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The Potential of Compressed Natural Gas Transport in Asia

Xiuli Wang, SPE, XGAS; and Matteo Marongiu-Porcu, SPE, Economides Consultants

Abstract

Natural gas use is expected to increase dramatically in the world over the next two decades, especially in the two fastest growing countries in Asia: China and India. Japan is already greatly dependent on natural gas. In connecting sources with markets, natural gas is transported with two well-established technologies: 70 percent by pipeline and 30 percent by liquefied natural gas (LNG). Pipelines traversing land masses, when feasible, are the obvious option. However, offshore pipelines have a distance limit and a terrain restriction. LNG facilities (both the liquefaction process at the source and the re-gasification process at the receiving end) are expensive to construct and the entire process is complicated, costly, and energy wasteful. It is applicable for long haul sea distances and large volumes of gas.

Waterways-going compressed natural gas (CNG) is an alternative that many people have proposed in recent years but has not made a substantial head start for two reasons. First, the emphasis for investments worldwide has been primarily on LNG and, second, CNG vessel designs and projects have been envisioned to eke a bite out of the LNG pie, which is not necessarily a good approach.

CNG must make a substantial impact in shorter distances and smaller offshore markets which are not connected to large pipelines or baseload LNG accepting facilities. We show that for shorter distances (e.g., 1,000 km or 600 miles) LNG simply cannot compete with CNG. Even at longer distances (e.g., 2,000 km or 1,200 miles) CNG is still more attractive, assuming that offshore pipelines are not feasible. For smaller volumes, such as 1 to 2 Bcm/yr (35 to 70 Bcf/yr) CNG is the only solution to bring this energy source to many markets.

We scope Asian potential for CNG by connecting suitable source and market candidates. In this paper, a particular feasibility study of CNG transport in domestic Indonesia is performed. Results show that CNG is an excellent solution to transport Indonesian natural gas from fields such as Arun, Bontang, and Tangguh to domestic customers in the areas of Jakarta and Bali, especially from smaller reservoirs not currently considered as attractive for LNG. On the other hand, it does make sense to export LNG from Brunei, Malaysia, and Indonesia to Japan, South Korea, and China.

Introduction

A significant portion of natural gas reserves worldwide is located relatively near population centers across bodies of water. In many cases, traditional natural gas transport methods such as pipelines or liquefied natural gas (LNG) are not feasible or are too expensive. A new application of an existing technology, CNG, provides a solution for shipping natural gas across water.

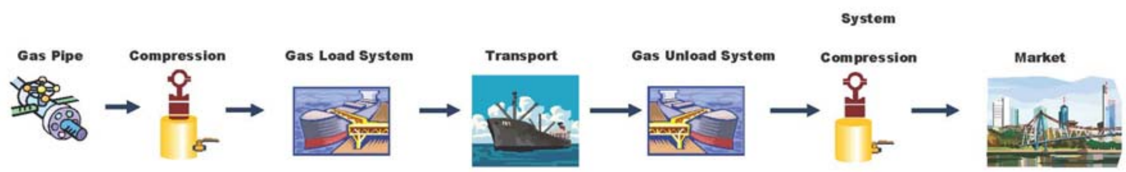
CNG Concept

CNG is compressed and sometimes chilled (but not liquefied) at pressures of 2,000 to 3,000 psi (130 to 200 atm). CNG ships are in effect “floating pipelines.” The on-shore facilities required for loading and off-loading from CNG transport, shown in Figure 1, consist of simple jetties or buoys which are minimal compared to LNG. The entire transport process (from the wellhead to the market) is described by the drawing in Figure 2. The chain for LNG is also provided in Figure 2 for comparison. The key differences between these two technologies are summarized in Table 1.

(a). At Source

(b). At Destination

Figure 1 Loading and Offloading Terminal for LNG and CNG (Source: XGAS website http://www.xgas.us)



(a) CNG Marine Transport

(b) LNG Marine Transport

Figure 2 CNG and LNG Marine Transport Chain

Table 1 Process and Cargo Differences between CNG and LNG (Data Source: ABS Technical Seminar)

	CNG	LNG
Fluid State	Gas	Liquid
Pressure	100-250 bar (1,450 - 3,600 psi)	1 bar (14.5 psi)
Temperature	30 ^{o}C to -40 ^{o}C (or 86 to -40 ^{o}F)	-163 ^{o} C (or -261 ^{o}F)
Loading	Dehydrate, compress	Treat, liquefy, store
Terminals	Jetty or buoy	Jetty, orregas offshore
Ships	Simple, like bulk-carrier	Sophisticated, efficient
Receiving	Heat & decompress - untilize energy released	Store, regasify
Loading/Offloading	Gas under pressure	As Liquid
Compression Ratio	~ 250-350:1	~ 600/1
Containment D/t	~ 25 to 60	~ 1000
Material	Fine grain normalized C-Mn steel, FRP	Aluminum, Stainless, Ni Steel

CNG is a technology proven in many applications, including transport by ship, truck and barge. CNG is used to fuel taxis, private vehicles and buses worldwide. The first commercial CNG transport ship was introduced in the 1960's (Broeker, 1969). Columbia Gas's SIGALPHA (originally named 'Liberty Ship') completed cycles of loading, transport, unloading and re-gasification of both CNG and MLG (medium condition liquefied gas) in cargo bottles. The capacity of the SIGALPHA was 820 Mscf of MLG and 1300 Mscf of CNG. The American Bureau of Shipping (ABS) classified the SIGALPHA for service and the U.S. Coast Guard awarded SIGALPHA a certificate of compliance.

The new generation of CNG ships is optimized to transport large quantities of gas. It is approximately one-fourth the amount of an LNG carrier of the same size, but at far lower costs per unit of gas than LNG for short journeys. Several companies (Stenning and Cran, 2000, Dunlop and White, 2003) have developed CNG delivery systems. Some of them have already received ABS and DNV approval and are ready to be commercialized.

CNG Application Areas

CNG is an obvious alternative to LNG and to pipelines for sea-going transport of natural gas (Economides and Mokhatab, 2007). It offers an economically attractive way to deliver commercial quantities of natural gas by ship to customers within 2,000 km (about 1,200 miles, Wood *et al.*, 2008). Figure 3 shows the range of applications of different options for monetizing stranded gas.

There are several areas where population centers are separated from natural gas sources by 2,000 km (or 1,200 miles) or less across water. In Figure 4, the areas are shaded in red when the distance between known natural gas producing or potentially producing regions to markets is within 2,000 km (1,200 miles). These areas will be excellent candidates for CNG transportation. Areas of particular interest in this paper include the transporting of stranded gas within domestic Indonesia and from Malaysia/Brunei/Indonesia to Japan, South Korea, and China.

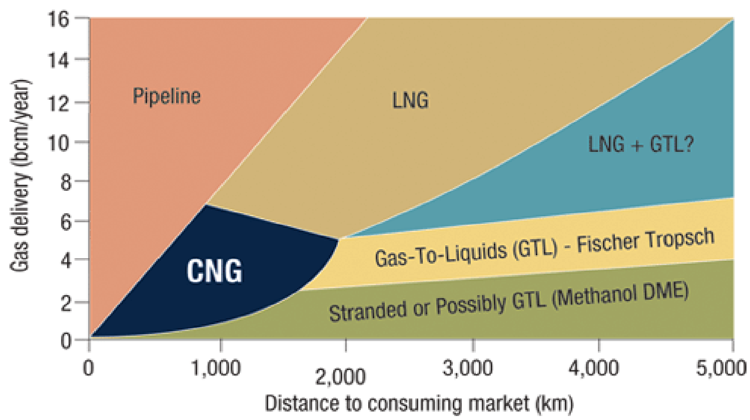


Figure 3 Options for Monetizing Stranded Gas - Range of Applications (Wood, *et al.*, 2008)

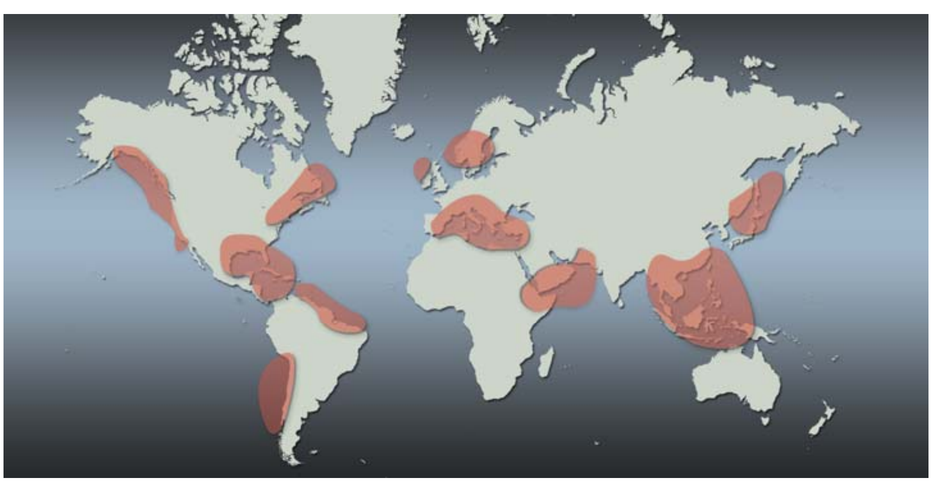


Figure 4 Regions Actively Investigating CNG Projects (Dunlop and White, 2003)

Case Study: CNG Transport in Indonesia

Why CNG in Indonesia?
Indonesia is located in Southeastern Asia, an archipelago between the Indian Ocean and the Pacific Ocean. It has the largest population in Southeast Asia and the fourth largest population in the world (behind China, India, and the United States, EIA, 2007). In 1962, Indonesia joined the Organization of the Petroleum Exporting Countries (OPEC). According to the *Oil & Gas Journal (OGJ)*, Indonesia had 4.3 billion barrels of proven oil reserves and 97.8 Tcf of proven natural gas reserves as of January 2007. Oil production in Indonesia has decreased steadily during the last decade, because of disappointing exploration efforts and declining production at Indonesia's large, mature oil fields. In 2004, it became a net importer of oil (OPEC Fact Sheet).

Indonesia is the tenth largest holder of proven natural gas reserves in the world and the single largest in the Asia-Pacific region (EIA, 2007). According to the Indonesian government, more than 70 percent of the country's natural gas reserves are located offshore, with the largest reserves found off Natuna Island, East Kalimantan, South Sumatra, and West Papua (also known as Irian Jaya).

Indonesia is a leading LNG exporter. It was the world's largest exporter of LNG in 2005, although it was surpassed by Qatar sometime in 2006. As shown in Figure 5, during 2005, Indonesia exported 23 million tons (MMt, or 1.12 Tcf) of LNG, or about 16 percent of the world total. LNG is shipped from two terminals: the Bontang facility in Badak, East Kalimantan and the Arun plant in North Sumatra. Most of Indonesia's LNG is exported to Japan with smaller volumes going to Taiwan and South Korea. An additional train at Bontang is under consideration but has yet to contract for the capacity. The Tangguh LNG is intended for China, other Asian markets, and potentially the United States (EIA, 2007). The current LNG contracts are summarized in Table 2 (Note, the data from EIA in Figure 5 is slightly different from that from the USA embassy in Jakarta shown in Table 2).

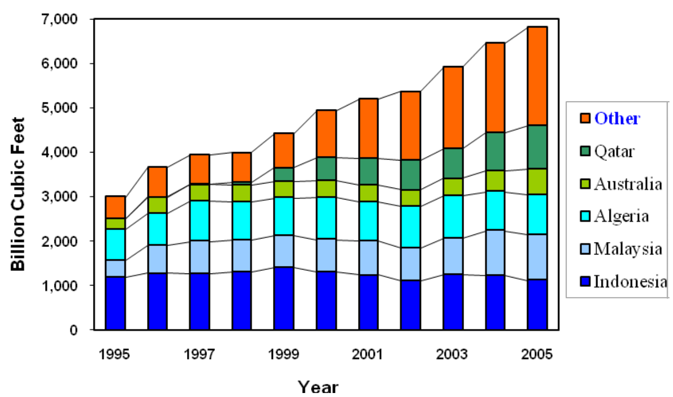


Figure 5 Global LNG Exports by Origin, 1995-2005 (EIA *Natural Gas Monthly*, August 2006-IEA *Natural Gas Information, 2006*)

Table 2 Indonesia LNG Contacts (in million of metric tons. Source: http://jakarta.usembassy.gov/econ/LNG_reports.html)

Importer	2004	2005	2006	2007	2008	2009	2010
Japan	18.18	15.63	15.63	15.63	15.63	15.63	15.63
S. Korea	5.3	6.35	4.05	4.05	4.05	4.05	4.05
Taiwan	3.42	3.42	3.42	3.42	3.42	3.42	1.84
China	0	0	0	2.6	2.6	2.6	2.6
U.S.	0	0	0	3.7	3.7	3.7	3.7
Total	26.9	25.4	23.1	29.4	29.4	29.4	27.82

Indonesia also has been exporting natural gas via pipeline starting in 2001, with the opening of the 400-mile, 325 MMscf/d subsea pipeline from West Natuna to Singapore. In August 2002, Indonesia began delivering 250 MMscf/d of piped natural gas to Malaysia's Duyong platform. And in August 2003, a second natural gas connection to Singapore was opened when the

South Sumatra-Singapore pipeline was completed. This line reached 350 MMscf/d maximum capacity during 2006 and will deliver natural gas to Singapore over a 20-year contract (EIA, 2007).

Although, historically, Indonesian natural gas production has been geared toward export markets, the country has made an effort to shift natural gas toward domestic uses in recent years as a substitute for the country's declining oil output. There are more than 3,100 miles of natural gas distribution and transmission lines, comprising nine regional networks in Indonesia. However, the networks have limited interconnectivity, which has restrained further growth of domestic natural gas consumption. Four additional domestic natural gas pipelines, known as the Integrated Gas Transportation System (IGTS), are proposed to improve the country's natural gas network connectivity. So far, the planned interconnection is only partially complete, and is scheduled to be fully operational in 2010 with a capacity to transport 2.2 Bcf/d of natural gas (EIA, 2007).

Based on background study and our economic evaluation in this area, we believe CNG is the obvious solution to provide natural gas to Indonesia's domestic customers who are in desperate need of natural gas.

Economic Evaluation of CNG and LNG Transport Feasibility

As mentioned in the earlier section, compared with LNG, CNG is much cheaper, the loading and offloading facilities are less complex, and the main investment is in the ships themselves. It makes perfect economic sense to use CNG when the distance from the source to the market is less than 2,000 km (1,200 miles).

Case 1: CNG and LNG Transport in Domestic Indonesia

Figure 6 is the map of Indonesia with locations of the LNG (liquefaction) existing terminals: Arun and Bontang; under construction terminal: Tanguh; and proposed terminals: Padang and Sengkang. The proposed LNG receiving (re-gasification) terminals in the approximate locations of Grati and Cilegon (www.energy.ca.gov) are also shown on the same map. The possible routes of CNG transport within domestic Indonesia are marked as red solid lines. The distances would be around 900, 1,500, and 2,000 km (or 560, 930, and 1,200 miles), respectively. In this study the market demands for each location are assumed as 1 and 2 Bcm/yr (35 and 70 Bcf/yr). For comparison purpose, the LNG transport in the same routes is evaluated as well. Some of the key input parameters for one of the case studies (1 Bcm/yr and 2,000 km or 35 Bcf/yr and 1,200 miles) are summarized in Table 3. Here gas offloading rate is assumed to be equal to the gas supply needed. For example, if the demand is 1 Bcm/yr (35 Bcf/yr), the gas offloading rate will be 96.75 MMscf/d. Gas loading rate is adjusted based on time schedule and the number of vessels. Capital cost of the vessels, loading/offloading facilities, and operating costs for both LNG and CNG are selected from published literature (Wagner and Wagensveld, 2002, Economides *et al.*, 2006, Marongiu-Porcu *et al.*, 2008). The net present value (NPV) for a 15-year project life is calculated for the three different distances (900, 1,500, and 2,000 km or 560, 930, and 1,200 miles) and two different market demands (1 and 2 Bcm/yr or 35 and 70 Bcf/yr). Results are shown in Figure 7.

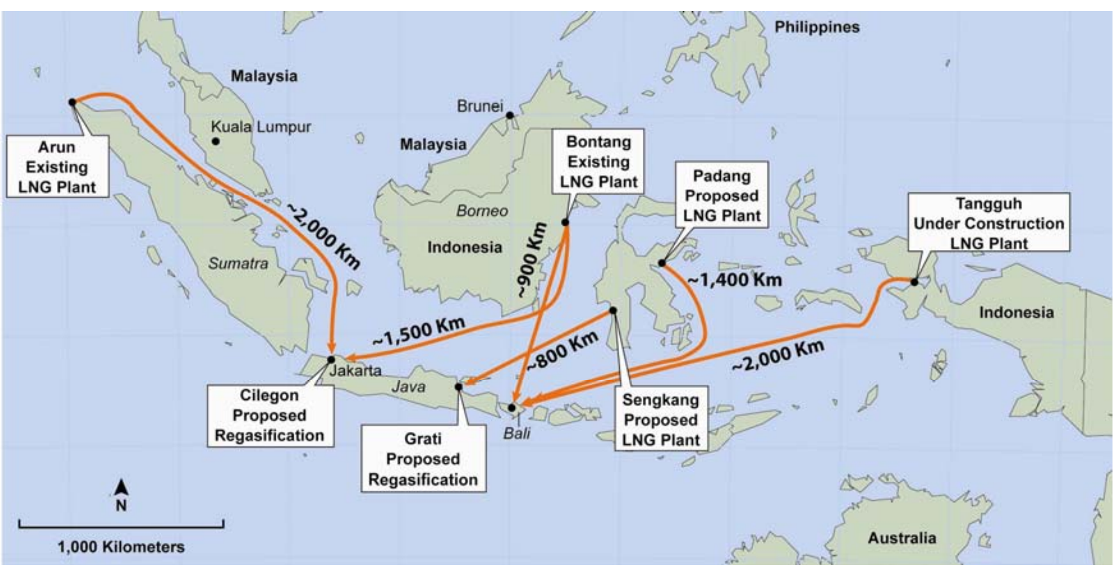


Figure 6 Map of Indonesia with Proposed CNG Transport Paths

Table 3 Some Key Input Parameters

Assumed Input Parameters for CNG	
Gas Supply Needed, Bcm/yr	1
Transit Distance, Km	2000
Sailing Speed, knots	14
Vessel Capacity, MMscf	150
CapEx per vessel, $	115,000,000
CapEx Loading Facility, $	50,000,000
CapEx Offloading Facility, $	25,000,000
Equity	100%
Project Life, yr	15
Gas Price at Source, $/MMBtu	8.00
Gas Selling Price, $/MMBtu	16.00
Discount Rate	15%

Assumed Input Parameters for LNG	
Gas Supply Needed, Bcm/yr	1
Transit Distance, Km	2000
Sailing Speed, knots	14
Vessel Capacity, MMscf	3000
CapEx per vessel, $	150,000,000
CapEx Loading Facility, $	500,000,000
CapEx Offloading Facility, $	400,000,000
Equity	100%
Project Life, yr	15
Gas Price at Source, $/MMBtu	8.00
Gas Selling Price, $/MMBtu	16.00
Discount Rate	15%

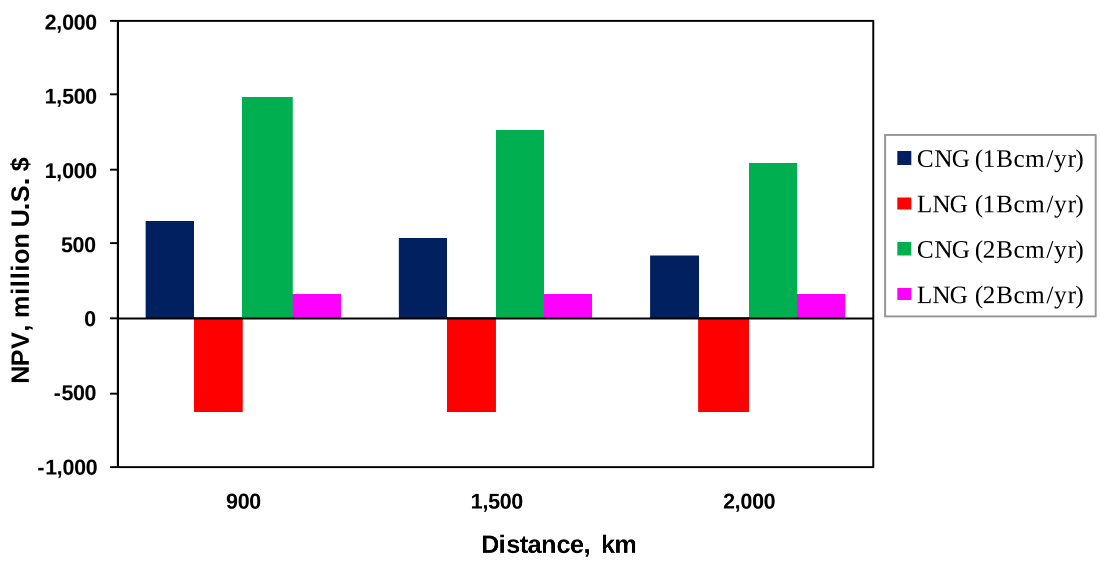


Figure 7 Comparative Results from CNG and LNG Seagoing Transportation

Results show that within 2,000 km (1,200 miles), when the market demand is 1 Bcm/yr (35 Bcf/yr), the NPV for CNG is $653, 540, and 426 million at distance of 900 (from Bontang area to Bali or from Sengkang to Bali), 1,500 (from Bontang to Jakarta or from Padang to Bali), and 2,000 km (from Arun to Jakarta or from Tangguh to Bali), respectively. When the market demand is higher e.g., 2 Bcm/yr (70 Bcf/yr), the NPV for CNG is $1,495, $1,268, and $1,042 million at the distance of 900, 1,500, and 2,000 km (560, 930, 1,200 miles), respectively. The number of CNG vessels (calculated based on the market demand, vessel capacity, and the schedule) needed increases when the distance is longer and the demand is higher. For this particular case, the number of vessels as a function of the distance and the market demand is summarized in Table 4.

Table 4 Number of Vessels Needed for CNG Transport

Distance km	No. of Vessels (1Bcm/yr)	No. of Vessels (2Bcm/yr)
900	4	7
1,500	5	9
2,000	6	11

Results also show that within 2,000 km (1,200 miles), when the market demand is 1Bcm/yr (35 Bcf/yr), the NPV for LNG is negative $627 million at all three different distances (900, 1,500, and 2,000 km or 560, 930, and 1,200 miles). When the market demand is 2 Bcm/yr (70 Bcf/yr) the NPV for LNG is ~$168 million at all three distance (900, 1,500, and 2,000 km or 560, 930, and 1,200 miles). The reason for a constant NPV at three different distances is because, in this study, we choose that the minimum number of vessels for LNG transportation is three even though the actual calculated number is less than three. This is because one ship is loading, one ship is offloading, and the third will be transporting in the middle. In this study, demands of 1 and 2 Bcm/yr (35 and 70 Bcf/yr) are a lot smaller to be used for LNG and the theoretically calculated number of vessels would be less than three. But for practical purpose, three vessels, as chosen for every case studied here are a logical choice. In summary, for the given economic parameters, when three ships are used for distances of 900, 1,500, and 2,000 km (or 560, 930, and 1,200 miles) and market demands of 1 and 2 Bcm/yr (35 and 70 Bcf/yr), LNG is not economic compared with CNG. The conclusion from this study is that in domestic Indonesia, CNG is an excellent solution to transport natural gas from the gas fields in Arun, Bontang, and Tangguh to domestic customers in the areas of Jakarta and Bali, especially from smaller reservoirs not currently considered as attractive for LNG. In the next case study, we will evaluate the feasibility of CNG transport from Indonesia/Malaysia/Brunei to Japan, South Korea, and China.

Case 2: CNG and LNG Transport from Brunei/Indonesia/Malaysia

Figure 10 shows the distances from Brunei to different locations in Japan, South Korea, and China. The distances from Indonesia and Malaysia to those destinations will be equivalent and will not be shown in the map for simplicity. In this case study, distances of 2,100 (from Brunei to Guangzhou), 2,600 (from Brunei to Taiwan), 3,400 (from Brunei to Shanghai), 3,900 (Tangguh to Guangzhou), 4,100 (from Brunei to Seoul), and 4,600 km (from Brunei to Tokyo) are selected. We make the same assumptions here as we made in Case 1 and the minimum number of vessels needed will be three. The NPV results are summarized in Figure 11.

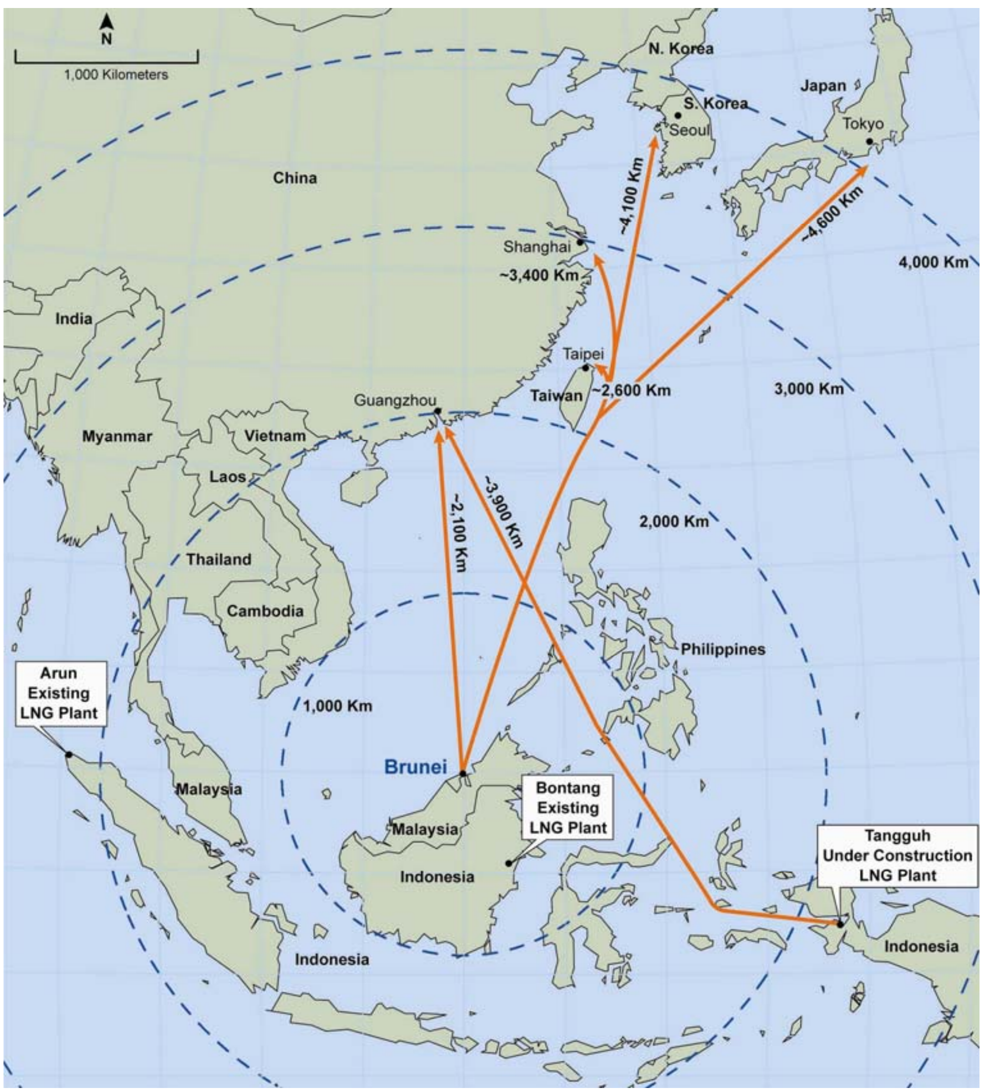


Figure 10 Proposed CNG Transport in Southeast Asia

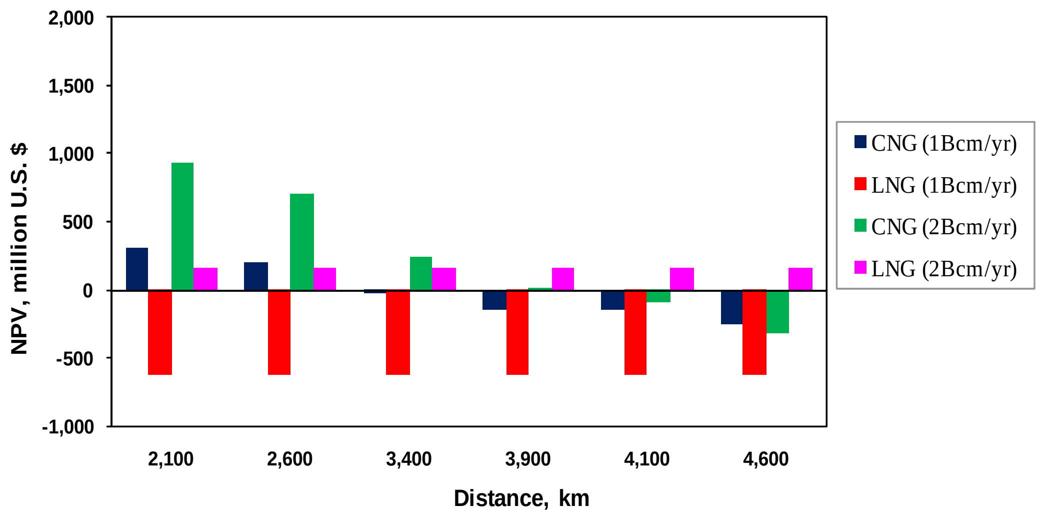


Figure 11 Comparative Results from CNG and LNG Seagoing Transportation

Results show that with market demand of 1 Bcm/yr (35 Bcf/yr), the CNG project is still profitable within 3,000km (1,800 miles). The breakeven point is around 3,400 km (2,100 miles). At this distance, when 9 vessels are used, the project is still promising (NPV is ~$85 million). When 10 vessels are used, the NPV is negative $29 million. This shows what has been obvious all along: in a CNG project, the NPV is very sensitive to the number of vessels since they constitute the main investment in any CNG project. On the other hand, such "floating assets" form another advantage of CNG over LNG because vessels can always be deployed to other places when a particular project is done. A correlation between the number of vessels (each of 150 MMscf capacity) and the distance at given market demand is plotted in Figure 12.

The NPV for LNG, on the other hand, is negative at all given distances (see Figure 11). The reason is the same as we discussed in "Case 1" that is: there is a "minimum capital cost threshold" for LNG project for liquefaction/re-gasification facilities and a minimum number of vessels (3). When the market is as small as 1 Bcm/yr (35 Bcf/yr), at the given distance (<4,600 km or 2,850 miles), the minimum cost is so overwhelming that it does not make any sense to use LNG to transport natural gas.

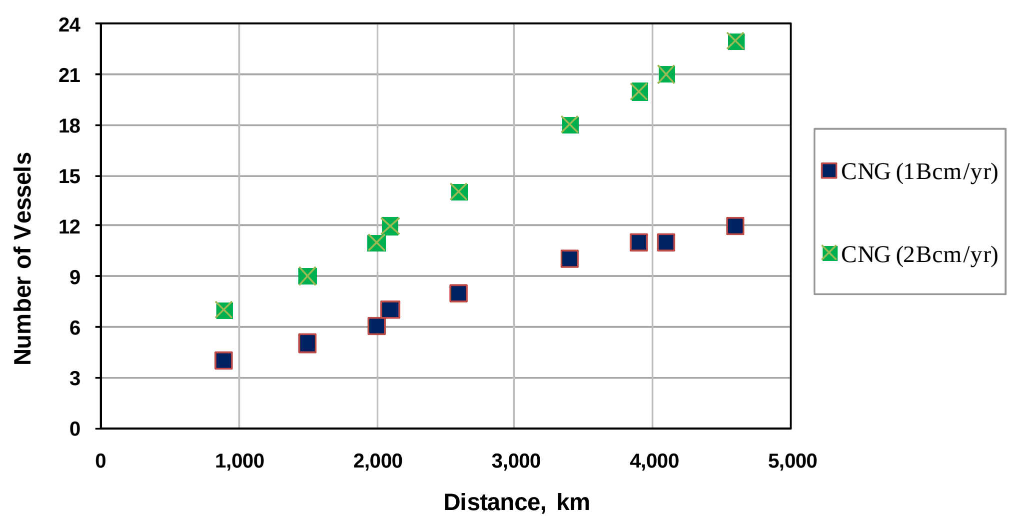


Figure 12 Vessel Number Needed as a Function of the Distance

At 2 Bcm/yr (70 Bcf/yr), the breakeven point for a CNG project is around 3,900 km (2,400 miles). For LNG, it is between 11,000 and 12,000 km (6,800 and 7,500 miles). When the distance is above 12,000 km (does not show in Figure 11), 4 instead of 3 LNG vessels will be needed for the given market demand of 2 Bcm/yr (70 Bcf/yr); therefore, the NPV changes from $168 million to negative $1.7 million as the cost increases. Although the NPV is positive for LNG within distance of 12,000 km (7,500 miles), it is significantly smaller than that from CNG when the distance is less than 3,400 km ($927 vs. 168, 700 vs. 168, and 246 vs. 168 million at distance of 2,100, 2,600, and 3,400 km, respectively). This implies that for a small market demand (~2 Bcm/yr or 70 Bcf/yr) and short distance (~3,400 km or 2,100 miles), LNG simply cannot compete with CNG. Although there are several LNG terminals already built in Brunei, Indonesia, and Malaysia to transport LNG to Japan, South Korea, and possibly to China in the future, instead they should have used CNG when the application falls within the distance range discussed above (such as from Brunei to Taiwan and Guangzhou, etc)

Case 3: Define the Boundary

So where is the limit for CNG? Based on the same assumption and using the same model, we extend the market demands to 5 and 10 Bcm/yr (350 Bcf/yr) for comparison purpose. Results (including 1 and 2 Bcm/yr or 35 and 70 Bcf/yr) are presented in Figure 13. The areas marked in “green” are the applicable areas for CNG and the areas marked in “red” are for LNG application. It is clear that for market demand of 1, 2, 5, and 10 Bcm/yr (or 35, 70, 175, 350 Bcf/yr), CNG is a better solution than LNG when the distance is less than 3,400, 3,600, 2,400, and 2,000 km (2,100, 2,200, 1,500, and 1,200 miles), respectively. So, in domestic Indonesia, to transport natural gas from any fields within Indonesia to either Jakarta or Bali (see the map in Figure 6), as far as the market demand is less than 10 Bcm/yr (350 Bcf/yr), CNG will always outperform LNG. For natural gas exported from Brunei/Indonesia/Malaysia (see map in Figure 10), it follows the same rule. When market demand is larger than 10 Bcm/yr (350 Bcf/yr) and the distance is longer than 2,000 km (1,200 miles), LNG is preferable to CNG. Otherwise CNG is the obvious solution. The summarized results are shown in Figure 14. Based on our economic analysis, it clearly shows that the CNG application envelop is bigger than that shown in Figure 3, done by Wood, *et al.* (2008).

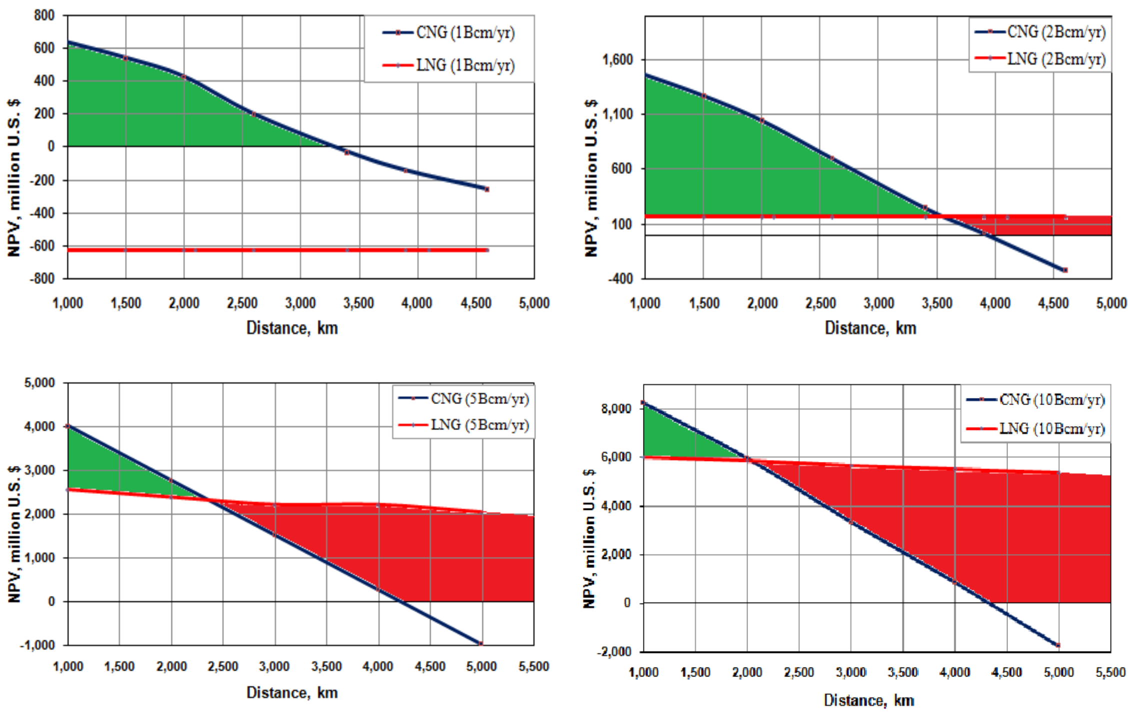


Figure 13 CNG and LNG Application Envelops

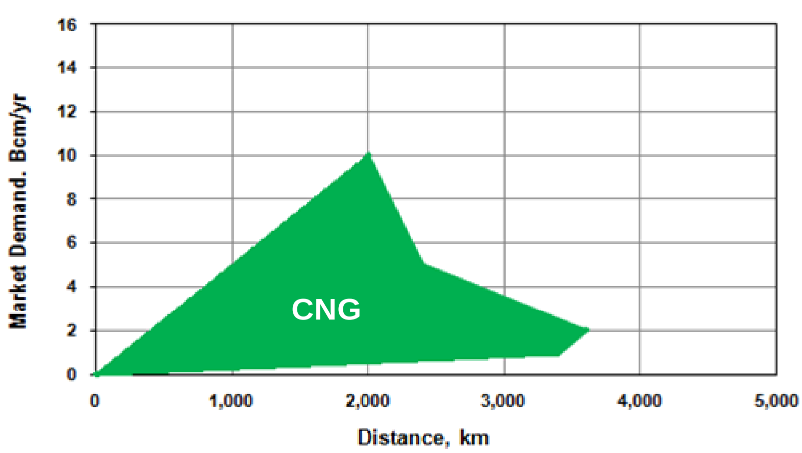


Figure 14 Range of CNG Applications

Conclusions

This study aims to evaluate the CNG feasibility within Indonesia and in the surrounding area. CNG application envelop is defined as a function of the distance and market demand. CNG is the perfect and obvious solution when

- market demand is 1 Bcm/yr (35 Bcf/yr), the distance is less than 3,400 km (2,100 miles),
- market demand is 2 Bcm/yr (70 Bcf/yr), the distance is less than 3,600 km (2,200 miles),
- market demand is 5 Bcm/yr (175 Bcf/yr), the distance is less than 2,400 km (1,500 miles),
- market demand is 10 Bcm/yr (350 Bcf/yr), the distance is less than 2,000 km (1,200 miles).

Results show:

- In domestic Indonesia, the distances from the well known fields (such as Arun, Botang, and Tangguh) to the markets (Jakarta and Bali) are less or around 2,000 km (1,200 miles). If the gas demand is less than 10 Bcm/yr (350 Bcf/yr), CNG is the indicated way to transport natural gas to the markets.
- To transport natural gas from Brunei to Shanghai, Guangzhou, or Taiwan, the distance is within 3,500 km (2,150 miles). If the market demand is 2 Bcm/yr (70 Bcf/yr) or less, CNG should have been used although LNG has been deployed or in the process of being so.
- To transport natural gas from Brunei, Indonesia, or Malaysia to Japan or South Korea, the distances are above 4,000 km (2,400 miles). CNG will not be a good option. LNG can barely break even when the market demand is 2 Bcm/yr (70 Bcf/yr). If the market demand is 5 Bcm/yr (175 Bcf/yr) or above, LNG is the solution.

Conversion Factors

Btu	x	1.055056	E+00	=	kJ
ft3	x	2.831685	E-02	=	m3
^{0}F		(^{0}F-32)/1.8		=	^{0}C
in.	x	2.54*	E+00	=	cm
mile	x	1.609344*	E+00	=	km
psi	x	6.894757	E+00	=	kPa

*Conversion factor is exact.

Nomenclature

Bcm/yr	billion cubic meter per year
Bcf/yr	billion cubic feet per year
Tcf	trillion cubic feet
MMscf	million standard cubic feet
km	kilometer
MMBtu	million Btu

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