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GASTECH 2000

“Passing the Baton Cleanly”

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Commissioning & Start-Up of the Atlantic LNG Project in Trinidad

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Introduction

Atlantic LNG Company of Trinidad & Tobago has been successfully operating a single-train LNG plant in the Atlantic region since the facility was taken over from Bechtel International on June 14th, 1999. The Project was completed one month ahead of schedule and was under budget. The plant performed favorably against guarantee rates for LNG production and fuel gas consumption during and after the performance test. The facility has been supplying LNG to buyers, Cabot LNG Corporation in the United States and Enagas in Spain utilizing minimal expatriate staff and maximizing national operations and maintenance staff.

The following paper is a review of the commissioning, start-up and operation of the Atlantic LNG facilities located at Point Fortin in Trinidad. The main objective of the paper is to highlight the activities that took place during the commissioning, start-up and operation of the plant allowing final hand over to the client Atlantic LNG before contractually specified turn over dates. The paper also explains the performance of the plant since final hand over and highlights the benefits of using the LSTK (Lump Sum Turn Key) approach where the contractor is responsible for the commissioning, start-up and operation of the plant until performance test requirements have been met. The paper explains how the transfer of responsibility for operating the plant from the contractor to the owner after completion of performance testing can be accomplished in a seamless manner. This approach enabled a very clean break between the contractor and the owner when the plant was handed over. There were significant benefits to both parties when this approach was used. The owner got the benefit of a plant that was in operation, had been proven and had all the little wrinkles ironed out. The owner did not have to go chasing the contractor for assistance with work items during the commissioning and start-up phases, as this was still the contractor's responsibility. The contractor also benefited from this by allowing a very clean break from the project having resolved the majority of "punch list" items thereby allowing a definitive schedule for demobilization of personnel and equipment.

As in a relay race, success depends on a clean passing of the baton from one member of the team to the next. In the case of the Atlantic LNG project a fully integrated team from Bechtel, Phillips and ALNG was formed very early in the project. This team worked together throughout the different phases of the commissioning, start-up and operation of the LNG plant. All members of the team were fully involved in the development of all required procedures and the training program.

The paper explains the development of the intensive training program that was jointly developed by Bechtel and Phillips and benefited all members of the integrated team. It also highlights the staffing strategy used by all parties in the team and the involvement of the ALNG personnel in the integrated team. This enabled the management of ALNG to operate the plant from hand over with a bare minimum of expatriate support. The paper also highlights details of the problems encountered during start-up and explains how those problems were resolved. It gives details of the simplicity and ease of plant operation from an operator's perspective. The paper closes with a brief explanation of the plant operation since final hand over to Atlantic LNG on June 14, 1999 and plans for the future expansions and de-bottlenecking of existing facilities.

Process Description

Inlet Area and Gas Treating

Natural gas from BP's offshore fields is supplied to Atlantic LNG via a 40" offshore pipeline and a 36" onshore pipeline. Feed gas enters the facility through a slug catcher where the vapor and liquid streams are separated. The onshore pipeline is pigged once a month. The liquid stream is stabilized and is exported offsite for further processing. The vapor stream is metered and filtered prior to entering the gas sweetening system where the CO_2 is removed. Diglycolamine (DGA) was selected as the solvent for the gas sweetening process due to low CO_2/H_2S concentrations in the feed gas and no other sulfur components (refer to figure 3). The acid gases – CO_2/H_2S and any incidentally removed hydrocarbon components are safely disposed of by incineration. Treated gas from the amine system is fed to mol sieve dehydrators where the water vapor is removed down to 0.1 ppm H_2O utilizing 4A molecular sieve. Dry gas from the dehydrators is further processed through activated carbon bed to remove any mercury that may be in the feed gas.

Refrigeration and Liquefaction

The treated gas is fed to the liquefaction unit where it is cooled and sub-cooled prior to entering the LNG tanks. The liquefaction system utilizes the Phillips Optimized Cascade LNG Process, a modification of the original Phillips LNG plant design at Kenai, Alaska. This process uses three pure refrigerants - propane, ethylene and methane circuits cascaded to provide maximum LNG production by utilizing the horsepower available from 6 Frame 5C gas turbines. Each refrigerant circuit uses two 50% compressors with common process equipment. The compressor/turbine packages are manufactured by Nuovo Pignone. Brazed Aluminum Heat Exchangers and Core-Kettle Exchangers were selected for feed gas, propane, ethylene and methane refrigeration circuits. All of these heat exchangers with the exception of the propane chillers are housed in two "Cold Boxes". All compressor inter-cooling, after-cooling and propane refrigerant condensing is provided by fin-fan heat exchangers. The LNG from the last stage flash drum is pumped to the LNG tanks where it is stored at 70 mbar and –160.6 ^{o}C.

Fractionation

Fractionation is provided to remove heavy components from the feed gas to prevent freezing in the liquefaction process and to recover 70% of the propane and heavier hydrocarbon components. The NGL stream is exported to a fractionation facility on the island for further fractionation into propane, butane and condensate.

Figure 1: Block Diagram

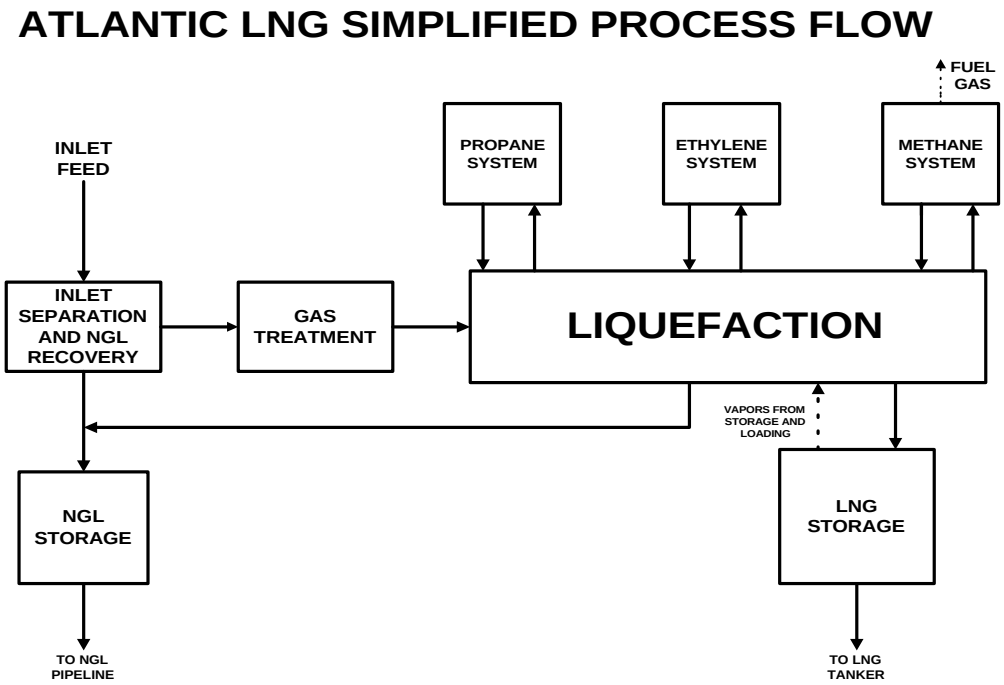


Figure 2: Gas Sweetening System DGA

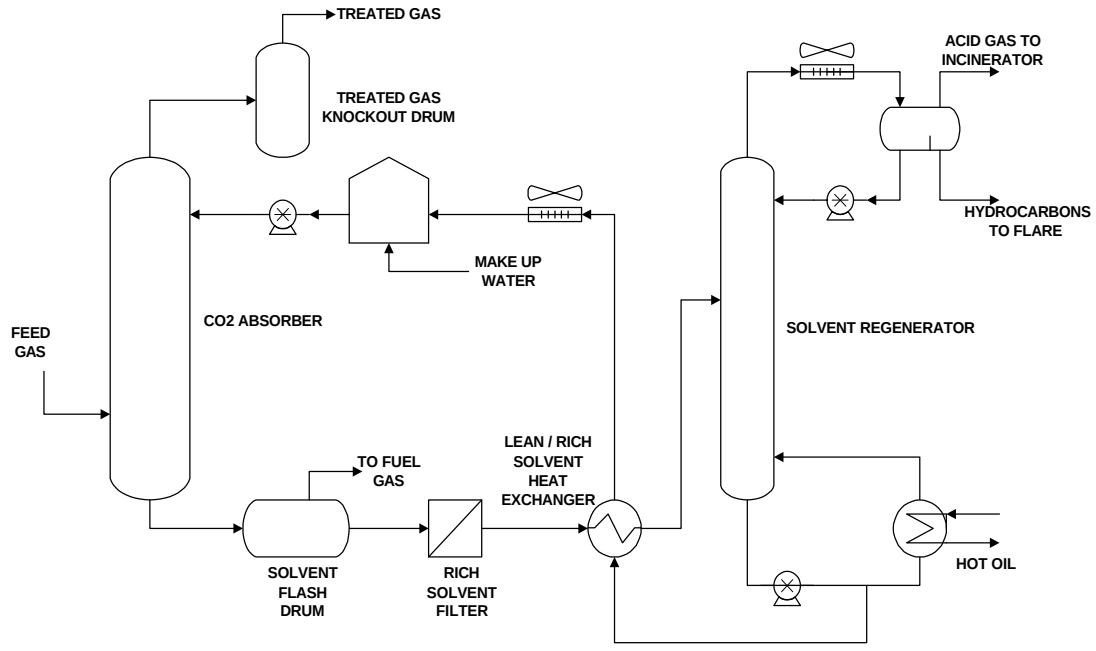
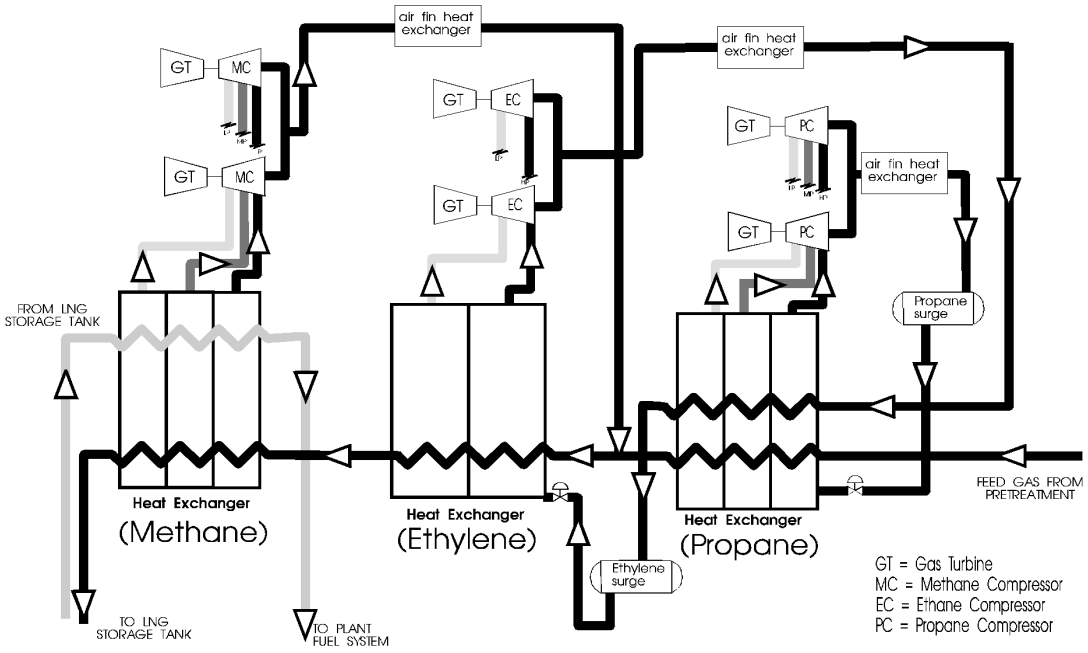


Figure 3: Phillips Optimized Cascade LNG Process



Utilities

The utilities required to support the main process are simple and small in size. The major utilities are:

- Power generation - three Solar Mars units are utilized
- Hot Oil system - two 60% indirect forced air heaters
- Firewater System
- Instrument Air System - bleed air from power generators with one standby air compressor
- Nitrogen System - one membrane N2 generation unit with two liquid N2 units
- Demineralization Package - water makeup to Amine system and water for turbine washes
- Refrigerant Storage - propane and ethylene storage
- Cooling Water - cooling water system for turbine/compressor packages
- Flare systems – consist of three separate systems, wet, dry and marine
- Incinerator – disposal of acid gases from amine regenerator

Commissioning & Start-up

Operator Training

The permanent plant operations staff was hired by Atlantic LNG sufficiently early in the project to ensure class room training could be provided prior to commissioning and start-up activities. Due to the large industrial base in Trinidad and Tobago a good selection of candidates with some relevant experience was available. Since Bechtel was responsible for starting up the plant and the initial operations until plant hand over to Atlantic LNG, experienced expatriate operations staff were hired. Nationals were also hired by Bechtel to work with the experienced Bechtel staff during commissioning and start-up. Many of the nationals were then hired by Atlantic LNG which facilitated technology transfer following hand over.

Bechtel was responsible for providing class room training which consisted of equipment theory, plant functions and layout, Phillips Optimized Cascade LNG Process, mechanical design, safety concerns, plant start-up and operation and facility troubleshooting. Personnel with operating and engineering experience from Phillips' Kenai LNG plant provided training based on first hand experience and knowledge of the long term successful operation of the Kenai facility. Field visits were included as part of the training. A number of Atlantic LNG operating, maintenance and supervisory personnel trained at Kenai to observe actual shutdown, start-up and turnaround procedures of a plant in operation. Vendors of critical equipment such as Solar generators, Altec, Nuovo Pignone, Honeywell and FMC provided additional operations training.

Once the classroom training was completed Atlantic LNG operations staff with the exception of maintenance personnel were handed over to Bechtel. This arrangement provided Bechtel with additional staff for commissioning and start-up activities and provided Atlantic LNG with staff trained in the operation of the LNG facility.

Milestones

Construction of the facility began in August 1996. Most of the utilities were commissioned by October 1998 to allow the introduction of the hydrocarbons into the inlet area up to the pig receiver for supplying fuel gas to the power generators. The offshore and onshore pipelines were commissioned in October 1998. The following outlines the commissioning and startup milestones:

- Power generators were started up - November 1998.
- Start loading ethylene into storage tanks December 1998
- Wet flare system started – January 1999
- Inlet area pressured up – January 1999
- HP/LP Fuel gas systems started up - January 1999
- Hot Oil system started up – February 1999
- Amine system commissioned – February 1999
- Cooling water system started up – February 1999
- Perform Solo & Mechanical runs on Turbine/compressor packages – February 1999
- Start loading propane into storage tanks – February 1999
- Startup molecular sieve dryers – February 1999
- Dry out liquefaction process system – March 1999
- Purge and dry out LNG tank 1 – March 1999
- Startup refrigeration compressors – March 1999
- Cool down process – March 1999

- Make LNG – March 1999
- Cool down LNG Tank 1 – April 1999
- Load 1st LNG Tanker Mathew – April 1999
- Cool down LNG Tank 2 – April 1999
- Complete Performance Test – June 14, 1999

Lessons Learned

During commissioning and start-up of the facilities a number of problems were encountered. The nature and number of the problems was not inconsistent with those one might expect from a project of this size. Some of these problems are highlighted here.

- During commissioning operations in December 1999 a flashback occurred at the dry gas flare knockout drum causing damage to the vessel and some of the piping.
- Spiral wound gaskets had to be changed from single ring CG type to double ring CGI type
- Modifications had to be made to some valve trims to improve operations
- Propane Chillers
  - dislodged 3 de-mister pad panels
  - modified inlet liquid nozzles
  - modified weir heights
- Hydraulic bottlenecks
- Replace molecular sieve due to amine carry over
- Drier support beds modified
- Welding dams in LNG loading lines/vapor lines
- Three weld failures

Despite these problems the start-up team was able to find and implement solutions and finish the project ahead of schedule without compromising safety of the start-up or long term plant operations. The value of these experiences will be realized when lessons learned as a result of knowledge gained are applied to design and operations improvements on the future trains.

PerformanceTesting

The contract between Bechtel and Atlantic LNG was truly ‘Turn Key”. Bechtel was required to supply all operating, maintenance, safety, technical support and supervisory personnel for the safe start-up and initial operation of the plant until at least one ship had been loaded and all final performance tests had been successfully completed. In actual fact, however, Atlantic LNG operations staff became a part of the integrated team and continued under Bechtel's direction to be the hands-on-operators for parts of the plant even during the performance test.

There were two types of acceptance tests which made up the plant performance requirements. These were commissioning tests for individual equipment or units and an overall performance test of the operating facility.

Commissioning Tests (process and utility)

Commissioning tests were required for all systems, all package units, various special items such as loading arms, metering skids, firewater pumps, and of course, all control systems, alarm systems and shutdown systems. The purpose of the Commissioning tests was to demonstrate that individual systems

within the facility performed according to design specifications within the EPC contract. There were 44 individual tests each with a procedure and a report documenting the results and individually signed off by both Bechtel and owner and witnessed by owner. All commissioning tests had to be completed before Performance Tests could begin.

Performance Tests

Performance tests were conducted to prove plant capacity and fuel efficiency, ship loading capability and LPG recovery rate. Ship loading was done as a separate test from the plant performance test and proceeded smoothly. All other plant performance aspects were measured in a continuous 72-hour test. This test was Bechtel's final deliverable required for contract completion and final turnover. There were significant incentives (positive and negative) for early contract completion (i.e. performance test completion) and also for good plant performance relative to guaranteed performance.

Bechtel and Phillips sent additional process engineering representatives to join the start-up team as time for the performance test approached. Computerized data logging, analysis and calculation routines were set up well in advance. Plant simulations under the exact conditions expected during the test were done ahead of time to determine the exact effects of site weather and possible variations in feed gas composition.

As the official test began, computer calculations were run hourly on plant production and fuel gas consumption. Data was recorded on major compressor power (torquemeter readings) every hour. LPG recovery was calculated on a regular basis.

The plant suffered a compressor trip only 4 hours into the performance test. A quick recovery to full production was made, but the performance test was re-started. The second test proved successful and smooth. High capacity operation was maintained throughout the 72 hours. The automatic data collection and calculation routines provided a rich data base at the end of the period and allowed the test report to be produced and on the Atlantic LNG Start-up Manager's desk the same day as the test was completed. The results showed that all requirements were met and LNG production was 2.5% above guarantee. During the performance test contractual requirements limited refrigeration compressor horsepower to account for air compressor fouling and long term degradation. This horsepower limitation was clearly the determining limit during the performance test. Subsequently, the plant has operated smoothly at up to 10% above performance guarantee.

The joint operations and maintenance team during the performance test consisted of:

- Atlantic operating personnel - operating gas treating and drying and ship loading
- Atlantic maintenance personnel - covering entire plant but still backed up by Bechtel specialists and skilled craftsman
- Bechtel operations staff - operating liquefaction, utilities and LNG storage and providing technical support and process engineering
- Phillips - providing operators, advisors, process engineers, lab analytical experts

The Atlantic LNG permanent plant operation and maintenance staff contained fewer than 10 expatriates during start-up, initial operations, plant performance testing, and still does. When Bechtel turned over the plant, a small number of Bechtel and Phillips Alaska Natural Gas Company experienced expatriate

personnel stayed on to assist during a short transitional period. The plant continued to operate well with this manning level.

During the performance test and a period time preceding the test, Atlantic operators did assume full operating duties for parts of the plant, although Bechtel was responsible and provided supervision. This is a tribute to the quality of the staff and to the ease of operation of the liquefaction process and the plant in general. Although Bechtel maintained responsibility for the facility, they had enough confidence in the Atlantic LNG staff to use them in responsible operating positions even during the performance testing.

Operating Experience – First 12 Months

Atlantic LNG took over the facility from Bechtel on June 14th, 1999. With the exception of a few key personnel for technology transfer there was minimal staff carryover from Bechtel and Phillips. Critical vendors such as Nuovo Pignone and Honeywell representatives were retained to provide assistance to the permanent operations staff. Out of the total Atlantic LNG staff very few expatriates are utilized for the day to day operations. All of the Bechtel, Phillips and vendor staff retained were released after four to six months of assistance with the exception of Nuovo Pignone personnel and one Honeywell representative. If required, shareholder companies or Phillips Petroleum, the Liquefaction technology licensor and Bechtel, the EPC contractor of the facility, can provide specialized engineering services as needed.

The operations staff was able to improve on the performance test results by identifying process bottlenecks and getting a better understanding of the process variables affecting the LNG production. They also improved on responding to day to night ambient temperature variations, by monitoring key performance criteria and maximizing plant throughput and production based on ambient conditions.

In October of 1999 Bechtel and Atlantic LNG ran a capacity test on the plant to help identify bottlenecks for the expansion project and to improve the Train 1 performance. The test was run on the same basis as the performance test conducted in June 1999. The following table tabulates the capacities achieved:

Table 1: Capacity Test Results

	Net LNG Production (MMBtu/day)	Fuel Gas Consumed (MMBtu/day)
Original Simulation	418 000	56 425
New Simulation	416 700	56 300
Performance Test	425 239	55 419
Capacity Test	450 000	-

During the early periods of operation there were several operational problems to overcome to increase the availability of the facility. Some of the difficulties encountered during the early periods of operations were:

- Repair mol sieve bed supports
- Replace mol sieve
- Piping vibration
- Repair weld failure
- BP problem with Beachfield slug catcher
  ~ 10,000 BBL slug had to be processed over several days

- Defrost plant
- Instrumentation problems with Nuovo Pignone
- Propane level control valve replaced
- Heavies removal column liquid carryover
- Water breakthrough on the mol sieve dehydrators

Despite these incidents the plant has operated very well overall as we will show in the following operating statistics. In addition the LNG facility has met all of its LNG delivery obligations to its customers and Atlantic LNG has been able to sell some spot LNG cargoes. As of July 17th, 2000 Atlantic LNG has exported 76 cargoes of LNG.

OPERATING STATISTICS

Some key operating statistics from the first year of the facilities' operation are presented here.

Definitions for the availability data presented are as follows:

1. **Availability** is the proportion of the total time that the plant *was able to be used* for its intended purpose. This is a combination of scheduled and unscheduled downtime.

   $$\text{Availability} = \frac{\text{Total Time} - \text{Scheduled Downtime} - \text{Unscheduled Downtime}}{\text{Total Time}}$$

2. **Production Efficiency** is the ratio of actual production to its rated output during the time it is operating (i.e. during the time it is fully available and fully utilized)

   $$\text{Production Efficiency} = \frac{\text{Actual Production / Rated Capacity}}{(\text{Total Time} - \text{Scheduled Downtime} - \text{Unscheduled Downtime} - \text{Standby Time})}$$

   To give a true measure of the efficiency of production actual production is adjusted for the reported average ambient temperature. The guaranteed production rate is used for the Rated Capacity.

3. **Overall Effectiveness** is a measure of how effectively the plant is being used altogether, including all incidents affecting production.

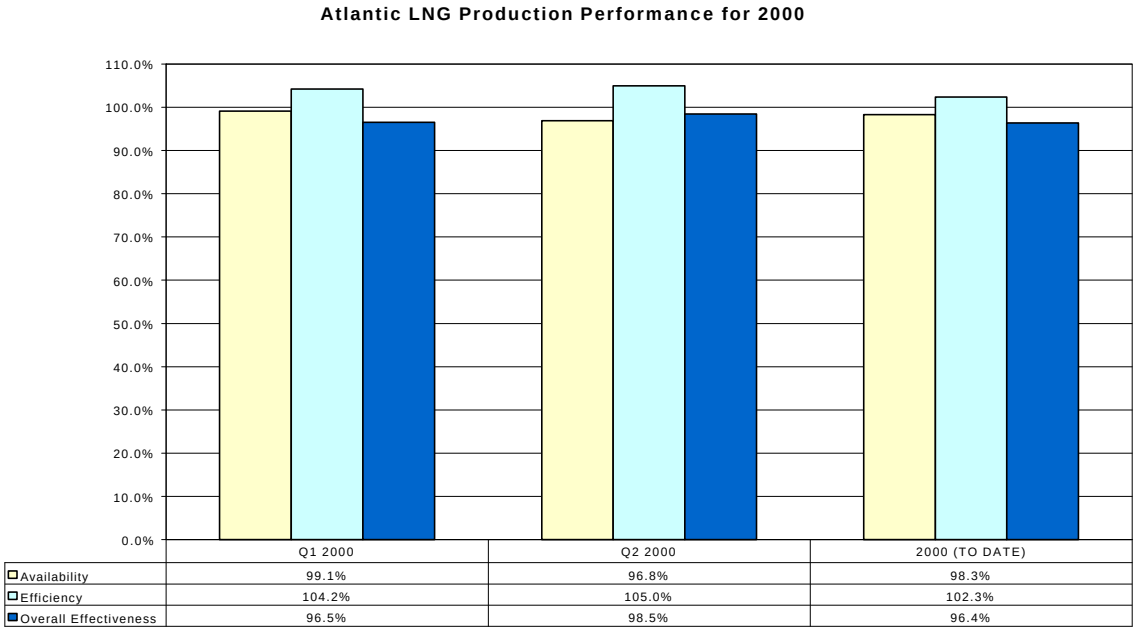
   Overall Effectiveness = Availability * Utilization * Production Efficiency

4. **Utilization** is the proportion of the time that the equipment is available that it *is actually used* for its intended purpose. This takes out any time that the plant could not be used for reasons outside its control, i.e. upstream problems or shipping problems causing a reduction in production. This is called standby time and again because we frequently run at partial rates instead of completely shutting the plant down we have used the concept of equivalent hours of standby.

   $$\textbf{Utilization} = \frac{\text{Total Time} - \text{Scheduled Downtime} - \text{Unscheduled Downtime} - \text{Standby Time}}{\text{Total Time} - \text{Scheduled Downtime} - \text{Unscheduled Downtime}}$$

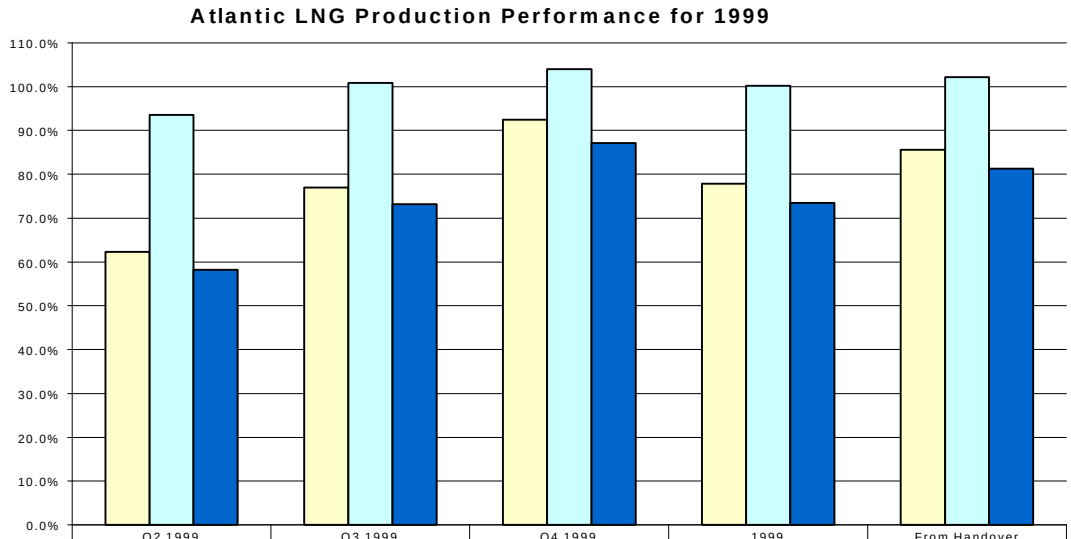
As can be seen from the availability data presented in Figure 4 and Figure 5 the efficiency of the LNG facility ramped up to 100% in a short time frame and the overall effectiveness for 1999 was 81% and as of July 2000 it is at 96.4%

Figure 4: Plant Availability Data - 1999



	Q1 2000	Q2 2000	2000 (TO DATE)
Availability	99.1%	96.8%	98.3%
Efficiency	104.2%	105.0%	102.3%
Overall Effectiveness	96.5%	98.5%	96.4%

Figure 5: Plant Availability Data – 2000



	Q2 1999	Q3 1999	Q4 1999	1999	From Handover
Availability	62.3%	76.9%	92.5%	77.9%	85.6%
Efficiency	93.5%	100.9%	104.0%	100.2%	102.1%
Overall Effectiveness	58.2%	73.2%	87.2%	73.5%	81.3%

Conclusions

The success of Trinidad LNG project cannot be overstated. It has met or exceeded the expectations of all parties involved from engineering design, construction, start-up and normal plant operations. The performance and attitude of the personnel associated with the project throughout its development has been the key to its success. This was truly a team effort where there were no boundaries between client and contractor. There was a common goal that all parties focused on and that goal was to be successful. This project was going to make the rest of the LNG industry sit up and take notice and it has certainly done that. All the members of the Trinidad LNG project team from ALNG, Bechtel and Phillips plus the supporting players must be thanked for their energy, commitment and most of all their belief that this project was never going to be anything else but “SUCCESSFUL”.