixed refrigerant and coil wound heat exchangers (CWHE) in liquefaction and sub-cooling, has been the work horse of the industry for several decades now. Mid-Scale LNG is still in an emerging phase. There are currently two approaches to Mid-Scale LNG: Scaling up small sized LNG concepts and customized processes for Mid-scale LNG production. Scaling up small-sized LNG concepts with simple process topography typically includes little or moderate energy optimisation, plate fin heat exchangers and standardized modules. On the other hand customized, energy optimized process topographies using coil wound heat exchangers and applying World-Scale LNG safety and design standards are optimized for Mid-Scale production.

The following scheme illustrates a single mixed refrigerant process of a Mid-Scale LNG project currently under execution near Stavanger, Norway. It is also applied in a Mid-Scale LNG plant in Shanshan, China, which was started up in 2004.

Figure 1: Process scheme of single mixed refrigerant process



Refrigeration for the liquefaction of natural gas is provided by using a closed loop cycle system of a mixed refrigerant composed of methane rich gas, nitrogen, ethane (or ethylene) and butane. Compression of the gaseous mixed refrigerant is achieved using a two-stage Cycle Compressor which is driven by an adequate, speed controlled driver (gas turbine, steam turbine or VSD motor).

Mixed refrigerant at low pressure from the shell side of the coil wound heat exchanger (CWHE) enters the first stage of the compressor where it is compressed to medium pressure and then partially condensed against air. The liquid phase is separated, pre-cooled in the CWHE and expanded via a Joule-Thompson valve. It enters the shell side of the CWHE and is used for pre-cooling of itself and natural gas.

The gaseous phase enters the second stage of the compressor, is compressed to a high pressure and again partially condensed. The liquid phase leaving the high pressure separator is fed back to the medium pressure separator; the gaseous phase is pre-cooled in the CWHE, partially condensed and separated into a heavy and a light mixed refrigerant. The liquid heavy mixed refrigerant is sub-cooled, expanded by a Joule-Thompson valve and fed to the shell side of the CWHE, thus providing sub-cooling for itself and liquefying the natural gas.

The gaseous light mixed refrigerant phase is first condensed and then sub-cooled in the CWHE, before being expanded by a Joule-Thompson valve into the shell side of the coil wound heat exchanger, thus providing sub-cooling for itself and the natural gas.

The three fractions of the refrigerant are recombined in between each bundle in the shell side of the CWHE and the mixture migrates to the bottom of the exchanger where it leaves the exchanger superheated towards the first stage of the refrigerant compressor as described above.

(c) Safety and Standards

Mid-Size LNG technology does not compromise on safety, reliability, robustness or efficiency. Applied processes and equipment are well-proven in base load service, comply with API standards and overall safety philosophies and are derived from World-Scale LNG projects. However, based on standard industry risk acceptance criteria, necessary safety distances inside of Mid-Scale LNG plants are significantly lower than those of World-Scale LNG plants. A comparison between an executed 4.3 and 0.3 million tpa LNG plant including respective calculations of risk contours result in safety distances from the centre of the process plant to the nearest possible location of the plant fence of about 250m and 750m for a World-Scale LNG plant respectively. One main reason for the differences is the significantly increased amount of hydrocarbon inventory in World-Scale LNG plants as a result of the increased mixed refrigerant inventory and larger tank sizes.

Increased hydrocarbon inventory raises the potential fire and explosion loads which, in turn, tighten the requirements regarding the so called design accidental loads (DAL) for the plant equipment and bulk material. This either leads to increased investment cost for reinforcement of the equipment or to increased plot space requirements to bring down the degree of congestion.

(d) Plot Space, Location and Infrastructure

Plot space requirements of Mid-Scale LNG plants differ significantly from World-Scale LNG plants. A Mid-Scale LNG plant including buildings, flare, LNG tank and utilities requires a plot space in the magnitude of 50.000 m^2, while World-Scale LNG plants require in excess of ten times more plot space. Generally spoken World-Scale LNG plants do not benefit from economies of scale regarding plot space, but may even require proportionally larger plot spaces than expected based on the sheer scale in capacity and equipment. There are several reasons for this tendency.

Firstly, a World-Scale LNG plant in most cases requires a dedicated power generation system. Although the main refrigerant cycle compressors are often mechanically driven by gasturbines, the large amount of smaller size machinery which is driven by electrical motors constitutes such high demand on electrical power that it cannot be supported from existing electrical infrastructure. In contrast, Mid-Scale LNG plants are connected to the electrical network and no dedicated power generation system is required if the main refrigerant compressor is directly driven by a gas turbine. Depending on the boundary conditions, Mid-Size LNG plants up to a capacity of 500.000 to 700.000 tpa may use the electrical network to electrically drive the main refrigerant compressor.

Furthermore, Mid-Scale LNG plants are often fed with pre-treated feed gas from existing pipelines systems. As a consequence, all or most plot space requirements for pre-treatment facilities, as well as condensate stabilisation and fractionation units are eliminated. In such cases where small quantities of natural gas liquids are removed, for example to adjust the heating value or achieve a methane number of the produced LNG, removed hydrocarbons are preferably used as fuel for the turbine or hot oil system and no condensate or LPG tanks are required.

Construction of a Mid-Scale LNG plant also requires significant less area for lay down and work camps. The sheer size of the work force in a World-Scale LNG project (typically exceeding several thousand men in peak times) itself poses one of the major challenges; especially since most World-Scale LNG plants are located in remote areas. Most of the World-Scale LNG projects are Greenfield projects for which a complete infrastructure incl. parking, access streets, administration buildings and also all utilities including the power plant must be established. In Mid-Scale LNG projects, the requirements for lay down areas and work camps are moderate in comparison and in many cases a significant part of the workforce recruits from the region.

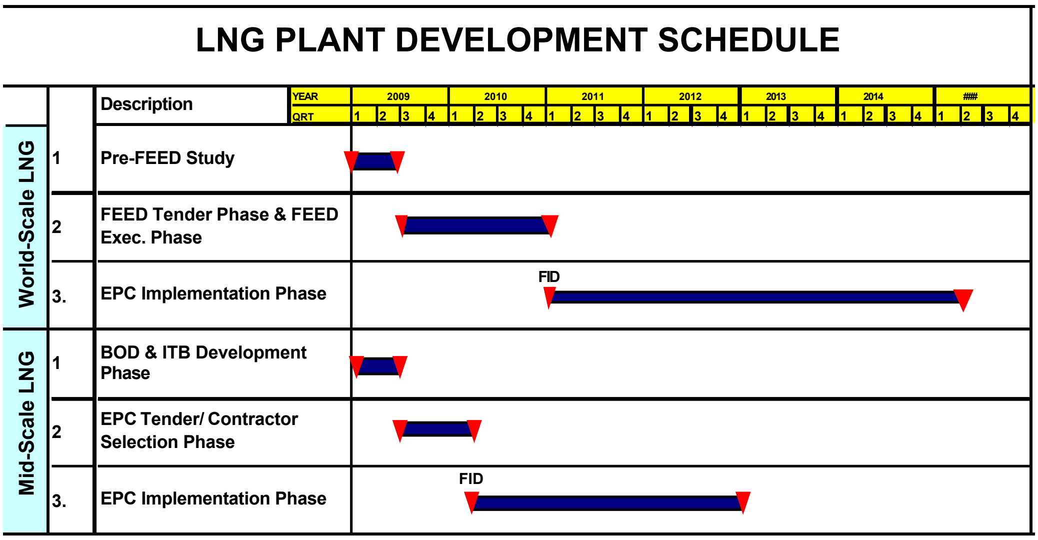
In summary, plot area, work force and camp size as well as explosion loads and building heights are lower for Mid-Scale LNG plants. These factors, especially at the lower end of the capacity range, allow the LNG plant to be located in industrial zones and thereby also benefit from existing infrastructure. Some sites which are typically considered as a Mid-Scale LNG location such as refinery sites, iron ore, bauxite or container terminals may even offer wharf and jetty infrastructure. All the above can reduce overall Mid-Scale LNG project costs significantly.

(f) Schedule

Prior to commencement of any significant plant engineering activities, items such as exploration in World-Scale LNG projects, appraisal and environmental approval activities as well as the development of field infrastructure may take many years. Plant engineering activities prior to a final investment decision (FID) in World-Scale LNG, in most cases, involve a Pre-FEED and a FEED study. The latter already includes a significant level of detail engineering activities, including a 30% plant model as a basis for a reasonably precise cost estimate. This need for detailed engineering is to a large extent driven by the sheer size and complexity of World-Scale LNG projects. It typically takes two years to complete Pre-FEED and FEED activities prior to any final investment decision.

Mid-Scale LNG projects, compared to World-Scale LNG projects, are fast track projects. Securing off-take rights from existing natural gas pipeline systems prior to starting serious plant engineering activities takes comparatively little time. Mid-Scale LNG projects in most cases can be tendered without upfront detailed engineering. Based on a high-quality basis of design there are contractors available to quote a firm price for engineering, procurement and erection (EPC) of a Mid-Scale LNG plant. All in all it may take around fifteen months to properly prepare for final investment decision from commencement of plant engineering activities. Construction activities of Mid-Scale LNG projects will take in the order of one and a half years less than construction activities of World-Scale LNG projects. Mid-Scale LNG projects from commencement of first plant engineering activities can be expected to produce first LNG at least two years earlier than a World-Scale LNG plant. Taking into account the entire project development phase Mid-Scale LNG projects, in many cases, will produce first LNG four to five years earlier than World-Scale LNG projects.

Figure 2: Typical Schedule of Mid-Scale and World-Scale LNG project



(g) Cost

While diseconomies of scale are certainly relevant for Mid-Scale LNG plants compared to World-Scale LNG plants, in reality, several benefits can be noted which may off-set diseconomies.

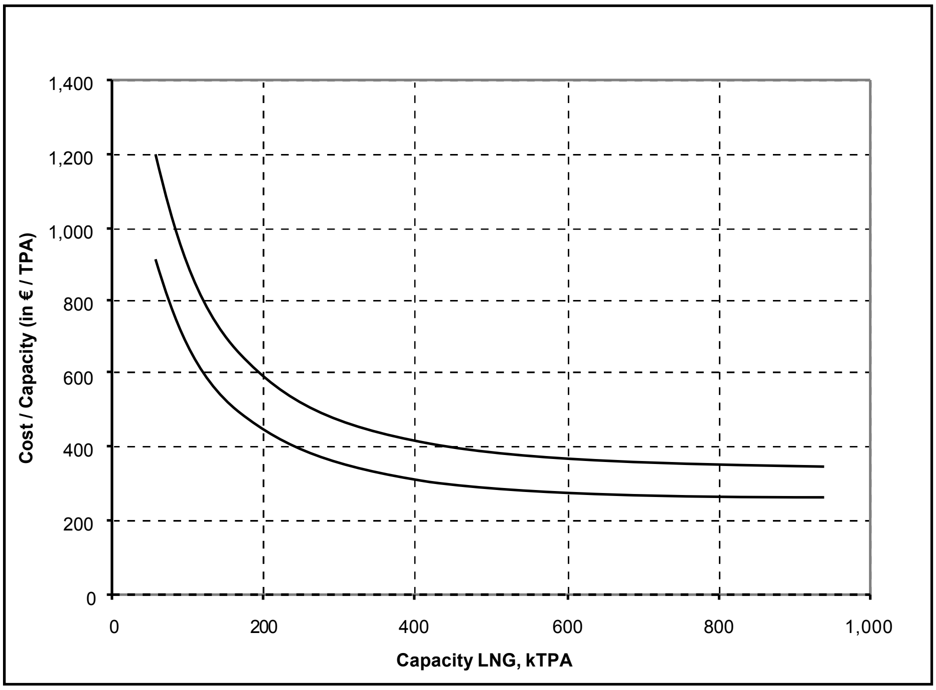
Mid-Scale LNG plants typically use standard sized machines, equipment and instrumentation and can draw upon a much larger vendor pool which results in more competitive pricing. This is particularly significant in the case of the main refrigerant compressor/driver-string. Due to shaft power requirements in excess of 60 MW_{el} (often combined with cold temperatures on the suction side) in World-Scale LNG plants, only single shaft centrifugal compressors manufactured by a limited number of companies can be used. For Mid-Scale LNG Plants the number of potential compressor suppliers with respective references is higher. If electrical motors are chosen as driver, integrally geared compressors are available for which a significantly higher number of manufacturers exist. This situation is even more distinctive for the gas turbines used as drivers of the refrigerant compressors. With the exception of the Snøhvit LNG project, all existing World-Scale LNG plants feature a direct mechanical gas turbine drive using Frame 7 or Frame 9 turbines. For Mid-Scale plants numerous proven gas turbines for mechanical driver applications exist (e.g. LM2500, Frame 5, SGT 700, RB211, Vectra), most of which in LNG service.

For instrumentation, electrical equipment as well as for piping, the situation is similar as described above; however, the number of potential suppliers for World-Scale LNG plants is somewhat higher. Local construction and erection markets are less strained by Mid-Scale projects and can draw upon mid-size segments of local and regional contractors.

In figures 3-5, following, costs of Mid-Scale LNG plants as a function of LNG capacity are illustrated by costs graphs for the three main functional groups: process plant including utilities, tank and jetty. All costs are based on Western European prices and are understood as all inclusive prices for the engineering, procurement and erection of the plant.

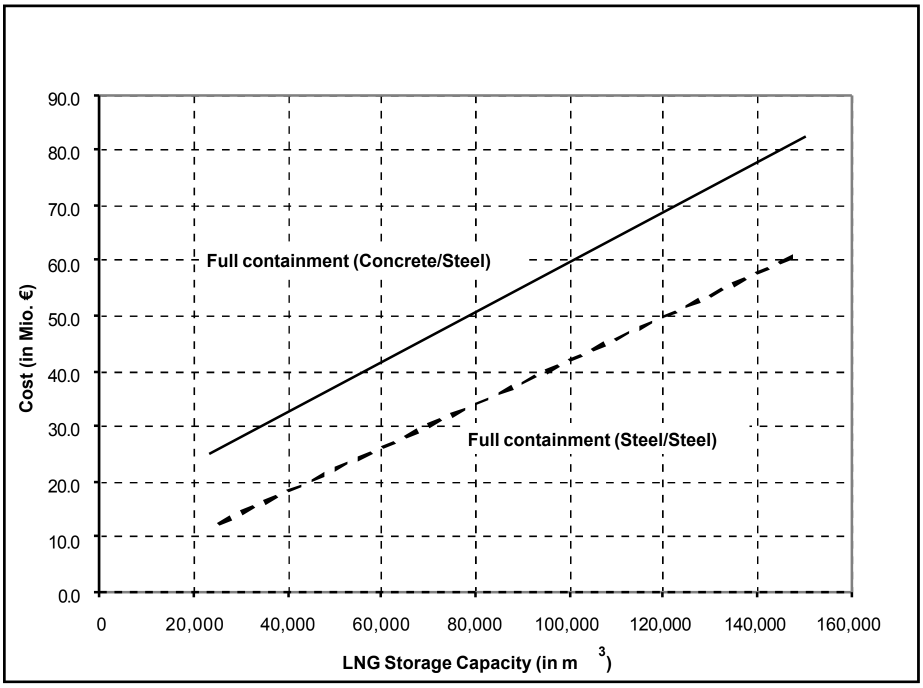
Figure 3 illustrates specific costs of Mid-Scale LNG plants in Euro per ton of installed LNG capacity (run-down to LNG tank). The upper and lower curves describe the bandwidth of costs depending on specific project boundary conditions e.g. feed gas conditions and composition, driver concept, location (especially influencing the construction cost). The data is derived from executed Mid-Scale LNG projects of Linde Engineering as well as from recent turn key lump sum cost estimates. Specific plant costs significantly decrease with increasing capacity up to approximately 300,000 tpa. Economies of scale are less significant for larger capacities.

Figure 3: Specific costs of Mid-Scale LNG plants



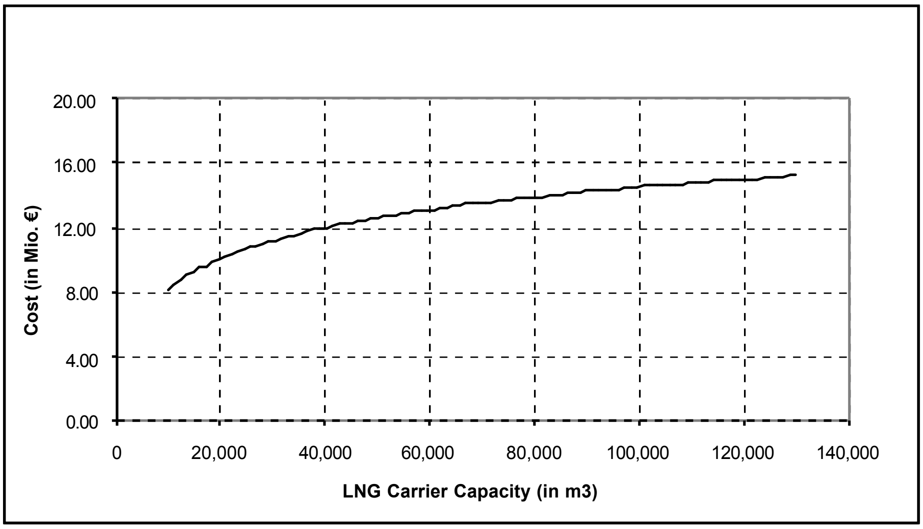
A relevant part of the overall cost of a LNG plant results from storage and loading. Cost curves in Figure 4 illustrate typical full containment storage tank cost as a function of tank size between 20,000 and 140,000 m³ of geometric volume. For steel/steel tanks as well as for concrete/steel tanks there is a linear correlation between storage capacity and cost. Concrete/steel tanks are more expensive than steel/steel tanks.

Figure 4: Costs of full containment tanks



Cost graphs in figure 5 illustrate costs for a jetty of moderate complexity as a function of the maximum possible size of LNG carriers to be moored at the jetty. The slope of the cost graph decreases with increasing capacity.

Figure 5: Costs of Jetty (moderate complexity)



By applying the three diagrams illustrated above a rough cost estimate for a Mid-Scale LNG plant with a given LNG capacity, LNG tank and jetty size can be developed.

(h) Modularisation

Modularisation is a valid strategy. Module sizes and weights are considerably smaller for Mid-Scale LNG plants where even the tallest modules would not exceed a footprint of 20 m x 20 m and weights would not exceed 1,000 metric tons. Such sizes and weights can be easily lifted without being limited to only a few available special cranes, as would be the case for bigger modules being applied for World-Scale LNG plants. Furthermore, sites are more accessible with smaller modules and it is likely that modules can be hauled in without dedicated new port investment in the case of Mid-Scale LNG plant modules. Last, but not least, a larger pool of potential module yards is available around the world for moderately sized modules. Some of the more complex and heavier modules of World-Scale LNG plants can only be built by a handful of yards.

(i) Economic Considerations regarding Mid-Scale LNG Projects

The economic viability of Mid-Scale LNG projects depends on many variables. Some of those variables, especially shipping cost and LNG market prices, depend on the destination of the LNG and the overall and specific market situation. Those variables are difficult to predict. Still, based above cost graphs specific liquefaction costs from feed gas off-take to jetty can be estimated.

Total EPC-costs for a Mid-Scale LNG plant with a capacity of 300,000 tpa, 140,000 m³ full containment concrete/steel tank and a jetty suitable to load carriers of up to 120,000 m³ are estimated to be in the magnitude of 320 million USD (@ EUR/USD: 1.40). During roughly three years of construction, approximately 20 million USD interest would accumulate during the construction period. Considering fuel gas consumption, maintenance, operations and a pre-tax internal rate on return of 12% over 15 years, specific LNG production costs, excluding costs for feed gas, would amount to approximately 4.20 USD per mmBTU of LNG. A similar calculation for a Mid-Scale LNG plant with a capacity of 500,000 and 1,000,000 tpa of LNG results in specific production cost of 3.40 and 2.30 USD per mmBTU of LNG respectively. All above scenarios assume that LNG is sold into the global LNG commodity market and, as a prerequisite, reasonably-sized LNG carriers will be used to achieve synergies with existing LNG carrier fleets and terminals. While the economics may have looked enticing across the entire capacity range just a year ago, in today's soft global LNG market conditions exporting from Mid-Scale LNG plants appears to require some reasonable plant size in excess of 500,000 tpa.

A number of Mid-Scale LNG projects have been developed to supply LNG to regional markets based on truck transport (rubber-tyre pipeline) or on smaller seagoing vessels in recent years. These projects, rather than targeting a global LNG commodity market, focus on substituting distillate fuels or LPG in trucking, remote power, shipping or process industries. In such cases, total EPC costs can be significantly lower since jetty or truck loading investments are lower and LNG tank capacities will typically be determined as a multiple of daily production (e.g. 10 days) rather than by minimum LNG carrier size. Total EPC-costs of such a merchant Mid-Scale LNG plant with a capacity of 300,000 tpa, a 20,000 m³ full containment steel/steel tank and a truck loading are estimated in the magnitude of 200 million USD leading to specific LNG production cost of 3.00 USD per mmBTU of LNG. Given healthy global distillate prices – especially low sulphur diesel which quotes above 10 USD per mmBTU at current crude prices of around 60 USD/bbl - such production costs appear viable in many regions with indigenous natural gas resources. Especially in instances where natural gas markets and pipeline distribution systems are poorly developed.

Complementing a Mid-Scale LNG export scheme with a merchant LNG component may be a good idea, not only from a commercial perspective, but also at a political level. Such approaches in some regions may gain political favour by directing part of the LNG to domestic applications in which a more environmentally friendly fuel replaces diesel and/or gasoline, while at the same time improving the trade balance if distillates are imported.

(j) Conclusions

Mid-Scale LNG plants are an economically interesting alternative to World-Scale LNG plants. While export schemes appear to require plant capacities above 500,000 tpa, merchant LNG schemes appear economically attractive already at smaller capacities. Mid-Scale LNG plants, by virtue of their moderate size and complexity, have the potential to be located in industrialized areas which allows investment in infrastructure to be kept at reasonable levels. Capital requirements and execution risks are significantly lower than in World-Scale LNG projects. Moderate size and complexity allows companies lacking the resources of an international oil & gas major to develop and even fully control an LNG project while enjoying an equal amount of off-take, level of safety, quality, reliability and a comparable efficiency as in a minority shareholding of a World-Scale LNG project. Moreover, Mid-

Scale LNG offers a unique opportunity to monetize local or regional gas surpluses of moderate size in a fast track fashion.