REDUCING CAPITAL AND OPERATING COSTS IN GAS PROCESSING, LIQUEFACTION, AND STORAGE

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Abstract

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The LNG industry is unanimous that capital costs must be reduced throughout the chain, and especially at the liquefaction facility including associated gas processing and LNG storage. The Kenai LNG Plant provides an example of how both reduced capital and operating costs were attained. This paper will cover cost reduction strategies that can be applied to liquefaction processes in general, and will than focus on their realization in the Phillips Optimized Cascade LNG Process. A brief overview will be given of the current versions of Phillips' designs, with emphasis on the world-scale 2.5-3+ MPTA plant and its low $/TPA. Consideration will be given to principles that should help to contain operating costs. The paper concludes that reduced LNG plant costs are attainable.

Introduction

The LNG industry is poised to enter the next millennium with both tremendous opportunity and challenges. The demand projections for LNG are well-known and encouraging (Figure 1). However, challenges also exist; such as more fragmented markets in the premium and mature LNG consuming countries, difficulties of establishing profitable LNG applications in emerging markets, competition with other energy sources, and competition between greenfield and incremental LNG projects.

Of course, LNG projects are by their very nature expensive due to the exotic metallurgy, large-scale equipment, and remote locations. Until fairly recently, the general trend of liquefaction plant costs expressed as $/TPA, has been increasing (Figure 2). All concerned in the LNG industry agree that this trend must be arrested and reversed.

The Kenai LNG Plant Point Of Reference

The Kenai LNG Plant has been operating safely and profitably since 1969, and enjoys a reputation as both a low-capital-cost and a low-operating cost facility. The plant is located in Kenai, Alaska, USA, and currently exports about 1.3 MTPA to buyers Tokyo Electric and Tokyo Gas in Japan. The facility is jointly owned by Phillips Petroleum Company (70%) and Marathon Oil Company (30%), and is operated by Phillips.

The plant was designed by Phillips and Bechtel, and employs an early closed-methane-cycle version of the current Phillips Optimized Cascade LNG Process. In this process, three essentially-pure refrigerants are optimally cascaded; e.g. propane refrigerant condenses the ethylene refrigerant, which in turn condenses the methane. The plant was the first to use gas turbines to drive the refrigerant compressors, and was completed within 26 months after the start of site preparation.

At the time Kenai was the largest single-train plant in the world, and to this day remains the only reliable single-train baseload LNG Plant. In fact, reliability is such that the Kenai LNG Plant has never missed a shipload.

If valued in 1995 U.S. dollars, the Kenai LNG Plant would cost about $200/TPA. The Kenai Plant also has a small O&M staff, which will be described later. Hence, Phillips' Kenai LNG Plant can serve as a useful reference for the LNG industry's efforts to contain costs.

General LNG Plant Cost Reduction Strategies

An unusual, but appropriate starting point for reducing LNG plant costs is acknowledging and using the superior process design tools that exist today. Steady-state process simulators and their improved physical properties packages can be benchmarked against existing plants and then run repeatedly to optimize designs. The cost implications of alternative approaches can be quickly evaluated. More exotic design techniques such as pinch analysis and dynamic simulation can be applied to fine-tune specific unit performance and to reduce design conservatism. Equipment, especially heat exchangers, can be more accurately rated today than in the past. The net result of all these design improvements is that today a plant can be "designed to capacity", with resulting capital savings.

The LNG industry seems to be moving towards optimum economies of scale in the range of 2.5-3+ MPTA per train. Train sizes smaller than this are dominated by relatively large fixed costs such as site preparation, LNG storage, and jetties. Train sizes much larger than 3+ MTPA (the exact cutoff is unknown) for most locations will probably observe reverse economies of scale; e.g. piping and valves will become prohibitively expensive, and large equipment will become unique and "one-off". Inherent in this exercise is selecting the gas turbines that will be used to drive the refrigerant compressors, as this is a major part of the plant's capital cost.

Other Value Improving Practices (VIP's) such as "process simplification" and "value engineering" can and should be implemented. Process functions can be combined, vessels and compressor stages may be eliminated, and other equipment may no longer be required. Non-traditional approaches in performing certain process functions can be brought in from other industries. New technologies can be evaluated. Of course, footprint reduction is a goal in itself, to the extent that safety, operability, and maintainability allow.

A new LNG plant design can also evolve as "fit for purpose". That is, the plant will comply with industry-accepted standards such as NFPA 59A, but arbitrary standards such as typically imposed by the operating company or technical lead might merit de-emphasis. Consideration should be given to using the EPC company's specifications. An atmosphere that encourages challenging the status quo ("why does it have to be this way?") should be maintained, and a cost reduction mentality should be emphasized throughout the design.

Successful application of "front-end loading" principles is also a key ingredient to reducing LNG plant costs. Site-specific engineering data must be collected quickly and applied to the design. Key operations and maintenance personnel must be assigned to the project and become integral to the design team. Hazard analyses should be performed as quickly as the design allows so that mitigation can be performed on paper instead of after the fact. The design must undergo constructability reviews. Proper application of front-end loading principles will reduce capital costs by ensuring that the design is "right the first time".

Lastly, proper execution of the design is also essential. Permitting, procurement, contracting, and construction strategies must all be formulated; all of at which today's large EPC contractors are proficient. Procurement strategies might include alliances or similar alignment mechanisms with equipment suppliers, and early procurement of long-lead-time items. Project controls must be established. Finally, startup planning needs to be an integral part of the design and construction process.

The Phillips Optimized Cascade LNG Process

A block flow diagram of the Phillips Optimized Cascade LNG Process is shown on Figure 3. Feed gas conditioning uses standard processes which can be tailored for specific gas compositions; and typically includes inlet separation, acid gas removal, dehydration, mercury removal, and solids filtration. The clean feed gas is then chilled in the propane refrigeration cycle and condensed in the ethylene refrigeration cycle. The condensed feed enters the open-loop methane refrigeration cycle, which produces the LNG stream that goes to storage, a recycle stream that re-enters the liquefaction processes, and a fuel gas stream (note that a separate fuel gas compressor is not required). Of course, storage tank boil off vapors are recovered and integrated within the methane cycle.

The standard Phillips design utilizes a concept referred to as "2 train in 1 reliability" (Figure 4). The feed stream (including gas conditioning, liquefaction, and storage) are sized for 100% of design throughput, while each refrigerant cycle consists of two 50% turbo-compressor sets in parallel. That is, there are two propane, two ethylene, and two methane turbo-compressor sets. This technique improves single-train reliability while enabling a broad operating range (from 10% to 100+%) as described below:

Description	Cause	Range
Full Rate	Normal	90-100+ %
One Machine Down	Turbine Maintenance	70- 80 %
Half Rate	Shipping Delay	40- 55 %
Idle	Extreme Delay	10- 15 %

Phillips typically assumes a conservative 93% overall plant availability in its designs. This can be compared to the Kenai experience of plant availability exceeding 95%, gas turbine reliability exceeding 99%, and never missing a shipload in 27 years.

Phillips Efforts at LNG Plant Cost Reduction

Building upon the Kenai success, in the early 1990's Phillips and Bechtel commenced intensive efforts to reduce the capital cost of the Optimized Cascade LNG Process. Numerous process simulations were run to establish the optimum cost/performance balance over a broad range of ambient conditions and gas compositions. As an example, the cost or savings of adding or deleting compressor stages to the various refrigerant cycles were calculated and compared to the resulting LNG output or efficiency variation, resulting in the current standard compressor lineup. Power was balanced between the three refrigerant cycles (propane, ethylene, and methane), which enables the use of identical compressor drivers with resulting reductions in spare parts costs and maintenance expense. Where appropriate, techniques such as pinch analysis or dynamic simulator were used to fine-tune certain unit characteristics.

Phillips then selected gas turbine drivers for its world-scale plant (around 3 MTPA) that offered a number of competitive possibilities: For the maximally efficient version, the LM2500 was used as the design basis; and for the lowest $/TPA version, the Frame 5 was employed. Both the LM2500 and the Frame 5 are well-proven in mechanical drive service, are priced in a competitive environment, and offer upgrade possibilities. Since both gas turbines are two-shaft machines, their starting motors are considerably smaller than the larger single-shaft machines, which has the added benefit of reducing the cost and complexity at the electrical plant. In addition, the use of parallel turbo-compressors reduces the cost of the flare system since the blocked discharge relief case is halved.

Process simplification techniques were applied to improve upon the Kenai-based design. Parallel vessels were eliminated wherever possible, certain refrigeration functions were combined, and numerous economizers were eliminated. In fact, one of the benefits of the open-cycle methane loop is the elimination of the separate fuel gas compressor. The net result is that for a plant twice the size of Kenai, efficiency is improved (typically 90-93%) while the cold boxes have been optimized to just two in the 500T to 600T range. Footprint discipline has been maintained to where the generic 3+ MTPA plant is not much larger than the Kenai LNG plant.

A "fit for purpose" approach was utilized throughout the design. Phillips' internal engineering standards served as useful references. Also, the EPC company's specifications were reviewed and used, but with an emphasis an allowing equipment vendor's standard equipment to comply as long as functional requirements were met. Of course, there were instances where ground could not be given, but in general, the atmosphere was one of open-minded intent to meet industry standards and government regulations.

Front-end loading principles were applied vigorously. The design effort, although generic in nature, was based upon a real site, with real ambient conditions, and a real gas composition. Feedback was obtained from the Kenai experience. Plant operations and engineering personnel were an integral part of the design team and participated in the process hazards analysis. Modularization was pursued where appropriate (although the overall plant is stick-built), and constructability reviews were held. The end result was a basic LNG plant design that costs significantly less than the industry paradigm.

Current Generation Of Phillips' LNG Plant Designs

As previously stated, Phillips has been working with Bechtel Corporation to offer the 1990's generation of the Optimized Cascade LNG Process. Phillips has spent over $12,000,000 to complete numerous engineering studies including Front-End Engineering Design (FEED) packages for three "generic" plants. That is, a number of "real world" design assumptions have been made, engineering has progressed to the 20-25% level, equipment and services specifications have been written, and equipment and service competitive bids have been received as if a real project was to be executed. Subsequent studies have expanded the options available from the three base designs.

The three generic FEED packages are described as follows:

Identifier	MTPA Range	Refrigerant Compressor Gas Turbine Drivers
2.5	3.0-3.6	6 LM2500's or 6 Frame 5's
1.1	1.3	6 Mars 100's
1.1 Expand.	1.5-3.0	3 LM2500's now, 3 more LM2500's later

Common assumptions to all three generic FEED studies include:

- fairly lean inlet gas composition (approximately 96% C1)
- low inert gas concentration
- low acid gas concentration, trace H_2S
- 26°C design temperature
- fairly significant site preparations
- foundations require piling
- good local construction infrastructure
- air versus seawater temperature suitable for airfin cooling
- single-containment LNG storage tanks
- low-cost jetty

The scope of the FEED packages include design and installation of the following facilities; e.g. the entire LNG plant:

- gas conditioning
- liquefaction
- storage and loading
- utilities (self-sufficient)
- buildings

Assuming that the site has been selected, the FEED work (20-25% engineering) has been completed, acquisition of environmental permits is underway, and business activities proceed as planned, then going from "start" (project approval, EPC award, etc.) to making LNG can occur in under 36 months (Figure 5).

The "2.5" Plant

As stated previously, the "2.5" is a nominal identifier for the plant's LNG output in MTPA. Given the aforementioned design conditions and taking 100% of the design output (e.g. no derating for gas turbine maintenance, unplanned outages, or turnaround activities such as vessel inspection), the "2.5" plant actually has an LNG output of 3.0 MTPA for the aeroderivative (6 LM2500) case, and 3.6 MTPA for the industrial (6 Frame 5) case. The gas conditioning and liquefaction process were described previously. Included in the design are two 95,000 M^3 single-containment LNG storage tanks, each with three in-tank loading pumps. A jetty complete with loading arms is also provided.

The plant complies with NFPA 59A, U.S. EPA environment regulations, and U.S. OSHA worker safety regulations. Appropriate safety systems such as fire, gas, and cryogenic liquid detection are included; along with emergency shutdown and various fire suppression systems.

Depending on whether the aeroderivative or the industrial version of the "2.5" is selected, the plant (e.g. gas conditioning, liquefaction, and storage) will have the following characteristics:

Parameter	Aeroderivative	Industrial
Refrigerant Gas Turbines	6 LM2500	6 Frame 5
Inlet Rate	455 MMSCF/D	556 MMSCF/D
LNG Output (100%)	3.0 MTPA	3.6 MTPA
Overall Plant Efficiency	92.5%	90.7%
Plantwide Electrical Load	16.5 MW	16.7 MW
2-Train-In-1 Reliability	Yes	Yes

The "2.5" is the world-scale flagship offering of the Optimized Cascade LNG Process, and can be designed and constructed in many locations for $200 - $250 per TPA. It should be noted that although this design makes a single-train projects reliable and profitable, the concept can also be applied to multi-train projects. That is, construction activities can be staggered and optimized to reduce overall costs on subsequent trains, while the initial train operates reliably.

Phillips is currently pursuing a single-train "2.5" LNG plant to develop the Bayu-Undan field, discovered in 1995 in the zone of cooperation between Australia and Indonesia. And of course, the Atlantic LNG (ALNG) consortium in 1996 selected the Bechtel/Phillips bid to construct a "2.5" plant in Trinidad.

Reducing Operating Cost

The Kenai LNG Plant has a reputation for low operating costs. An excellent process design, a "good" feedstock (99% C1) for making LNG, a highly-skilled workforce, and a good location are all parts of the equation. Total Phillips employee workforce at Kenai is about 50; more or less equally divided between plant operations, plant maintenance, offshore platform operations and maintenance (the platform is the source of the Phillips feedstock), and front office staff (management, engineering, administration, etc.). As an example of the low head count, on weekends there are typically only three people in the plant: a shift supervisor, and inside operator, and an outside operator.

How can this be translated to other locations? Phillips has not yet had this opportunity come to fruition regarding LNG. However, Phillips is no stranger to successfully operating safe, profitable, and efficient upstream and downstream business units outside of the USA. The following are guidelines that could be employed:

- Select technology that is appropriate for the region
- Design & construct on "operator-friendly" and maintainable facility; involve O&M personnel throughout
- Consider life-cycle costs
- Focus on startup throughout the design
- Develop operating procedures during design
- Hire and train national work-force early
- Assign experienced expatriate personnel to key positions
- Use contractors for non-core or intermittent services
- Respect the local culture and work practices, utilize their strengths

Phillips intends to apply the computerized process training methods developed at Kenai, and use Kenai as a training springboard, to improve operating consistency and reduce costs on future LNG projects.

Conclusion

The Kenai LNG Plant has operated safely, reliably, and profitably for over 27 years, and serves as a reminder that reduced capital and operating costs are attainable. There are many evolutionary design practices that can be applied to reduce the capital costs of today's LNG plants. Phillips and Bechtel have demonstrated their commitment in this regard as evidenced by the award of the ALNG Project. In addition, Phillips and Bechtel have recently announced the formation of a Global LNG Alliance, with a mission of reducing LNG plant costs. In conclusion, the LNG industry will enter the next millennium with the tools and the competitive arena to reduce capital and operating costs in the liquefaction portion of the LNG chain.

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