COMMERCIAL AND TECHNICAL CONSIDERATIONS IN THE DEVELOPMENTS OF OFFSHORE LIQUEFACTION PLANT

Chen-Hwa Chiu
Senior Technology Advisor
Chevron Energy Technology Company
1500 Louisiana Street
Houston, TX 77002
USA
ABSTRACT

Offshore LNG plants that liquefy natural gas in order to avoid flaring are getting more attractive in the current market of clean energy. It will become more attractive in the future as the reserves of the natural gas offshore will provide more LNG. As the offshore production of LNG is the natural extension of the offshore oil production, the developments of the offshore LNG plants will be inevitable. However, there are areas of commercial and technical challenge and considerations that need to be addressed during the development of these projects.

The risks in the commercial arena may be more complicated than those of the LNG plants. Major challenges will require addressing commercial concerns of the host government, the LNG buyers and the lenders. There are issues concerning the ownerships of the offshore facilities, the local employment and content, domestic gas use and spin-off industrial development. This paper will elaborate and discuss means to resolve these problems to avoid both the commercial and political concerns for the offshore liquefaction projects.

On the technical aspects, the considerations surround the developments of technologies for both the liquefaction process and equipment, the effects of motion, the transfer of LNG from the offshore facilities to LNG ships, the operational flexibility and availability of the plants and the safety concerns due to the congestion of areas. Process efficiency will be less important than process simplicity and overall safety. Offshore LNG transfer needs to be reliable, and meets the marine and environmental challenge. Safety considerations on the plant layouts, spacing and level of risks are important. This paper discusses these aspects and summarizes the current thinking on these issues.
1. Abstract

2. WHY OFFSHORE LNG PLANTS

COMMERCIAL CHALLENGES

HOST GOVERNMENT CONSIDERATIONS
  Commerciality and Ownership
  Industrial Development
  Fiscal Concessions

BUYER'S CONCERNS
  Reliability of System and LNG Carriers
  Resource Certification
  F.O.B. Limitations
  Expanded Force Majure Terms
  Debottleneck and Expansion Quantities

LENDER'S PRIMARY CONCERNS
  Reliability and Reserves
  Safety and other Concerns

TECHNICAL CHALLENGES

PROCESS AND EQUIPMENT
  Industrial Development
  Process Consideration
  Equipment Consideration

LIQUEFACTION AND LNG STORAGE
  Liquefaction Process Comparison
  Expander Processes
  LNG Storage
  Sloshing of LNG

OFFSHORE LNG TRANSFER
  Subsea LNG Pipelines

IMPROVEMENT AND SAFETY

CONCLUSION

3. References

4. Table 1  LNG Processes for Offshore LNG Projects
  Table 2  Improvement Concepts for Offshore LNG Plants

5. Figure 1  Floating LNG Plants
  Figure 2  Offshore Cryogenic Loading System
1. WHY OFFSHORE LNG PLANTS

Offshore LNG plants may make sense in cases where large ‘stranded’ gas reserves exist at a great distance from any shore line. In these cases, use of a floating plant may be more economical than a traditional shore-based approach. As the oil and gas industry moves further offshore into deeper water searching for oil more natural gas will be discovered. Some of the gas will be associated gas produced with oil while other discoveries will be natural gas reservoirs. Offshore liquefaction is not a new or novel idea. It was considered in the Kangan natural gas field in the Persian Gulf during 1970s. Several studies have been made by Air Products for different companies for building a barge mounted LNG plant offshore. Moss Rosenberg also did the barge design for offshore liquefaction plant. The Salzgitter Group and LGA Gastechnik of Germany in the mid-1970 conducted feasibility studies on construction of barge mounted liquefaction plants using modular construction techniques. The scheme envisaged constructing and outfitting a barge mounted plant in a European ship yard, towing it to West Africa and sinking the barge on the foreshore. The idea was conceived to overcome poor site conditions existing along the coast of West Africa that require extensive land reclamation, dredging and long LNG loading line trestles. Kvaerner took the offshore concept further and did a full front end engineering design (FEED) on a two-train, 2.8 MTPA APCI process, mounted on a steel mono-hull vessel with 165,000 m\(^3\) of Moss storage.

Unlike oil, natural gas cannot be seen, it has no odor, and you cannot put in a bucket and carry it around like a peddler to sell it. Natural gas has inherent market risk. As a fuel it competes and in most instances can substitute for oil and coal but other hydrocarbon fuels can substitute for natural gas. i.e. LPG, naphtha, crude oil, etc. Once the final investment decision is made it entails a high fixed investment in stationary facilities that cannot be easily changed without incurring substantial expense. A floating facility that can be moved and re-used will substantially reduce the risk associated with a stationary investment facility. An LNG project represents an integrated chain of investments and commercial agreements linking exploration, production, transportation and marketing activities. A floating liquefaction plant can reduce the cost of the production link as well as provide maximum flexibility in developing a gas resource. It has been estimated that a floating LNG project might be 20-30% cheaper than a comparable size project and the construction time 25% faster. The floating plant’s mobility will reduce the construction cost of new pipelines and compression facilities that might otherwise be required to bring the gas to a land-based plant.

2. COMMERCIAL CHALLENGES

The size and the production of the gas resource is one of the biggest commercial challenges in developing LNG projects. Associated gas development presents many more technical and commercial development challenges due to the uncertainties associated with the quality and deliverability of the feed gas and the economy of scale required for a liquefaction plant. LNG projects are designed to handle large quantities of gas in the order of 300-400 MMSCFD as a minimum. An associated gas project is more likely to be driven by oil development considerations, economics or host country laws and regulations related to gas flaring than economics of a gas or LNG project. Most commercial issues associated with an offshore LNG plant will be resolved on the same basis as a plant by the project sponsors, suppliers, contractors and host government but will probably take longer due to the trade-offs required to make the project viable.

The commercial risk entails balancing the capital and operating cost with the project’s expected cash flow generated by the LNG production. There is no commercial distinction in this risk whether the plant is located onshore or offshore. An offshore LNG project will be just as site specific as a plant. Current floating LNG concepts generally envisage using a facility in benign conditions such as exist along the coast of West Africa or Western Australia. West Africa is ideally suited for a floating LNG facility primarily due to its lack of suitable deep water coastal sites required for the 13 meters draft of an LNG carrier. A floating facility can reduce years off of a project schedule in terms of land acquisition and reclamation and save $100’s millions of dollars in site preparation and dredging cost. Western Australia is a good candidate because its deep water natural gas fields are located
approximately 200 miles or more off the coast requiring very expensive, $500 million dollars plus, large diameter pipelines to transport the gas to shore.

• **HOST GOVERNMENT CONSIDERATIONS**

The contractual relationship for the exploitation of a country’s hydrocarbon resources is generally governed by a Production Sharing Contract (PSC), Concession Agreement, or some other agreement entitling the contractor to a share of the oil and gas discovered and produced. PSC terms vary from country to country; however, most PSCs are for a term of 20-25 years and designed for exploration and production of oil. Gas contact terms, if any, are often vague or incomplete unless a country has a developed domestic market infrastructure or an export scheme in place but always require a longer period to recover the investment than an oil project.

• **Commerciality and Ownership**

The PSC generally requires a contractor to declare a discovery commercial within 3-12 months of drilling a well and submit an appraisal or development plan for approval to the government. The commerciality of a gas cannot be ascertained until the size of the resource has been delineated and the conditions for gas utilization and marketing defined for the life of the field. Gas can only be commercial if there is a market for the gas and a way to move the gas to market. The lack of PSC provisions covering gas commercialization automatically leads to protracted negotiations on the appraisal program, cost recovery, profit sharing, royalties, fiscal terms, pricing, PSC extension, commercialization process, and market development. These issues can be overcome by bringing in the government as a partner to jointly develop the market at the onset of development.

Many PSCs provide that all structures, facilities, installations, equipment and other property used for producing oil and gas becomes the property of the government. In other instances, the title to the property remains with the contractor but the government has an option to acquire the property with or without payment of compensation on expiration of the PSC term or depletion of the resource. Frequently, the government’s rights of ownership is granted by laws outside the Petroleum Development Laws but these laws clearly impact the sponsor’s ability to reuse capital intensive floating production facilities and make the development of other stranded gas reserves more feasible.

Local content and employment are major host government considerations in exploiting its natural resources and economic development. A plant at peak construction may employ five to six thousand skilled and unskilled laborers. Many of these employees will receive training and develop skills transferable to other projects and industry. Additionally, the multiplier effect of a land-based facility costing billions of dollars will ripple through the whole economy of the country. All of these considerations must be taken into account to meet the government’s objectives without penalizing the floating facility.

• **Industrial Development**

Land-based LNG facilities because of the capital investment required to deliver the gas to shore generally fosters development of domestic use of gas and other industrial developments requiring natural gas as fuel or feed stock. These spin-off developments generally develop over a period of years raising the overall economic development of the area and providing more employment. If an offshore facility is not self-contained, a land-based support facility will be required for moving personnel and materials to the offshore facility. Such a facility can lead to additional economic developments.

• **Fiscal Concessions**

Greenfield LNG projects traditionally have received tax holidays and other incentives necessary to justify the large capital investment of the sponsors. The host government needs to grant fiscal concessions without reciprocal benefits such as increased employment, training, local content, etc. that are normally associated with a land base plant. Government support, guarantees and assurances will be required to launch a successful project.
BUYER’S CONCERNS

Reliability of System and LNG Carriers

LNG buyers have been large regulated utilities or government owned monopoly companies capable of executing long-term take-or-pay contracts. With limited suppliers and receiving terminals scattered around the world security of supply has become almost equally as important as price. While the restructured world gas industry is now more market responsive and the price risk has shifted more to the producer, the need for security of supply has not diminished. The primary concern of a buyer will be the reliability of the system to produce and deliver LNG as contracted. The reliability of special purpose LNG vessels required for bow or stern tandem loading or with side thrusters for side-by-side loading will remain a concern even though it’s proven technology that has been employed for many years by the shipping industry.

Resource Certification

Buyers will still seek assurances sufficient gas resources exist to meet the contractual obligations. Contracts may be for shorter periods, provide more flexible off-take provisions and destination clauses; however, LNG is still not a commodity that can easily be replaced in the open market. The short-term and spot market has a number of characteristics of a commodity market but in reality these sales only accounts for approximately 12% of the world LNG trade. The spot and short-term market only exist because of surplus capacity in over designed and constructed liquefaction plants.

F.O.B. Limitations

The use of special purpose vessels required for offshore loading limits the attractiveness of an F.O.B. trade and the buyer’s shipping options. The vessels should be dedicated to the floating project to enhance the buyer’s security of supply and plant off-take. The purchase of “spot cargos” will be limited to the availability of a special purpose vessel for delivery to a buyer within the shipping distance of the projects annual delivery program. This could limit arbitrage opportunities unless the alternate market is closer to the production facility than the primary target market.

Expanded Force Majure Terms

Until the floating LNG facilities have established a proven record of safety and reliability, it is anticipated the sponsors will insist on more liberal force majure provisions to cover the inherent risk associated with an extension of existing technology to an offshore environment.

Debottleneck and Expansion Quantities

Because of the size and weight of a floating LNG facility a floating facility will be designed and constructed to the owners name plate specifications thereby limiting the opportunities for significant debottleneck quantities. Floating LNG plants will require more optimization of the LNG chain links than a typical land-based plant due to the inherent physical limitations of a floating structure. Once the facility has been designed and construction underway change orders may not possible.

LENDER’S PRIMARY CONCERNS

Reliability and Reserves

Reliability of a floating LNG plant will be the sponsors and lenders primary concern whether it is limited recourse, or equity financing. Will the facility generate sufficient revenues to repay the loan? Lost production days due to weather, damaged to equipment, lack of spare parts, etc. can be modeled to determine the impact on a project’s revenues. Lenders will need to be satisfied there are sufficient resources are available to the sponsors to produce the revenues required to pay back the loan. This could entail a scheme encompassing relocating the facility within the host country or to another project for continuous operations.
• **Safety and other Concerns**

Safety of the floating facility and its ability to resist damages resulting from a collision, system failure, gas leak or other unplanned event are major considerations for all parties involved. Quantitative Risk Assessment tools and Monte Carlo simulations can be used to understand the risk and determine its acceptability. Det Norske Veritas (DNV) has performed a number of studies comparing a floating facility to a land-based facility and has concluded that the overall risks are similar; although, the risks are different due to the inherent differences in a floating and land-based facility. Lenders will look at the sponsors experience and reputation in LNG and their ability to execute large multi-billion dollar projects; although, capital markets today may not be as picky about a sponsor’s demonstrated experience in the LNG business in comparison to the banks and export agencies.

LNG projects were financed historically on the credit of large, regulated utility companies or state monopoly companies capable of executing long-term, take-or-pay contracts. The credit worthiness of the sponsors, buyers and host country may not be as important as in the past because the security for the loan is the floating LNG plant rather than the contracts supporting the LNG trade. Financing a floating facility is comparable to financing a ship or other marine type structure that can be moved and reused again.

## 3. TECHNICAL CHALLENGES

• **PROCESS AND EQUIPMENT**

• **Industrial Development**

Most floating LNG schemes envisage subsea well completions thereby eliminating the need for costly production platforms and large diameter transmission pipelines to transport the gas to shore. Other advantages of an offshore facility include eliminating costly site preparation, harbor or breakwater developments and continuous dredging that are generally required for a land-based plant.

In recent years, several major industry participants have performed various generic and site specific feasibility studies or Joint Industry Project (JIP) on floating LNG plants for locations in the West Africa and Western Australia. First, there was the Gas Utilization Research Forum (GURF) which has addressed the offshore LNG and GTL issues in the 1990s. Then there was the Azure project, which was also partially funded by the EU’s Thermie Programme. This project has demonstrated the integrity of the membrane containment system in partially filled mode. It proved aspects of the control of an LNG transfer system, and developed the design for a novel concrete hull. It also developed steel hull design for LNG FPSO and developed the topside layouts to meet safety and operability requirements. Chevron and Texaco were among the industrial sponsors of the Azure project. For the liquefaction barge, a dual mixed refrigerant process cycle was used in Asia and in West Africa, a nitrogen expander cycle for the liquefaction of the associated gas for a deep sea oil field. The transfer of LNG in open seas can be performed safely in a tandem loading configuration, using the Boom-To-Tanker designed by FMC. The project included both steel and concrete hull designs for the LNG FPSO. Chantiers de l’Atlantique developed the steel hull options, while Bouygues Offshore designed the concrete hull alternative.

Chevron and Texaco were also among the industrial sponsors for the JIPs of the Verification of the OCL Concept and the BG Offshore LNG Safety Assessment. The former one dealt with the technical verification for the development of the OCL system, while the latter one was assessing various safety issues on the offshore LNG facilities layout design and accident prevention measures. These JIPs were very helpful in advancing the offshore LNG technologies toward workable and safe operating ones. Shell has also pursued possible design options of offshore LNG for Kudu in Namibia and for Sunrise in Australian water, while Statoil has studied using offshore LNG for Nigeria.

The technical challenges involve process and equipment considerations, LNG storage, LNG product transfer, and safety and risk considerations. Offshore LNG facilities can be built on fixed facilities such as GBS (Gravity Based Structure) platforms and floating facilities such as floating LNG plants or floating vessels. Besides the main facilities of LNG process equipment and LNG storage,
there are the berthing and mooring arrangements, and the transfer of LNG between the LNG carrier and the terminal. Figure 1 shows an offshore LNG plant with the LNG carrier alongside. Floating offshore LNG production avoids the flaring or re-injection associated with crude production. Shell has developed the concepts such as the floating LNG (FLNG) and floating oil and natural gas (FONG) for processing natural gas and associated gas respectively. Many of the technical challenges will be discussed in the following sections.

Figure 1   Floating LNG Plants

- Process Consideration

   The liquefaction process for the offshore application needs to be compact. The high efficiency C3-MR process cycles that are preferable ones for onshore LNG plants will not meet the future needs of the offshore liquefaction projects. It needs to minimize hydrocarbon refrigerant and its storage. The effects of motion have shown to be of concern to the separation process and that may also cause maldistribution of fluid phases. Thus the efficiency of heat and mass transfer may be reduced and affect the desired results. Change of design material to increase the strength is considered. Also, it is preferable to minimize the equipment count. Due to the offshore location it is desirable to increase the flexibility of the process with respect to variations in feed conditions and the availability of the process so that more production days can be achieved without too many shutdowns. The utmost important issue is that safety needs to be intrinsic to the process in its design and operation.

- Equipment Consideration

   The mechanical integrity, especially those of the liquefaction heat exchangers, has been a concern. It is necessary to increase the shell side design pressure than that of the land-based plant to minimize the incidental flares required for temporary trips of the plant. Also mechanical devices may need to be installed to guarantee that maldistribution can be minimized and avoided altogether. Some of the major cryogenic equipment may need to have their mechanical integrity verified at a scaled down size. Because of the offshore location it will be necessary to reduce unusually high tower by using multiple units. Modularization whenever possible needs to be considered. Again, flexibility and reliability of equipment need to be emphasized.
• **LIQUEFACTION AND LNG STORAGE**

• **Liquefaction Process Comparison**

The liquefaction process to be used for the offshore natural gas liquefaction plant has to consider safety and simplicity more than its thermal efficiency. Propane refrigerant, for instance, needs to be eliminated. There are a few processes that are suitable for the offshore application. The classical one is the multiple expander one, then the nitrogen expander cycle. Several versions of single mixed refrigerant cycle and double mixed refrigerant cycle are available. Linde’s multiple fluid cascade cycle is also applicable. Condensate and LPG could also be produced along with LNG on the same floating facilities.

In Table 1, it compares C3-MR, cascade, single MR, N2 expansion, DMR or MFCP on several factors such as thermal efficiency, specific power, equipment count, hydrocarbon refrigerant, reliability, specific capital investment, suitability for FPSO and availability. It can be seen that both C3-MR and cascade are not suitable for offshore application due to their large hydrocarbon refrigerant use and storage of liquid propane. However, the single MR, N2 expansion, DMR or MFCP are suitable for the offshore LNG application.

<table>
<thead>
<tr>
<th>Table 1 LNG Processes for Offshore LNG Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C3-MR</strong></td>
</tr>
<tr>
<td>Thermal Efficiency</td>
</tr>
<tr>
<td>Specific Power, kW/ton LNG/day</td>
</tr>
<tr>
<td>Equipment Count</td>
</tr>
<tr>
<td>Hydrocarbon Refrigerant Storage</td>
</tr>
<tr>
<td>Reliability</td>
</tr>
<tr>
<td>Specific Capital Investment</td>
</tr>
<tr>
<td>Suitability for FPSO</td>
</tr>
<tr>
<td>Availability</td>
</tr>
</tbody>
</table>

* Note: Statoil-Linde’s Mixed Fluid Cascade Process is similar to the DMR in thermal efficiency, etc.

• **Expander Processes**

Expander process and several of its variation can be considered for offshore LNG applications. Expander cycles using nitrogen as the refrigerant have all gas service and no refrigerant storage, which decrease the plot requirement. There will be less distance between equipment due to the non-flammable nature of nitrogen. It is more suitable for desirable heat exchanger core arrangement and modularization due to most surface area is dedicated to gas to gas service. However the process efficiency is the lowest for the expander process in the comparison in Table 1, but it is possibly the safest process for the N2 expander process.

• **LNG Storage**

Floating LNG production, storage and offloading (FPSO) technology is going to become reality in the future at some offshore locations. The shape of floating barge design is such that the
rectangular shape favors spacing. There are preferences on using either concrete hull or the steel hull. The use of concrete as the primary component has shown to be cheaper and efficient. The hull design using vaulted cylindrical sections used less concrete. Other companies, however, prefer the use of steel hull. The spherical storage is more robust and because of the space required will have less deck space for equipment. Membrane tank storage, where the sloshing effects can be reduced by rounding off the corners, has more deck space. Prismatic tank is another alternative, but it is more expansive.

- **Sloshing of LNG**

  Offshore LNG production will encounter the partial filled LNG storage tank. During the motion of the facilities by the effect of the environment sloshing of LNG in the LNG storage tanks can occur. These phenomena have been studied and found out the severe cases can be dealt with by changing the shape of the storage tanks to strengthen the edges and corners around the tank. It was found out that this can significantly alleviate the sloshing problems. Of course, the spherical tanks of Moss design are more robust and resistant to the sloshing effects of LNG.

- **OFFSHORE LNG TRANSFER**

  The offshore LNG transfer is a developing area with a few years to reach maturity. It is the weakest link in the LNG chain. There is the boom to tanker version of FMC. The BTT can remain connected in sea states up to 5.5 meters significant. It is suitable for exposed environment and has undergone extensive testing. Newer developments include the Offshore Cryogenic Loading (OCL), the Colflexip and SPM articulate arms, among others. Figure 2 shows the tandem loading by the OCL system. The OCL system consists of several cryogenic LNG transfer hoses, which are vacuum insulated double-wall, along with the hawsers required. The LNG carrier is tandem moored to the floating LNG production facility with a distance of 65 meters. A crane carries seven flexible hoses will transfer the LNG. The OCL is an extension of proven technology and has relatively few moving parts and simpler to maintain. There are other LNG transfer system such as the SBM floating soft yoke and the Eurodim concept. It suffices to say that there are still areas of development before these concepts can be adopted.

![Figure 2 Offshore Cryogenic Loading System](image)
• **Subsea LNG Pipeline**

Subsea cryogenic LNG pipelines either jacket insulated or vacuum insulated. There are manufacturers of both types of lines. Subsea cryogenic pipelines have been identified as one of the most critical components for future LNG loading terminals. Successful implementation of subsea cryogenic pipelines has the potential to reduce the capital costs of LNG terminals. Of the jacket insulated cryogenic subsea pipeline concepts, the concept which has been matured the furthest is that developed by InTerPipe (ITP). On the other hand, Chart Industries makes a vacuum insulated pipe for low temperature service. This pipe has been used in above ground LNG services at the Trinidad LNG plant for a 4” cool down line, and at the Everett LNG receiving terminal for the inlet lines to the LNG tanks.

• **IMPROVEMENT AND SAFETY**

There are many aspects of the offshore LNG production plant that can be improved. In general one can consider the different areas of liquefaction process, utilities, storage, and LNG transfer. In each area, one can further divide the improvement into technology, equipment and safety. Table 2 shows the results of such efforts. One can pursue similar efforts for the future improvements of the offshore LNG production. The offshore LNG plant considered here are more suitable for the smaller to medium sizes such as from 1 to 3 MTPA. Larger size plants, possibly around 5 MTPA, will possibly be the limit.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Improvement Concepts for Offshore LNG Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td><strong>Equipment</strong></td>
</tr>
<tr>
<td><strong>Liquefaction</strong></td>
<td>Better compressor fit with aero-derivative turbines</td>
</tr>
<tr>
<td><strong>Utilities</strong></td>
<td>Use gas turbine to generate electricity for all electric driven refrigerant compressors</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Improve other storage concepts for effects of motion</td>
</tr>
<tr>
<td><strong>LNG Transfer</strong></td>
<td>Transfer of LNG of side by side or in tandem between FPSO and ship or ship and FRSU</td>
</tr>
</tbody>
</table>

The safety record of land-based LNG plants will need to be extended to offshore LNG plants. Besides adapting equipment design for a marine environment and process option for a moving environment, Quantitative Risk Analysis (QRA) has been used to analyze the safety risks of equipment congestion, effect of refrigerant and to understand mitigation measures that can minimize
overpressure and incident escalation. This will lead to a better equipment layout and a safer offshore LNG plant.

4. CONCLUSION

Offshore LNG liquefaction offers an attractive means to monetize the stranded gas fields in the deep seas and to stop flaring of associated gas produced along with oil, among other advantages. However, there are potentially many commercial and technical challenges ahead. This paper attempts to delineate these challenges and discuss means to resolve these problems to avoid both the commercial and political concerns for the offshore liquefaction projects. It also discusses the technical challenges and offer options for them. It is believed that offshore LNG plants will be built in the future to offer more clean energy, to stop the environmental impacts of flaring natural gas and to capture the stranded gas.

REFERENCES