Tangguh LNG - Energy Efficiency Measures through Life Cycle Cost Analysis

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ABSTRACT

The increasing worldwide demand for LNG is reflected in the number of both current expansions of existing facilities and proposed new LNG Export and Import facilities. Consistent with BP’s gas growth agenda, the Tangguh LNG Project is progressing to further Indonesia’s prominent and long established role in meeting this worldwide LNG demand. The Tangguh LNG Plant design is also moving forward by incorporating increased energy efficiency and optimized facility design concepts, while reducing Green House Gas emissions.

The Tangguh LNG project team approach establishes a project framework and philosophy that challenges energy efficiency, facility life cycle cost, and social and environmental issues to deliver best in class performance, all underpinned by delivering a safe, robust and reliable facility. Approximately 160 MW of waste heat is recovered in each LNG production train, and is utilized within the LNG Train and for electrical power generation. This deep combined cycle concept, coupled with additional energy efficiency and environmental design applications, have set new benchmark metrics for a grass roots LNG project, energy efficiency and CO2 emissions.

The plant facilities have also been optimized from a cost standpoint, through the application of innovative dynamic relief analysis techniques, to reduce constraining design basis flare loads. Application of Computational Fluid Dynamics modeling of hot air re-circulation has also yielded significant plot plan improvements.

When viewed through the lenses of energy efficiency, life cycle cost and environmental impact, the incorporation of innovative energy efficient designs, advanced facility design concepts and environmentally friendly measures allows the Tangguh LNG project to raise the performance bar for future LNG Plant designs. It also provides a solid platform to support long-term, highly reliable operations, both for the initial project and for future brown-field expansions.
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**Introduction**

The application of a deep combined cycle configuration utilizing Frame 7EA industrial gas turbines, in the Tangguh LNG Project, serves to set a new standard for energy performance and LNG production cost within the global LNG industry.

**Tangguh LNG Project Overview**

The Berau-Bintuni Bay region of Papua is located approximately 3,200 km from Indonesia's capital, Jakarta. Oil exploration began prior to World War II, but it was not until the mid-1990s that exploration teams discovered two large offshore gas fields, Wiriagar Deep and Vorwata. In 1997, these discoveries gave rise to the Tangguh LNG Project. Current proven gas reserves have been externally certified at 14.4 tcf with a projected potential of 24 tcf (i.e. total of proven, probable and possible reserve estimates).

The total Tangguh project scope will involve developing these offshore fields, processing the gas into liquefied natural gas (LNG) in onshore facilities and loading it for shipment to the ever expanding global LNG markets. The Tangguh LNG Project intends to set high standards in socially and environmentally responsible resource development.

A unique feature of the Tangguh Project is that BP will be the project executor and operator for both the offshore and onshore portions which will permit synergies between these two very different work scopes to be realized. The offshore design for the reservoir, platforms and sub-sea pipelines for the Tangguh Project evolved from the initial traditional concept of a large manned central gas processing platforms involving phase separation, gas conditioning, dehydration, power generation and fed by numerous wellhead platforms to highly simplified, reduced cost design utilizing two "normally unattended installations" (NUI's) that have no offshore gas processing/power generation facilities. All such facilities have been shifted to the scope of the onshore LNG plant design where these functions can be performed in a more cost effective, safe, efficient and reliable manner. The design decision to utilize special corrosion resistant alloy (CRA) metallurgy for the sub-sea lines was integral to the advancement of the NUI design. The two NUI platforms will collect the three phase reservoir fluid, and transport it via sub-sea CRA pipelines to an LNG Plant facility.

The land acquired for the onshore LNG Plant facility measures 3200 hectares, much of which will remain a 'green zone'. When fully operational, the Plant would need 240 site positions of all skill levels and disciplines. The grass roots LNG Plant will consist of two nominal 3.8 million tonnes per annum (mtpa) capacity LNG trains, utilities, offsites, condensate stabilization, product storage, marine loading facilities, as well as an aircraft landing strip, maintenance facilities, bulk cargo handling facilities, offices and a personnel accommodation complex. A master plan development for an ultimate 8 train facility, with supporting community infrastructure facilities has been considered in the design of the initial grass roots launch, the land purchase and plot plan development.

The Tangguh LNG Project is working with local government and other partners to implement a Diversified Growth Strategy; which promotes project-related activities in regional towns that can accommodate economic growth-rather than in the project area itself. From the outset, the Tangguh LNG Project is being designed and implemented according to an integrated, holistic approach-emphasizing community, partnership, consultation and corporate responsibility. In addition to generating substantial government revenues, the project will work with diverse partners and local communities to attain sustainable development, cultural preservation and biodiversity conservation.

A Tangguh International Advisory Panel (TIAP) composed of USA Senator George Mitchell, UK Lord Hannay, Papuan Reverend Saud and former Indonesian Ambassador to Australia Sabam Siagian has been formed to conduct periodic, independent reviews of the Project's efforts to address social, cultural and environmental issues.

In June and July of 2004, the Tangguh LNG Project relocated 127 families of Tanah Merah Village. The relocation of the village has paved the way for the Project to start its LNG processing plants construction. Of the 127 families, 101 have chosen to move to an area nearby Saengga village which is located 3 km away from their previous site while 26 families have voluntarily chosen an area close to Onar village which is approximately 12 kilometers away from their settlement site. All resettled villagers received increased space, lighting, running water, sanitation, and better quality construction. The new community building and facilities also exceed previous standards, and the Project is committed to safe, hygienic systems that can be maintained by the village with minimum external help. The Project is also introducing modern technologies where appropriate - for example, solar energy as a clean and efficient way of supplementing diesel generation. The Project also has been working closely with the community to re-establish independent family livelihoods. Resettlement of Tanah Merah village has been developed to adhere to World Bank and international standards and it included close involvements of an Advisory Panel comprised of two of the world's top resettlement experts. To ensure that resettlement project provides best interests of the resettlement affected
communities, the Project has developed an implementation document on Land Acquisition and Resettlement Action Plan (LARAP) which provides details of measures and represents the Tangguh LNG Project commitments to addressing the impacts of the resettlement on the three resettlement affected communities.

The Tangguh LNG Project establishes a framework and philosophy that challenges the traditional design concepts to incorporate energy efficiency, green plant design features and life cycle cost methodology to deliver a safe, reliable and cost effective offshore and onshore facilities. The remainder of this paper/presentation shall concentrate on the onshore LNG plant facility design

Historical LNG Plant Design

Historically LNG Plants have been designed to a high availability. To assist in achieving this design goal, production critical equipment proposed to be utilized in the LNG Plant must demonstrate high operational performance for an extended period in operating facilities. Reliability, Availability, and Maintainability (RAM) analyses of typically LNG Plants clearly indicate that the refrigerant compressor drivers in the cryogenic section are one of the most important pieces of production critical equipment. It is within this context that the historical application of driver selection, operating configuration, and LNG train capacity can be discussed.

Starting with the first LNG Plants, and still present in today's designs, is the application of proven drivers for the refrigerant compression systems. Selection of driver type – steam turbine or industrial gas turbine has been driven by proven operational experience and plant location. With the ever maturing gas turbine technology and operational experience, the open cycle gas turbine configuration has become the norm for the refrigerant compressor drivers.

Single LNG train production capacity has increased to the current maximum design of +/-5.0mtpa. This capacity increase has been achieved through the application of multiple parallel strings of two shaft industrial gas turbines, or larger single shaft industrial gas turbines. The choice of turbine configuration is a reflection of separate design philosophies. In step with the application of the larger gas turbines has been the increased capacity and efficiency of the refrigeration compression. Recent information has indicated that the increased scale of production has been accompanied by a decrease in LNG Specific Cost [1], [2].

![LNG Production Capacity – Trends in scale](image1)

Figure 1. LNG Production Capacity - Trends in Scale [1]

![LNG Plant – Specific Costs](image2)

Figure 2. LNG Plant – Specific Costs [2]
Still larger LNG Train production capacities (in the range of 7-8mtpa) have been the focus of recent engineering studies [1], [3], in an effort to identify the controlling parameters for the scale up of production capacity. The realities of market pull and its interaction with the overall LNG Project, alongside equipment technology, are seen to be significant considerations in the LNG production train capacity scale up.

**Energy Performance**

The production of LNG, from untreated feed gas, is an energy intensive process. For the purposes of this paper the LNG Plant will be divided into two pieces – the cryogenic section and balance of plant.

**Cryogenic Section** - The cryogenic section is defined to include feed gas pre-cooling, heavy ends removal, refrigeration and liquefaction to produce liquefied natural gas (LNG).

**Balance of Plant** - All other facilities, inclusive of feed gas conditioning, dehydration, mercury removal, boil off gas et. al. are defined to be included in balance of plant.

Overall internal LNG Plant energy consumption can be as high as 14% of the incoming feed gas to the cryogenic section. The latest most efficient designs have reduced this to as low as 7%. At the next level of detail – the cryogenic section can account for 75-80% of the overall energy demand. As the refrigerant compression systems dominate the cryogenic section energy consumption, the compressor and driver efficiencies are a major determining factor for both the cryogenic section and overall plant energy performance. As discussed above, to date, either steam turbines or industrial gas turbines, operating in a simple or fundamentally open cycle have been utilized for the refrigeration compression drivers. The application of these drivers in an open cycle fundamentally dictates the energy consumption profile and associated energy performance for the LNG Plant.

**Combined Cycle LNG Plant Design**

Combined cycle operation of large scale industrial gas turbines has been utilized within the electrical power generation industry for over three decades. The period 1995-2000 saw the application of large scale gas turbines (approx. 235MW, high pressure multi level steam combined cycle plant designs) [4]. Within the historical design approach for the LNG Plant facilities, based on production critical equipment with demonstrated operational performance, the application of a combined cycle design concept, for the industrial gas turbines, is now well within the LNG industry practice design guidelines.

The application of the Frame 7EA industrial gas turbine, as the refrigeration compressor drivers, presents an opportunity to configure the gas turbine in a combined cycle operation. Project specific decisions will have to be taken to understand how to best utilize this recovered energy from the turbine exhaust stack. Notwithstanding, the combined cycle application can be designed to meet the open cycle plant availability, while delivering a safe, robust and reliable facility, with increased overall plant energy performance, at best in class LNG production cost.

**Combined Cycle – Potential Applications**

When we look at the potential major applications of waste heat recovery within the LNG Plants, three potential candidates readily present themselves:

- Acid Gas Removal Unit
- Incremental LNG Production
- Electrical Power Generation

**Acid Gas Removal Unit (AGRU).** As a function of the acid gas content in the feed gas, the energy consumption for the AGRU could span the range of 2-20% of the overall plant energy demand. Recovered energy could be utilized for AGRU regenerator reboiler duty requirements.

**Incremental LNG Production.** Another potential application for the recovered energy is to provide incremental LNG production. Recovered energy can add about 50% to the available power for the refrigeration compression energy demand.
Electrical Power Generation. Recovered energy, in a classical combined cycle configuration, could be used to meet the entire plant electrical power demand (notwithstanding integration and start-up issues).

When viewed through a technical lens, the implementation of combined cycle operation has a number of applications within the LNG plant. Project specific decisions will have to be taken to understand how to best utilize the recovered energy. Although technically sound, the economics surrounding the monetary value of energy inside the LNG Plant will impact the depth of the combined cycle applications and waste heat recovery.

Energy Value Inside an LNG Plant

Within any fungible energy market, supply & demand, alternate fuel capability, and a great number of other factors play into the determination of the final energy price. As LNG plants are not located near significant energy markets, the basis for determining the energy value inside the plant does not follow any single template or is necessarily consistent between LNG Projects.

Prudent capital investment and overall life cycle cost analyses are required for any grass roots or expansion LNG Project to compete in today's market. Considering the large energy consumption for an LNG Plant, valuation of energy inside the plant will have a tremendous impact on the overall project success, its design and green house gas emissions. Some factors that may play into the determination of the energy value for an LNG Plant:

- Is an alternate fuel comparison valid
- Is the value of associated products from the reservoir to be included
- Energy value if taken from the front end of the plant vs. from within the LNG Train
- Environmental issues to be reflected in the pricing
- Operational flaring requirements
- Offshore/upstream considerations
- Possibility of natural gas feed supply for production of alternate products

Clearly each project, based on their philosophy and project framework, must take these and a number of other factors into consideration to reach a representative value for energy inside the LNG Plant.

Tangguh LNG Project – Raising the Performance Bar

The Tangguh LNG Project design reflects a philosophy and framework that challenges historical design boundaries to incorporate energy performance, green plant design features and life cycle cost methodology to deliver safe, robust and reliable offshore and onshore facilities. The Tangguh LNG Project spans the full value chain from reservoir, platforms, sub sea pipelines, onshore liquefaction processing to marine transportation facilities.

The overall LNG plant facilities plot plan, major equipment and piping layouts have been finalized through detailed engineering which included; Quantified Risk Assessment (QRA), Blast & Overpressure modeling, Vapor Cloud Dispersion Modeling, and a Fire Risk Assessment. The results of these studies, in combination with the most recent lessons learned within the LNG industry, provide the basis for the design of the LNG plant facilities. The final result has been a facility which falls well below the BP Group Risk acceptance criteria for new facilities.

With respect to key project performance indicators of Energy Performance, Environmental Performance, and LNG Production Cost, the Tangguh LNG Project design has advanced the performance bar upward for LNG Plant designs.

Reflecting increased LNG market demand, the individual LNG production train capacity has been increased to a nominal 3.8mtpa. The increase has been achieved whilst still focusing on energy performance and green plant design concept. Fundamentally the LNG train design has moved to an End Flash configuration, with liquid expanders on the heavy MR refrigeration circuit and LNG product streams.
Frame 7EA industrial gas turbines have been purchased for the refrigeration compression drivers of the Tangguh LNG trains. The project has taken the next step in LNG plant design by providing each of these engines with Heat Recovery Steam Generators (HRSG) in a deep combined cycle configuration. For the Tangguh two train LNG plant, approximately 27% of the total energy demand is supplied from waste heat recovery.

The following Table 1, Tangguh LNG Project Deep Combined Cycle Application, is a summary of the recovered energy and its application for the two train configuration. More detailed description of each application is provided below:

<table>
<thead>
<tr>
<th>Recovered Energy (MW)</th>
<th>Total Plant (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGRU Note 1</td>
<td>259.1</td>
</tr>
<tr>
<td>Frame 7EA Steam Helper Turbines</td>
<td>50.3</td>
</tr>
<tr>
<td>Power Generation</td>
<td>11.0</td>
</tr>
<tr>
<td>Total</td>
<td>320.4</td>
</tr>
</tbody>
</table>

Table 1. Tangguh LNG Project Deep Combined Cycle Application

Note 1: Includes all normal operating reboilers and heaters using waste heat steam.

**AGRU.** As a result of the high acid gas content of the feed gas, a back pressure steam turbine has been selected for each Frame 7EA helper unit with the exhaust steam used to provide AGRU reboiler heat duty requirements (as well as other miscellaneous reboiler and heaters duty loads within the plant). This recovered energy represents 21.7% of the overall plant energy demand.

**Frame 7EA Steam Helper Turbines.** Each Frame 7EA turbine is operated with an 12.6 MW steam turbine helper to meet the refrigeration compressor power demands. High pressure steam from the Heat Recovery Steam Generators (HRSG) on the Frame 7EA turbines supply the motive steam for the steam turbine starter/helpers. This recovered energy represents 4.3% of the overall plant energy demand.

**Power Generation.** The balance of recovered energy, (after the process applications of the steam turbine starter/helpers and AGRU) is used to supplement the motive steam for the condensing steam turbine driven power generation sets. This recovered energy for the utilities area represents 0.9% of the overall plant energy demand.

**Liquid Expanders.** Liquid Expanders have been added to the Heavy MR refrigeration circuit and LNG product streams. The expanders were incorporated as part of the End Flash design to increase the LNG train capacity. Approximately 3.0MW of electrical power will be recovered from the expanders which represent about 5% of the electrical power requirements.

**Impact of Improved Energy Performance on Green House Gas (GHG ie CO2).** For quantification of the Tangguh LNG Project design energy performance and green house gas reduction, a metric of ton CO2 emission per ton of LNG production is used. The Merlin Associates’ Oil and Gas Journal April 14, 2003 article titled “Benchmarking Study Compares LNG Plant Costs” is used as a reference source of data from 5 other recent grass roots LNG projects.

The Tangguh LNG Project design is burdened with a high acid gas content of 12.5 mol% CO2 (and 10 ppm H2S) of the incoming feed stream whereas the total acid gas composition (CO2 and H2S) from these 5 other LNG projects is less than 3.1 mol % per Merlin Associates reference.

The attached Figure 3, Specific Combustion CO2 Emissions Metric reflects an extension of the Merlin Associates article [2] to include the Tangguh LNG Project design. Figure 3 displays the combustion CO2 which is a byproduct result of fuel consumption for gas turbine combustion (both compressor drives and power generation), boiler combustion and miscellaneous process/utilities needs, as a ratio to LNG production.
Figure 3. Specific Combustion CO2 Emissions Metric

The data of Figure 3 reflects the overall plant energy efficiency as a function of the process design (heat and cold integration for optimized usage), the main compressor drives, power generation equipment types, waste heat recovery maximization, minimization of venting/flaring, incoming acid gas content and feed gas molecular weight.

From Figure 3 the Tangguh LNG Project design is found to have a combustion CO2 metric of 0.26 tons CO2 per ton LNG and is amongst the lowest of the five other recently completed grass roots LNG projects. Despite the lean Tangguh feed gas composition/high acid gas content, the application of waste heat recovery/combined cycle applications have resulted in significant improvement of the specific combustion CO2 metric than what would otherwise have been expected.

Environmental Performance

Consistent with the increased energy performance for the LNG Plant, through the application of the deep combined cycle configuration the Tangguh LNG Project design has also implemented the items listed below in an effort to reduce the environmental impact of the overall project:

- recovery of LNG ship vapors during LNG ship loading and achievement of a “no operational flaring” goal
- selection of energy efficient, proprietary activated tertiary amine solvent for the gas conditioning system
- unique design feature employing a dual flash separation step further reducing the energy consumption of the gas conditioning system
- selection of dry low NOx combustion system for the process frame 7 gas turbine drivers
- establishment of single status employee basis for the operating company thereby reducing infrastructure needs and minimizing environmental impact
- selection of tandem seals for compressor and pump applications in hydrocarbon service thereby minimizing fugitive emissions
- application of liquid expanders and back end flash within the cryogenic section

LNG Production Cost

For a grass roots LNG Plant, plant infrastructure and LNG Trains constitute the majority of the overall project cost. The Tangguh LNG Project design has implemented the items listed below to ensure the overall facility is fit-for-purpose:

- Innovative relief analysis within the cryogenic section refrigeration circuits, to reduce flaring loads and relief system equipment designs through the application of dynamic system modeling.
- Plot Plan improvements, substantiated by extensive use of Computational Fluid Dynamics (CFD) modeling of hot air re-circulation from the air cooled heat transfer equipment.
- Siting of marine facilities to avoid operational dredging.
The foregoing features described in this paper presentation are the major items that have allowed the Tangguh LNG Project to achieve a specific cost metric consistent with the range of values indicated in Figure 2.

The Tangguh EPC bidding phase was very competitive and produced a cost metric of slightly less than 200 USD per ton. Over the past 15 months, bulk material deliverability/pricing have increased substantially and bid validity price extension negotiations are in progress to address these present commodity supply conditions. We are confident that the final Tangguh LNG Plant EPC cost metric will compare favorably with other LNG projects within the Asia-Pacific region.

**Conclusion**

The Tangguh LNG Project has established a philosophy and framework that incorporates innovative energy efficient designs, green plant design features and environmentally friendly measures, using a life cycle cost approach as an objective measure, to deliver what is believed to be new benchmark metrics for a grass roots LNG project design regarding costs, energy performance and minimization of CO2 emissions that advances the performance bar upward for LNG Plant designs.

**REFERENCES CITED**