

## **HYDRATE NON-PIPELINE TECHNOLOGY FOR TRANSPORT OF NATURAL GAS**

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### **SUMMARY**

The economics of natural gas transport depends greatly on the annual volumes and transport distances. Pipelines are readily used for distances less than 1000 km and large volumes, while LNG (liquefied natural gas) technology is used for much larger distances. Other non-pipeline technologies are considered suitable for other annual volumes and transport distances. Natural gas hydrate (NGH) technology represents a new non-pipeline technology that is suitable for the transport of small-to-medium annual volumes of natural gas over moderate distances. Surveys of natural gas resources world-wide indicate that about 80% of new discoveries will be smaller than the minimum required to make LNG transport economical (mature technology). Hence the great interest in NGH and similar new technologies. Several groups are developing NGH technology world-wide, including NTNU and Aker Kvaerner Technology in Norway. NGH technology is lower in cost than LNG technology, based on mid-1995 and mid-2002 cost studies for large-scale natural gas chains (NGH will be even more competitive for small-to-medium sized chains). When NGH technology matures its costs are expected to decrease and be even more favourable compared to LNG technology.

## **LA TECHNOLOGIE DU TRANSPORT HORS PIPE DE GAS NATUREL SOUS FORME D'HYDRATES**

### **RESUMÉ**

Le choix d'un mode de transport pour le gaz naturel dépend beaucoup des débits annuels et des distances considérées. Le transport par pipeline peut être utilisé sans grande difficulté pour des distances inférieures à 1000 km et des gros débits, tandis que la technologie du GNL (Gas Naturel Liquéfié) est employée pour des distances bien supérieures. Pour des débits annuels et/ou des distances différentes, de nouvelles solutions seraient plus à même de convenir que le transport par pipe. Les technologies fondées sur les Hydrates de Gas Naturel représentent une alternative adaptée au transport de débits petits à moyens sur des distances raisonnables. Des études portant sur les ressources mondiales en gaz naturel indiquent que 80% des nouvelles découvertes concerneront des gisements trop petits pour être exploités de façon rentable en utilisant la technologie du transport par GNL (technologie mature). D'où le grand intérêt des hydrates et des autres nouvelles technologies. Plusieurs organisations sont en train de mettre au point la technologie du transport par hydrates dans le monde, dont NTNU et Aker Kvaerner Technology en Norvège. Le transport sous forme d'hydrates promet d'être moins coûteux que le transport sous forme de gaz naturel liquéfié, selon des études de coûts réalisées mi-1995 et mi-2002 sur des chaînes de traitement (production, transport, regazification) de grande taille (la technologie des hydrates sera encore plus compétitive pour des productions petites à moyennes). On s'attend à ce que l'emploi des hydrates devienne de plus en plus économique à mesure que la technologie se développe et encore plus avantageux comparé au transport sous forme de GNL.

## 1. INTRODUCTION

The economics of natural gas transport depends greatly on the annual volume and transport distance. Pipelines are used for distances less than 1000 km and large volumes, while LNG (liquefied natural gas) technology is used for much larger distances. Other non-pipeline technologies are considered suitable for other annual volumes and transport distances. Natural gas hydrate (NGH) technology represents a new non-pipeline technology that is suitable for the transport of small-to-medium annual volumes of natural gas over moderate distances. Surveys of natural gas resources world-wide indicate that about 80% of new discoveries will be smaller than the minimum required to make LNG transport economical. Hence the great interest in NGH and similar technologies.

LNG technology is well established and continues to be improved to give lower costs [1]. The liquefaction of methane reduces its volume by about 600-times. CNG (compressed natural gas) technology suitable for natural gas transport is under development [2]. The compression of natural gas reduces its volume by about 200-times. NGH technology is being developed in Norway for associated and non-associated natural gas applications [3, 4] and in England [5].

The choice of technology for natural gas transport applications depends on many factors. Among the factors are the scale (capacity, size) of development and distances to markets. The feasibility of LNG technology is highly dependent on scale, making development less than 4 BCM (billion cubic metre) per year of limited economic interest. This rules out the use of LNG technology in small-to-medium sized applications because most of the resources are much smaller [6]. CNG and NGH technologies are more suitable for such applications because they better match the scale of development and are reported to cost less. An important cost advantage of LNG technology is that it has matured, while NGH and CNG technologies are new and not yet mature.

## 2. HYDRATE R&D

Research and Development at the Norwegian University of Science and Technology (NTNU) on the use of hydrates to store and transport natural gas dates back to the early 1990's. The work demonstrated that natural gas hydrate solids produced in a particular way remain practically stable at atmospheric pressure when refrigerated to about  $-15\text{ }^{\circ}\text{C}$  and stored in air [7]. Other and lower temperatures can also be used. In subsequent laboratory work the production of hydrate in a continuous stirred tank reactor (CSTR) was studied and the flow properties of hydrate slurries measured.

Parallel with the laboratory work at NTNU, Aker Engineering (now Aker Kvaerner Technology), designed hydrate production processes for dry hydrate and slurry hydrate. The dry hydrate process is intended for long-distance transport of natural gas, while the slurry process is suitable for capturing of associated gas on FPSO's (floating production, storage and offloading). The investment costs of the two processes (dry hydrate and slurry hydrate) were estimated and found to be attractive [4, 8].

In-house studies in several companies indicate that NGH technology has a special role to play when moderate (small-to-medium) volumes of natural gas are involved; that is, not the large volumes needed to make LNG technology attractive. Therefore, the capital cost of NGH technology in small-to-medium sized developments is expected to be more attractive than estimated for large-scale development.

Current work at NTNU is on the rate of hydrate formation in a stirred reactor [9, 10]. The work aims to extend the previous reactor results to higher superficial velocities and to model the rate of hydrate formation at conditions planned in pilot-scale and eventually commercial-scale reactors. In previous work the production rate achieved in a 9 litre reactor was about 1 tonne/day; in recent work the production rate obtained is about 2 tonne/day of hydrate. It is not the reactor that limits the production rate, but the hydrate handling facilities in the laboratory. Several doctoral studies have been completed under the umbrella of the NGH at NTNU project [11, 12, 13, 14].

## 3. COST STUDIES

Natural gas hydrates contain 150-180  $\text{Sm}^3$  of natural gas per  $\text{m}^3$  of solid, depending on the pressure and temperature of production, and the composition of the natural gas feedstock. This property makes hydrates economically interesting for storage and transport of natural gas, especially when refrigerated at the right conditions to a low-enough temperature to be practically stable at atmospheric pressure. The frozen hydrate is transported at atmospheric pressure in

large bulk carriers to market, where the hydrate is melted and the natural gas recovered. In situations where gas storage is required, natural gas can be converted to hydrates and stored at atmospheric pressure and refrigerated. The storage operations can be small or large, and can be land-based or offshore.

An early study of a dry-hydrate application was an offshore natural gas field in the Barents Sea of Norway [15]. Cooling water (seawater) temperature was taken as 5 C. The natural gas was assumed piped to shore and two alternative gas chains were studied: LNG chain and NGH chain. Both chains consisted of on-land production facilities, sea-transport by tankers and on-land regasification. The capacity of the chains was assumed 4.1 BCM per year (same as one standard LNG train of 400 MMscfd (million standard cubic foot per day)) and the transport distance from Norway to Continental Europa was assumed 3500 nautical miles. The results obtained are shown in Table 1. It was found that the capital cost of NGH technology was about 24% lower than the capital cost of LNG technology.

| Chain          | LNG         | NGH         | Difference |
|----------------|-------------|-------------|------------|
| Production     | 1220 (51%)  | 792 (44%)   | 428 (35%)  |
| Carriers       | 750 (32%)   | 704 (39%)   | 46 (6%)    |
| Regasification | 400 (17%)   | 317 (17%)   | 83 (21%)   |
| Total          | 2370 (100%) | 1813 (100%) | 557 (24%)  |

Table 1 - Comparison of capital cost of NGH and LNG chains for 400 MMscfd production and transport over 3500 nautical miles (6475 km). Million US dollars mid-1995.

A recently completed study compared the capital costs of NGH technology and LNG technology at current cost conditions (mid-2002). The situation studied was a natural gas field in South-East Asia. Cooling water (seawater) temperature takes to be about 35 C. Both chains consisted of on-land production facilities, sea-transport by tankers and on-land regasification. The capacity of the chains was assumed 400 MMscfd, equivalent to 3 MMTPY (million tonne per year) of LNG. The transport distance from production site to market was assumed 6000 km (3243 nautical miles). The results obtained are shown in Table 2.

| Chain          | LNG         | NGH         | Difference |
|----------------|-------------|-------------|------------|
| Production     | 1144 (55%)  | 992 (54%)   | 152 (13%)  |
| Carriers       | 660 (32%)   | 628 (34%)   | 32 (5%)    |
| Regasification | 285 (13%)   | 218 (12%)   | 67 (24%)   |
| Total          | 2089 (100%) | 1838 (100%) | 251 (12%)  |

Table 2 – Comparison of capital cost of NGH and LNG chains for 400 MMscfs production and transport over 3243 nautical miles (6000 km). Million US dollars mid-2002.

It was found that the capital cost of NGH technology was about 12% lower than the capital cost of LNG technology. The 2002 LNG costs were 12% lower than the 1995 LNG costs; that is, LNG costs have become lower (probably due to increased competition and improved technology). The 2002 NGH costs were about the same (1% higher) than the 1995 NGH costs. The NGH design has been improved. It was established in the recent 2002 study that the cooling water temperature has an important influence on the NGH costs; much more so than on the LNG costs. It means that NGH technology is more sensitive to cooling water temperature than is LNG technology. Four trains of 100 MMscf were used for NGH production, while one train was used for LNG production. It means that NGH can be produced at lower rates without much penalty in economy-of-scale, making NGH technology more suitable for small-to-medium scale developments.

#### 4. CAPEX-DISTANCE DIAGRAM

In the early feasibility study (mid-1995 costs) the NGH and LNG chains were compared [8]. The capital cost of the production and regasification plants were estimated, also the transport cost by ship. The cost data with transport distance are shown in Figure 1 [3]. The figure shows the mid-1995 capital costs for the NGH and LNG plants (production plus regasification) plotted at zero distance. The transport distance was assumed 3500 nautical miles, which equals 6475 km

(from North Norway to the Continent of Europe). By adding the capital costs of the ships to the plant costs, the total capital costs for a chain distance of 6475 km can be plotted. Therefore, Figure 1 shows also how the total capital cost of an NGH chain and a LNG chain depend of transport distance.

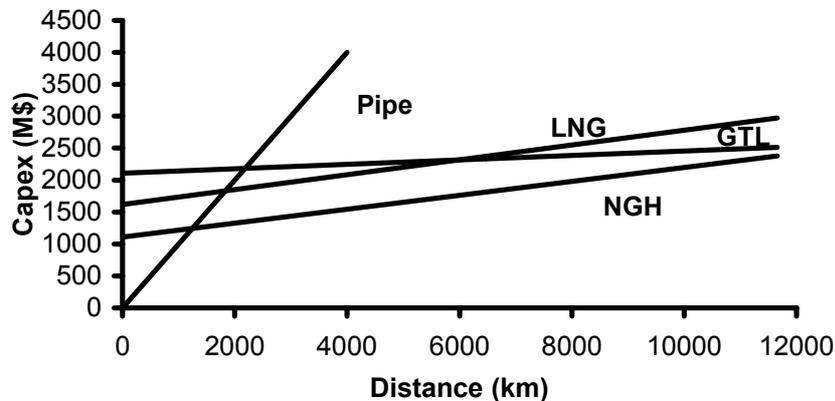


Figure 1 Approximate capital cost (million \$) with transport distance (km).

The line for pipeline in Figure 1 represents the capital cost of a typical pipeline transporting natural gas. The capital cost was assumed 1 million US dollars per km. The capacity of such a pipeline will likely be greater than the 4.1 BCM per year [8]. The pipeline line illustrates the overall relationship compared to transport by ship. For distances greater than about 1000 km the capital cost of a pipeline is higher than for NGH. In the case of LNG the cross-over distance is about 1800 km. The fourth line in Figure 1 represents the capital cost of natural gas transport chain based on synthetic petroleum, also called GTL (gas to liquid) [3]. The cross-over distance from LNG to GTL is about 6000 km. GTL shows lower cost than LNG for long distances [15].

### 5. CAPACITY-DISTANCE DIAGRAM

Factors that influence the feasibility of natural gas developments include the size of the resource, the distance to the market, the size of the market and the technology used. Of the 150 TCM (trillion cubic metres) world reserves of natural gas, 38% are in the Former Soviet Union, 35% in the Middle East, 9% in OECD-countries and 18% the rest of the world [16]. Of the natural gas fields world-wide still to be developed, about 80% are less than 7 BCM in size, and about one-half of the fields are considered to contain stranded gas [6, 17]. Assuming a project life of about 20 years, a 7 BCM field size will sustain a delivery of 0.35 BCM per year. The technology used needs to be appropriate for the size of the resource.

Pipelines are universally used to transport natural gas from field resource to market. Economy-of-scale effects influence what transport capacity and distance a particular pipeline will be feasible. The shorter the distance and larger the capacity, the more feasible a particular natural gas pipeline.

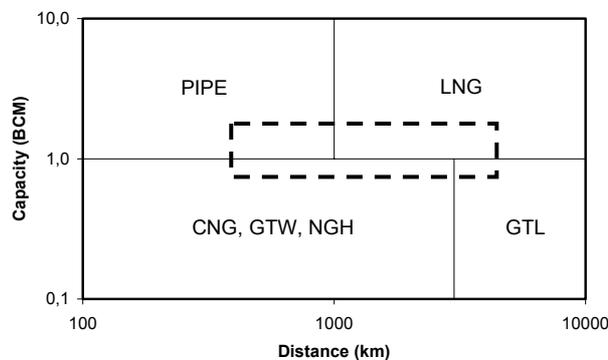


Figure 2 - Capacity-distance diagram (BCM per year versus km).

The size of the market influences the transport capacity of a particular pipeline. Furthermore, with increasing distance the feasibility of a particular pipeline decreases. The distance the feasibility of a particular pipeline becomes marginal depends on many factors. When the feasible pipeline distance is exceeded, other natural gas transport technologies become appropriate.

A new capacity-distance diagram for the transport of stranded natural gas is shown in Figure 2. The diagram illustrates what stranded gas technologies are likely to be appropriated with respect to distance and capacity. LNG is generally considered appropriate for large-volumes for long-distances; GTL (gas to liquid) is generally considered appropriate for medium-to-low volumes for long-distances. Offshore pipelines in Norway are less than 1000 km in length are generally considered appropriate for large-volumes, for example above 1 BCM. CNG, GTW and NGH technologies are considered appropriate for medium-to-low volumes and medium-to-short distances. An overlap region is shown in Figure 2, to reflect the wide range of conditions that affect the gas technology selected for a particular application.

## 7. CONCLUDING REMARKS

There is a need for non-pipeline technologies that can capture natural gas and transport to markets. NGH technology is being developed for this purpose and is increasingly recognised as an attractive alternative. Several groups are developing NGH technology world-wide, including NTNU and Aker Kvaerner Technology in Norway.

LNG technology is recognised as the technology of choice for large-volume, long-distance transport of natural gas. However, about 80% of the natural gas resources yet to be developed world-wide are too small for state-of-the-art LNG technology and about one-half of these (40% of total) are stranded, calling for non-pipeline technologies. NGH and CNG technologies are suitable for small-to-medium size discoveries.

NGH technology in 2002 is about 12% lower in cost (CAPEX) than LNG technology, in warm climates (in cold climates the advantage of NGH is greater). LNG technology has reduced in cost by about 12% from 1995 to 2002 (increased competition and technology improvements). NGH technology has not yet been developed for world-wide use. When NGH technology will be taken in use and matures, its costs are expected to decrease.

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