CHINA MODEL PAVES THE WAY FOR TRANSPORTATION LNG IN THE U.S.

By Black & Veatch
ABSTRACT

LNG for vehicles is a hot topic in North America today. A number of projects are announced or considered to convert natural gas to LNG for a variety of transportation applications from autos and trucks to marine applications. While the US is still in the very early phases of development, China has been developing LNG projects steadily for more than a decade. These plants supply distributed LNG applications such as factories, businesses and residences as well as making LNG available for the transportation industry. Recently, many of the plants are being constructed solely for vehicle fuel applications. By 2015, China is projected to have 1.5 MM natural gas vehicles on the road.

Black & Veatch has been a big part of this LNG development. B&V now has 21 projects in China with an aggregate capacity of 9.2 Million gallons/day (15,000 tonnes/day). These projects handle a wide variety of feed gases from pipeline quality gas to high nitrogen and high hydrogen gases. Two projects convert Coke oven gas, which is normally vented, to transportation grade LNG for vehicles. Another project produces LNG and syngas from coal gasification. This paper will share the experiences and examples of the variety of plants being developed and the unique challenges of non-traditional gas sources for producing transportation quality LNG.
INTRODUCTION

The world is currently undergoing a transformation from traditional fuel sources for vehicles, homes and industry. One of the key fuel supply resources for these uses is natural gas. Gas can be used as a vehicle fuel and as an energy source for household and industrial uses. Gas has also become a fuel of choice for power generation with reduced CO₂ emissions. One key method of supplying this gas is by using LNG. LNG can be produced at remote locations and distributed to end users easily and quickly. China has been progressing rapidly down the path of increased utilization of LNG for basic fuel needs. Other areas of the world such as the United Kingdom and Australia also use LNG as a portable fuel.

China is a large country with vast underdeveloped areas as well as large population centers that lack reliable and clean energy supplies for residential and industrial users alike. Electricity may be available, but only to light the home at night. Storing a propane tank inside living quarters for cooking and heating is often done. Coal is also often used in residential applications. Such is the case for many remote areas of China and other parts of the world. In many areas, gas is available from small and newly developed fields, but infrastructure to distribute the gas is non-existent.

The use of LNG for distribution and supply of gas to people in China is one method for expanding the use of clean fuel. The facilities being developed would supply LNG from liquefaction facilities to remote facilities which would vaporize the fuel for local use. By using this approach, gas supply can be provided quickly and flexibly to multiple locations from a single source.

In addition, the LNG is being used as a clean vehicle fuel to replace diesel and gasoline. Currently there are an estimated 1300 LNG fueling stations and over 80,000 vehicles operating on LNG. Projections of over 1,000,000 vehicles in operation in the next few years are well within reach.

PROJECT DEVELOPMENTS

Black & Veatch has been active in China in the past decade. With our in-country partner, Chemtex Intl. we have 21 liquefaction plants in operation or development at this time. These plants represent over 9.2MMGal/day of LNG (15,000 tons/day) which is equivalent to 745 MMSCFD. These plants have the flexibility to supply fuel to a number of markets. Figure 1 shows a schematic of the distribution system. Once a tank and vaporizer or filling station are sited, deliveries of LNG can commence. An average size plant can supply up to 40 truck loads per day of LNG to these markets. The flexibility of supply and rapid schedule for adding customers makes the LNG production for fuel use very attractive versus pipeline supply to fixed users or CNG supply for vehicles.

Figure 2 shows the location of the 21 B&V plants. These plants are clustered in northern China and central China where gas supply is available and where population centers such as Beijing and Chengdu provide readily accessible markets. The overall movement into LNG is driven by environmental desire for clean fuel and the cost advantage of LNG over other fuels. Many more plants will be developed as the country moves toward more application of clean fuels.

TECHNOLOGY SELECTION

Existing LNG production facilities in the small scale area employ a variety of LNG production technologies. These older plants are either 1) Cascade refrigeration, 2) Expander, 3) Single Mixed Refrigerant (SMR), 4) Nitrogen Refrigeration, or 5) Other multiple refrigerant schemes. After the initial developments in the 1960-70’s, the predominant technology has been the mixed refrigerant system with over 80% of the installations. Modern LNG production facilities are either SMR designs with selected sites using Expander or N2 Refrigeration. The cascade and other multiple loop systems have proven to be too complex and too costly to operate for these projects.
The SMR process has been shown to be the most versatile and efficient of the processes available and is the predominant technology of choice in vehicle fuel developments. The PRICO® process offered by Black & Veatch is just such a mixed refrigerant process that has now been applied or is being applied in 30 facilities around the world. This technology (Figure 3), in contrast the others offered has only a single compression system for the refrigeration. Also, the main exchanger is a very simple plate-fin unit with a minimal number of connections. This results in a simple, easy to operate liquefaction process. The system is designed such that during a shutdown the refrigerant inventory is maintained in the system. No venting or pressure relieving is needed. This type of process has thus become the workhorse of the industry.

Improvements in the PRICO® process by B&V over the years have resulted in a 25-35% reduction in power versus older facilities. Generally, these processes require about 260-370 kW per MMSCFD of LNG capacity. Modern SMR plants have much more efficient main exchanger designs than do the more complex facilities using spiral wound exchangers.

The other critical item in an LNG process is the refrigeration compressor. Black & Veatch favors a simple, repeatable design using a single body, two section unit. This compressor can be purchased in a wide range of sizes from about 5 MW to over 100,000 MW.

The full liquefaction plant schematic (Figure 4) illustrates the philosophy for development. The feed gas will be treated to remove CO2 and water before liquefaction. The liquefaction block is a standard design which can be applied to any feed gas available. Process modules can be added to this base plant to handle special gases containing a large amount of nitrogen or hydrogen. Also, NGL recovery and/or benzene removal steps can be added to the plant design. These additional removal steps can be integrated with the liquefaction quite easily without radically changing the base liquefaction unit. These additions provide flexibility in handling multiple feed gases which is the hallmark of the PRICO® process.

**CHINA FACILITY DEVELOPMENTS**

As new facilities are developed across the world to satisfy the need for clean fuel in vehicles, factories and homes, the SMR process has become the leading technology for these new facilities. China is the prime example of a country that is rapidly developing LNG supply facilities. The low capital cost and small footprint results in a reduced time to market and allows these plants to be started up in around 20 months from project kickoff.

These facilities are being developed from the long term technology base from the US and other countries. The difference is in the handling of the LNG product. While in peak shaver facilities, the LNG is revaporized for send-out, in these facilities all LNG is trucked out to customers. The portability of LNG makes it an ideal fuel to be supplied from a single point to multiple customers. Also, users can access supply from a variety of sources as with other liquid fuels. The model for the China developments is a central plant for distribution of LNG to multiple gas users in industrial and residential markets.

The various facilities located in China use the same PRICO® process but vary in both capacity and in the driver for the main refrigeration compressor. Most of the plants are motor drive but others are gas or steam turbine. The selection of the driver is dependent on the economics of gas versus electricity supply as well as the availability of reliable electrical supply. The first projects to come on stream were the Erdos and Zhuhai (CNOOC) projects in 2008, Figure 5 shows the Erdos plant and Figure 6 shows the truck fleet needed to handle the 33 trucks per day of LNG production. These projects were followed with 10 additional projects coming on stream in the past 6 years with a typical plant capacity feed gas rate of 1,000,000 Nm³/day. In 2014 alone, B&V, will bring 9 projects on stream to further supply the rapid transition to clean fuel in China.

The high energy demand in China has necessitated the construction of many new LNG facilities focused on vehicle fuel. The Guang’an plant (Figure 7) which came on stream in 2012 was the first to have both a dedicated 6-bay, truck loading station (Figure 8) and a also a public filling station for LNG vehicles (Figure 9). The Guang’an loading station (Figure 10) also shows the loading arm configuration which is now the norm in most China plants since code requirements do not allow loading hoses.
Within the past year plants have started up in Bazhou, Wuhai, Xingyuan and Yuanheng. The Bazhou plant is specifically designed to supply LNG to Beijing in order to provide a clean form of energy to power their public transportation systems.

The Bazhou plant came on stream in 2013 (Figure 11) and was designed to handle a variety of feed gas compositions with varying hydrogen and nitrogen concentrations. The plant uses multiple pressure let down steps in order to separate the hydrogen and nitrogen from the LNG and meet the required product specification. Due to environmental concerns, the plant has been designed to recover the resulting flash gases and use them as fuel. This reduces the overall fuel gas requirement for the plant and limits the amount of hydrocarbons that must be vented or flared.

**LNG FEED STOCKS**

Most of the feed stocks for the various facilities developed by Black & Veatch and Chemtex rely on feed gas from traditional sources of gas fields and pipeline gas. However, the PRICO® process can also be tailored for applications from non-traditional gas sources. A new type facility has been developed which is based on producing LNG from coal gasification. The Xinjiang project is designed to take 10.9 x 10^6 Nm3/day of feed gas from the gasification unit to produce 1214 tons/day LNG product and produce 4040 tons/day of CO/H2 gas for downstream methanol production. The process for this is similar to other liquefiers, but requires an additional step to separate the products. Figure 12 shows a schematic of the process which utilizes the basic PRICO® loop with added nitrogen refrigeration to achieve the CO/H2 separation step. This facility is in a region of China with very harsh sand storms and winter weather. Thus, much of the plant rotating equipment is housed in large buildings (Figure 13). With the continued development of coal gasification in China, this plant will be a blueprint for other such facilities across China.

A second feedstock being considered is coal seam gas. The coal seam gas tends to be very lean gas, with a small amount of CO2 and varying amounts of N2. The same liquefaction process can be used for this gas with the only variation being the possible need to reduce the N2 in the product gas. This N2 reduction can be handled by simple flashing of the LNG or with N2 stripping of the LNG similar to what is used in base load facilities. For higher nitrogen contents, a nitrogen rejection step can be added either downstream of the liquefaction unit or integrated with the PRICO® liquefaction process.

The Jilin Songyan Qianyuan Energy LNG Project, which is scheduled to start up in 2014, is designed to process feed gas containing up to 6% N2. The process is similar to a typical PRICO® liquefaction plant but with an additional nitrogen rejection step. A nitrogen fractionation tower is integrated into the liquefaction design to purge the excess nitrogen in the system and meet a specification of less than 1% N2 in the LNG product.

China is the largest processor of petroleum coke in the world. The Wuhai Xilaifeng LNG plant (Figure 14) began producing an LNG product stream, in January 2014, using Synthetic Natural Gas (SNG) as the feed gas from an upstream coking gas methanation process. Due to the high nitrogen and hydrogen content, simply liquefying the SNG would result in very high flash gas production, off-spec LNG and high methane losses. These components are handled in a modified PRICO® unit which flashes off the inerts. The process uses a high pressure, cryogenic tower to separate the methane from the SNG. The excess nitrogen and hydrogen contained in the feed (up to 20% hydrogen and 10% nitrogen) is removed, while the purified LNG is directed to an LNG storage tank. An identical plant, Wuhai Qianlishan, is currently being completed for 2014 operation.

One of the challenges for LNG production facilities is that many locations are served by multiple pipelines which may cause the feed gas composition to change significantly throughout the life of the plant. Many of the new LNG plants are unable to specify a detailed gas composition that is normally desired by plant designers. This can cause significant operational problems if not properly designed for. It is especially problematic when heavier components (C6+) are unknown or vary significantly from different gas sources since these components must be removed to protect the facility from solid formation.

The Meifeng Shuangrui project, scheduled for startup in 2015, was designed to have increased operational flexibility for a wide range of feed compositions. A heavies fractionation tower is used due to the uncertainty regarding the amount of heavy hydrocarbons in the feed gas. This tower allows increased levels of heavy
hydrocarbons to be removed and the plant to maintain a high LNG production capacity with varying feed compositions. The feed gas has an expected nitrogen content of 4.5% but due to expected composition changes, a nitrogen stripping tower has been added. This allows the plant to operate with feed gas compositions containing up to 10% nitrogen while still meeting the required 1% nitrogen specification in the LNG product.

US APPLICATIONS

As the market for transportation LNG developed in the United States, Black & Veatch saw the need to team with a quality modularization contractor to provide modular LNG plants. Many of the plants previously developed by B&V in the US for peak shaving were modular to some extent. However, to maximize the application of our experience more standardization and increased modularization was desired. Thus, B&V teamed with UOP as our partner in this development of LNG vehicle fuel plants for North America. UOP (formally the Thomas Russell Company) has a successful history of skid mounted/modular gas plant development.

In developing a standard plant concept, Black & Veatch examined the history of the many LNG plants designed with the PRICO® technology. Figure 15 shows the size ranges developed. This table shows a concentration of 12 plants around the 100,000 gal/day range, 6 in the 200,000 gal/day range and 12 plants in the 400,000 gal range. Thus, these are the sizes chosen or the B&V-UOP standard plant development effort. Figure 16 shows a standard 200,000 gal/day layout. This plant is very compact (150’ x 200’) and can be developed rapidly due to the pre-engineering and equipment selection that has been completed. This standardization and modularization results in a 6 month shorter schedule than a custom designed unit. And the plant can be delivered at a lower cost without sacrificing any efficiency advantage over other technologies.

As in the many China projects, gas feedstocks with high nitrogen or rich in NGL’s can be processed with the standard plant design. Modules are added to handle the nitrogen removal and/or the NGL recovery. This flexibility in design and operation is important as LNG is developed for vehicle fuels with a wide range of gases from the shale developments in the US.

CONCLUSION

The small scale LNG market in China are examples of an innovative approach to providing vehicle fuel and gas supply to remote and distributed users in a rapid development model. The experiences gained from developing these LNG products should allow the US to easily adopt a similar distribution model. These types of facilities can supply basic needs for many people while providing a clean alternative to conventional fuels. The flexibility of the Black & Veatch PRICO® process and proven applications in vehicle fuel make this a wise choice for transportation LNG facilities.
Figure 1
DISTRIBUTED LNG – China Model

FIGURE 2
CHINA LNG PLANTS

- Xinjiang Syngas
- Wuhai 1 & 2
- Hongji-Yitai
- Erdos
- Qianyuan
- North Energy
- Hongxing
- Erdos Huaqing
- Bazhou
- Erdos Shida
- Lanzhou
- Tianjin
- Yuanheng
- Guipinghui
- Guang’an
- Dazhou
- CNOOC
FIGURE 3
SINGLE MIXED REFRIERANT-PRICO® PROCESS

FIGURE 4
PROCESS PLANT SCHEMATIC

MODULAR APPROACH
(Same Core Process- Any Gas)
FIGURE 7
GUANG’AN LNG PROJECT – VEHICLE FUEL

FIGURE 8
TRUCK LOADING STATIONS
FIGURE 9
VEHICLE FILLING STATION

FIGURE 10
GUANG’AN LOADING CONFIGURATION
FIGURE 13
XINJIANG- TWO TRAIN SYNGAS TO LNG

FIGURE 14
WUHAI COKE OVEN GAS TO LNG
### FIGURE 15
**PRICO® SMR EXPERIENCE**

<table>
<thead>
<tr>
<th>Capacity, Gal/day</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;75,000</td>
<td>2</td>
</tr>
<tr>
<td>75,000-150,000</td>
<td>12</td>
</tr>
<tr>
<td>180,000-250,000</td>
<td>6</td>
</tr>
<tr>
<td>300,000</td>
<td>1</td>
</tr>
<tr>
<td>400,000 - 450,000</td>
<td>12</td>
</tr>
<tr>
<td>500,000-700,000</td>
<td>1</td>
</tr>
<tr>
<td>700,000-1,000,000</td>
<td>3</td>
</tr>
<tr>
<td>&gt;&gt;1,000,000</td>
<td>4</td>
</tr>
</tbody>
</table>

### FIGURE 16
**STANDARD PLANT LAYOUT (150’ x 200’)**