Atlantic LNG Train 4
"The World's Largest LNG Train"

Tony S. Diocee
Project Engineering Manager, Trinidad LNG Project
Atlantic LNG Company of Trinidad & Tobago

Phil Hunter
LNG Group Manager Petroleum & Chemicals
Bechtel Corporation

Anthony Eaton
Director of LNG Product Development Center
ConocoPhillips Company

Amos Avidan
Technology Manager Petroleum & Chemicals
Bechtel Corp

Published at LNG 14, Doha, Qatar – March 2004

ABSTRACT

The Atlantic LNG facility located in Point Fortin, Trinidad is comprised of three LNG trains using the Phillips Optimized Cascade LNG Process and each producing approximately 3.3 MTPA of LNG. The fourth LNG train will be designed for a nominal production capacity of approximately 5.2 MTPA, which is the world's largest LNG Train currently under construction.

In this paper we present the design premise for the fourth LNG train and discuss how the basic "Two-Trains-in-One" concept was maintained whilst taking the capacity to the higher production level. The changes to layout, equipment, piping and instrumentation are addressed, as are the dynamics of the plant operating with such high throughputs. The selection processes for major equipment in the process are also discussed.

General areas of concern were addressed during the conceptual phase of the project, and we discuss how these concerns were overcome. The paper also discusses some of the decisions made concerning the use of multiple pieces of equipment versus going to larger pieces of equipment.

RÉSUMÉ

Le site d'Atlantic LNG, situé à Point-Fortin, à Trinidad, comprends trois trains (ou unités de productions) de GNL utilisant le Procédé d'Optimization en Cascade de Phillips Pétroleum. Chaque train produit approximativement 3.3 million de tonnes par an de GNL. Le quatrième train de GNL sera conçu avec une capacité nominale de production d'environ 5.2 million de tonnes par an, ce qui représenterait le train (ou unité de production) le plus large au monde en cours de construction.

Dans cette présentation, nous allons détaillé les bases du procédé de ce quatrième train de GNL et allons expliquer comment le concept de base "Deux-Trains-en-Un" a été maintenu, tout en augmentant la capacité de production à un niveau plus élevé. Les modifications effectuées sur la disposition des équipements, tuyaux ainsi que les différents instruments vont être présentés, ainsi que les dynamiques d'un site opérant avec de telles capacités de production. Le choix des principaux équipements du procédé sont également présentés.

Les principaux points délicats ont ete adréssés pendant la phase conceptuelle et initiale du projet. Nous allons expliqués comment ces problemes ont été résolus. Cette présentation explique aussi les décisions qui ont été prises concernant l'usage de multiples pièces d'équipement au lieu d'utiliser des pièces d'équipement de taille plus importante.

INTRODUCTION

The Atlantic LNG facility located in Point Fortin, Trinidad is comprised of three LNG trains using the Phillips Optimized Cascade LNG Process and each producing approximately 3.3 MTPA of LNG. Two 102,000 m^3 and one 160,000 m^3 LNG tanks along with one jetty the LNG export complete the facilities. Figure 1 shows the plant site and the existing facilities.

Figure 1: Site Photo

The fourth LNG train has been designed for a production capacity of nominally 5.2 MTPA. Included in the project is one additional 160,000 m^3 LNG tank and one additional jetty. Due to the perimeter constraints of the existing site, the newly constructed LNG Train needed to be optimized for the amount of land available at this location.

A new 56" onshore pipeline will supply additional feed gas to the LNG Trains at Pt Fortin, Trinidad. The basic design premise used for all Atlantic LNG Company of Trinidad & Tobago facilities apply for the fourth LNG train and maintains the basic "Two-Trains-in-One" at the higher production level. Train 4 is scheduled for start-up during the last quarter of 2005.

To maintain the overall project schedule only minor modifications were made to the process. Building a scale model of the propane refrigeration compressor allowed for fine-tuning the design prior to manufacturing the actual compressor. This was able to mitigate some risks. Air re-circulation studies were also performed to optimize the layout of the propane condensers, process equipment and the power generators. The increase in production was achieved by adding additional refrigeration compressors and propane condensers. The efficiency was further optimized by modifications to the compressor wheels, including intercoolers on the methane compressor circuit and changing the scheme used to remove heavy components from the feed gas.

The layout of the facility was maintained as per the original design to minimize conceptual plot plan layout rework. The majority of the major equipment selected was similar to the existing LNG Trains to maintain minimum spares inventory and due to operations/maintenance staff being familiar with the equipment.

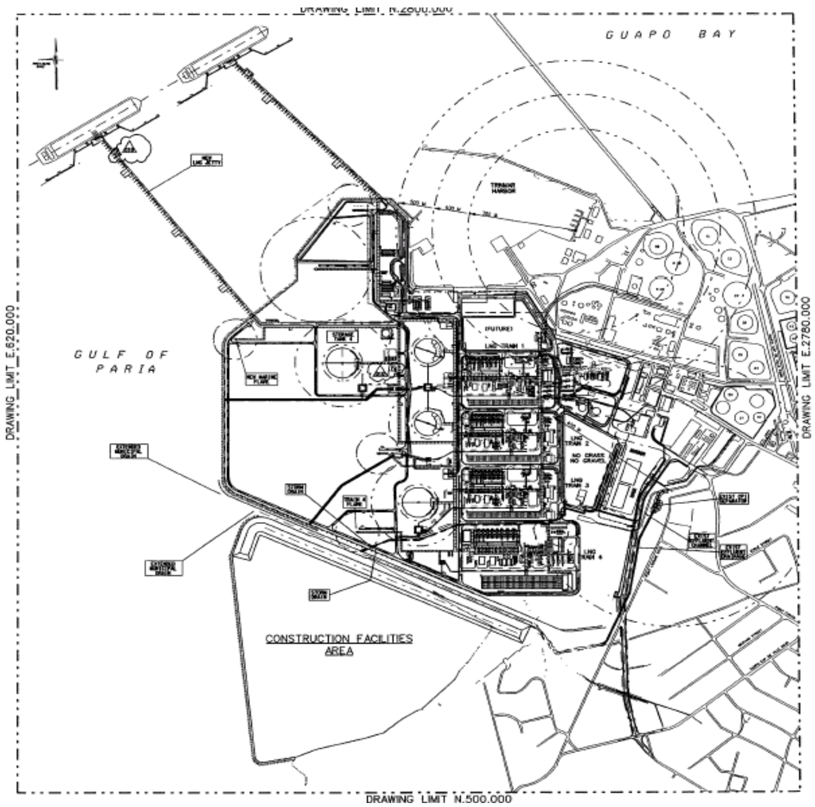
PLANT LAYOUT

The fourth LNG Train is located south of Train 3 and the second jetty is located south of the existing jetty as indicated in Figure 2. The minimal required plot plan is set by the size of the propane condensers and the main process area. On Train1 only forty propane condensers were utilized and Train 2 utilized forty bays but on Train 4 eighty-four propane condensers are utilized. Air circulation studies were performed of all the LNG Trains to optimize the layout of the propane condensers including the height, cold boxes, and the power generators. Skirts were also added to the propane condensers to minimize air circulation effects on LNG production. Process and marine flares are located west of the LNG tanks. Additional Boil Off Gas compressors are installed to recover the vapor generated during ship loading operations. The existing control room will be used to accommodate the new control system for Train 4. The existing maintenance shop and the warehouse will also serve Train 4.

Additional land reclamation was not required for the process area but was required for the construction of the fourth LNG tank. The fill material the LNG tank area and additional reclaimed land were sourced from the incremental dredging required to widen the existing ship channel. A study was performed to evaluate land reclaiming versus disposal of spoil materials at a designated disposal site, 53 hectares (131 acres) have been reclaimed.

Several options for widening the ship channel were evaluated by BMT Seatech Ltd utilizing simulations to pilot the ship into the channel and berthing the LNG carriers onto the jetties.

Figure 2: Train 4 Layout



PROCESS DESIGN

All small modifications made by the operations staff to the existing LNG Trains were incorporated into Train 4 by reviewing all the Management of Change notices (MOC's) generated by the operations engineering team.

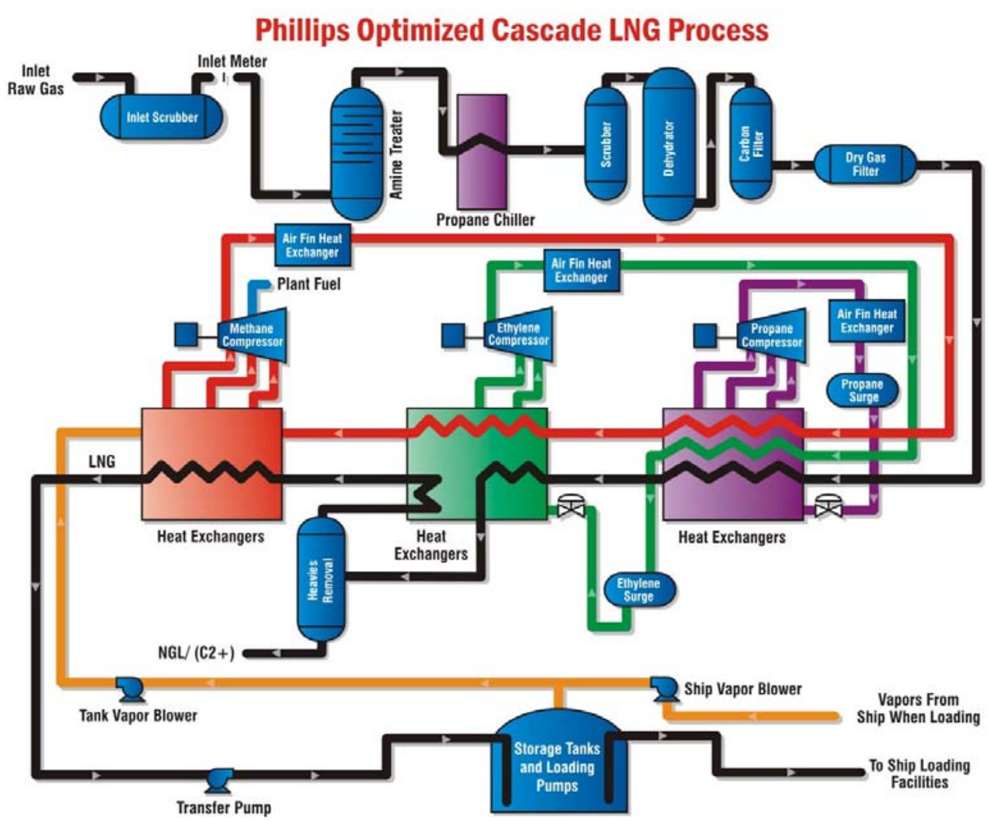
During the early periods of the FEED phase of the Train 4 project, simulations studies were performed to increase the plant capacity without significantly altering the process scheme and finding ways to improve the efficiency of the LNG Train. Table 1 compares production and emissions data relative to Train 1. The obvious items studied were adding compressors, air coolers, and liquid expanders. The simplified flow diagram for Train 4 is shown in Figure 3.

Table 1: Production and Emissions Comparison

	Train 1	Train 2-3	Train 4
LNG Prod	1.0	2.23	1.80
HP/t_{lng}	1.0	0.995	0.892
CO_2 (t/t_{lng})	1.0	0.91	0.81

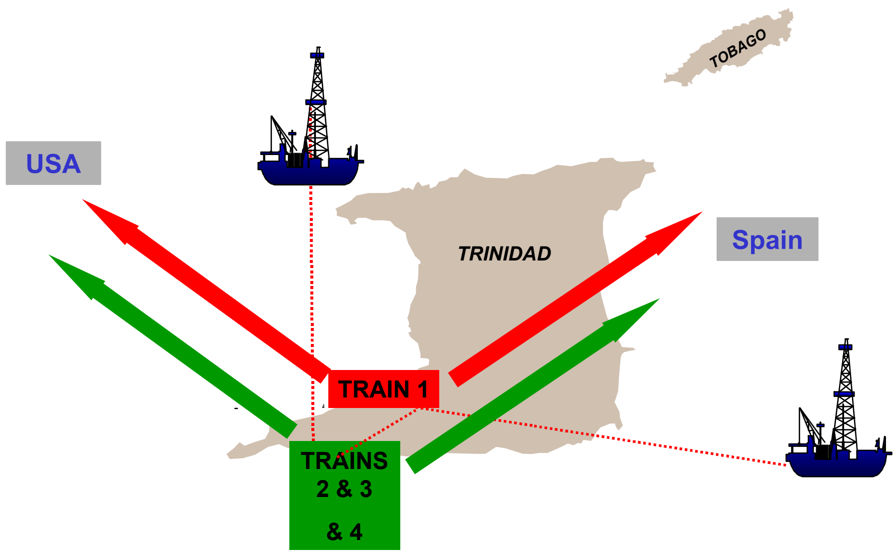
Phillips Petroleum Company developed the original Optimized Cascade LNG process in the 1960's. The object was to devise a natural gas liquefaction system that permitted easy start-up and smooth operation for a wide range of feed gas conditions. The Phillips Optimized Cascade LNG Process was first used in 1969 in the company's Kenai, Alaska LNG facility. Designed and constructed by Bechtel, the facility was the first to ship LNG to Japan and is the only LNG project in the world to achieve 34 years of uninterrupted supply to Japanese customers.

Figure 3: Train 4 Process Flow



The new 56" onshore pipeline will supply additional feed gas to the LNG plant. (Figure 5) The feed gas will flow into a 2000 bbl slug catcher where the gas and liquid phases are separated. The transient analysis completed on the onshore pipeline predicted pigging frequencies of several times a week. This new 56” pipeline will be the third pipeline feeding into the LNG Trains. An existing 36” pipeline from the east coast and a 24” pipeline from the north coast supply Gas to the plant today.

Figure 5: Map of Trinidad and Offshore Fields



The liquid from the slug catcher is treated in the stabilizer, dehydrated and is exported offsite for further processing. The vapor is metered and filtered prior to entering the gas sweetening system where the CO_2 will be removed. Diglycolamine (DGA) was once again selected as the solvent for the gas sweetening process due to low CO_2/H_2S concentrations in the feed gas and no heavier sulfur components. Based on lessons learned from previous trains a coalescing filter was added upstream of the amine contactor and the amine contactor bottom section redesigned. The acid gases will be safely destroyed in an incinerator.

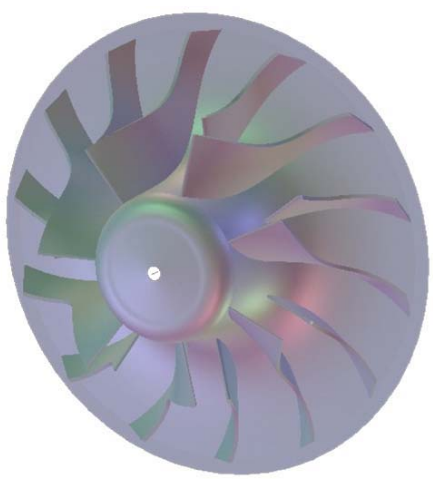
Treated gas from the amine system will be fed to the dehydrators where moisture will be removed down to 0.1 ppm H_2O utilizing 4A molecular sieve. A coalescing filter was also added upstream of the molecular sieve beds. Dry gas from the dehydrators will be further processed through activated carbon bed to remove any mercury that is in the feed gas.

The Phillips Optimized Cascade LNG Process uses three refrigeration circuits: propane, ethylene, and methane. The final methane circuit is an open cycle loop for improved efficiency. The process for the original three trains also maintained a “ Two-Trains-in-One” reliability concept, which has been extremely successful. The turbines for the original train were Frame 5C’s, and Frame 5D’s for Train 2 and 3. These factors were taken into consideration in developing the process for Trinidad Train 4. The utilization of proven technology was paramount in obtaining a plant as reliable as the previous trains. Therefore, a modular design was conceived that would add Frame 5 turbines to the required refrigeration circuits for the additional capacity. The design for trains 1, 2, and 3 at the Trinidad site utilized two propane, two ethylene, and two methane refrigerant compressors and turbines.

The fourth LNG train was designed to use to three propane and three ethylene compressors and turbines the two methane compressors and turbines sets. Intercoolers were added to the methane compressors above the standard design to improve efficiency resulting in increased LNG production. In order to maintain proven equipment and attain incremental LNG production the single propane compressor case was split into two. The ethylene compressor single case was also split into two and a gearbox was installed between the casings. Rotordynamic stability was also improved by splitting the compressor casing. To provide additional flexibility for day/night ambient temperature variations splitter vanes (Figure 5) were utilized in the all the propane compressors. Additional propane condensers were also added to optimize the propane refrigeration circuit power requirements.

An aerodynamic performance test was carried out according to ASME PTC-10 to verify the mechanical performance of the compressors. The compressor will be tested in a closed loop using natural gas with carbon monoxide mixture to reproduce the actual plant thermodynamic properties.

Figure 5: Splitter Vanes



The heat exchangers used for the Phillips Optimized Cascade LNG Process are standard Plate Fin type. Since the process utilizes essentially pure component refrigerants, the risks of two-phase flow are minimized. This can limit the potential for thermal shock. Cold boxes are used for the ethylene and methane refrigerant circuits. The cold box design for trains 1, 2, and 3 were the largest at the time for the Phillips Optimized Cascade LNG Process. The design for Train 4 had to be evaluated for a capacity of approximately 50% greater than previously employed. The benefits of utilizing the cold boxes with pearlite insulation instead of conventional foam glass insulation is the ability to maintain refrigerants in the cold boxes without venting the inventory and reducing insulation man-hours in the field. Based on lessons learned from previous LNG Trains additional defrost connections were added to provide additional flexibility. The cold boxes were designed for efficient shipping.

The technology for removal of NGL's in the Phillips Optimized Cascade LNG Process was improved for the fourth train to achieve higher levels of ethane recovery. The heavies removal process was improved by adding reflux to the absorber column. The reflux provides improved operability and flexibility for the gas compositions anticipated for Train 4. It also provides the capability of deep LPG recovery when desired. The design can accommodate for up to 80% ethane recovery from the natural gas feed stream. The process can easily shift from a NGL recovery to LPG recovery to ethane recovery configuration depending upon economic drivers.

UTILITIES

Expansion of the existing utilities will minimize new equipment to be installed and increase the reliability and availability of the utility infrastructure that supports the LNG complex. The following utilities are being expanded:

- Nitrogen system
- Instrument Air
    - Bleed air from power generators eliminated
    - Standalone packages installed with backup from power generators
- Ethylene/Propane storage
- Defrost Gas
    - System tied to all LNG Trains
    - Dry gas available to perform defrosting operations
- Fuel Gas
    - System tied to all LNG Trains if required startup
- Deminerization water
- Firewater system
    - New firewater tank with pumps installed and located west side of the plant
- Power generation
    - One unit added to existing grid in utility area
    - Three units added to support the new LNG Train
- Diesel fuel storage
- Amine storage

STUDIES

As with most LNG projects, various studies were completed during front end engineering (FEED) to optimize the design and reduce capital expenditures. The objectives of the studies were to look at full cycle economics, simplicity, commonality with existing equipment to reduce spare parts requirements and reduced training requirements for

Atlantic staff. Most of the studies were completed and decisions were made early during the FEED of Train 4. Some of the studies required additional effort to complete and are discussed in this paper.

Refrigeration Compressor Drivers

Refrigeration compressors are an integral part of the LNG plant process, the drivers for these compressors have traditionally been either steam or industrial gas turbines. The process design in these plants is tailored to fit the selection of the driver in order to maximize LNG production. In recent years, industrial gas turbines have been used exclusively. The most recent plants have used two constant speed turbines as the prime movers. These plants have used combinations of a Frame 6 B (43.6 MW ISO) and a Frame 7EA (85.4 MW ISO) or two Frame 7EA's. The use of these large drivers allows the use of highly efficient turbines but introduces operational constraints at the same time.

For Atlantic LNG Trains 1, six Frame 5 C's turbines are used and for Trains 2/3 six Frame 5D's turbines have been used for each Train, two each per refrigeration service. These turbines can be operated as variable speed drivers, which add to the flexibility of the process operation and provides an inherently more efficient process operation. The higher efficiency arises from the ability of the compressor performance to be adjusted to daily and seasonal process variations without compressor recycle, i.e. without wasting horsepower.

There are two primary reasons for considering aero-derivative gas turbines (aero's) for the refrigeration compressor drivers. First, aero's are inherently more fuel efficient than industrial gas turbines, in simple cycle service. Secondly, aero's produce significantly less NO_x and CO_2 emissions per MW-Hr and therefore are viewed as environmentally friendly. There are several aero's in the power class range of the Frame 5D's. The goal of the study was to see if any of these could combine the benefits of fuel efficiency and reduced emissions while maintaining the operability and reliability of the Frame 5D plant in a cost effective manner.

Several aero-derivative turbines were evaluated, specifically the Rolls Royce Coberra 6761 and the LM-2500+ and LM-6000 After preliminary investigations the Rolls Royce Coberra and the LM-2500 were eliminated. We have technically qualified the LM-6000 turbine for use and completed risk identification / risk mitigation exercises

Full cycle economics were run for each driver, which included installed costs, maintenance costs over a 20 year period, reliability, feed gas ramp up rates, plant availabilities, special tooling costs and spare parts costs.

The results of this analysis has shown that there is no advantage for aero-derivative turbines, and Frame 5D gas turbines were chosen as the drivers for the refrigeration compressors for Train 4.

Power Generation

Power system calculations, including load flow, short circuit, load analysis, and system stability, concluded that the existing three Trains power system could not be expanded to accommodate all of the new Train 4 loads. The existing 12.47 kV switchgear's short circuit ratings are not adequate for adding more than one new generator to the system.

After reviewing the available larger capacity generators, the existing Solar Mars 100 generators were chosen for the expansion due to cost, spare parts compatibility, and training considerations.

The new intelligent 480-volt motor control center by Cutler-Hammer was specified for Train 4. Its DeviceNet capabilities for interfacing with the new DCS system will allow more data to be available on motors for operations and maintenance, reduce the amount of field wiring needed, and its 24 VDC control scheme will increase personnel safety.

DCS System

The DCS for Trains 1, 2 , & 3 is a Honeywell TPS system. Several different systems were evaluated fro Train 4, including Profibus, ASi-bus, Foundation Fieldbus, HART and Control Net. We have chosen Foundation FieldBus "open architecture" system. The benefits include wiring and installation reductions, less equipment space requirements, easier installation, checkout and commissioning time. Foundation Field Bus offers a wealth of information about the instruments, and process conditions, Advanced diagnostics in the instruments can provide predictive maintenance information to avoid doing routine maintenance on devices that don't really need it, while concentrating on the ones that do.

The team found that, based on the results of the evaluation, Fisher Rosemount Delta V were selected for the project, due to ease of configuration (plug and play, bulk loading/editing of data, the capability of internal simulation of control strategies, etc.), simplicity of architecture, self documentation capabilities, the ease of connection to third party equipment via OPC, etc., alarm management capabilities, the use of standard communication protocol (such as TCP/IP) and the use of commercial, as opposed to proprietary hardware.

Storage and Loading Options

Studies were conducted by Lloyd's Register to determine the requirements for one additional LNG tank. The scenarios modeled indicated the benefit or need for additional 160,000 m^3 storage. The study was carried out using LR's FLEET, a Monte-Carlo based simulation program. The excess speed capacity of the shipping is a flexible source of risk mitigation which may be used should unexpected plant outages, major ship failures etc occur. Too much pressure on the ship speed would mean that there would be no capability in the system to recover from a delay or an incident. An additional fourth LNG storage tank at Point Fortin was selected

PROJECT STATUS

As of October 2003 engineering was 70% complete, all major equipment has been purchased and Factory Acceptance Tests (FAT) were begun. Purchasing of bulk materials was started as well. Construction activities began in 2002 with the soils improvement program that utilized Deep Soil Mixing, this activity was completed by August 2003. Temporary facilities required for construction such as cement batch plants were completed by February 2003, other temporary facilities for subcontractors are ongoing. As of October 2003 concrete mats have been poured in most of the process areas, started pouring columns for the compressor deck, erecting structural steel in the process area, installing underground firewater piping, pitching and driving production piles in the LNG tank area, driving test piles for the Jetty and dredging and land reclamation activities. Progress photos are presented in Figures 6,7,8,9, and 10.

Figure 6: Propane Compressor Mat – April '03

Figure 7: Concrete Mats Process Area – June '03

Figure 8: Tank 4 Pile Driving – July '03

Figure 9: Compressor Deck – Aug '03

Figure 10: Process Area – Oct '03

CONCLUSION

Due to land constraints and LNG demand in the Atlantic basin, the fourth expansion in Trinidad that was larger in capacity than previous Trains was studied and ultimately selected. Lessons learned from previous LNG Trains and results from optimization studies were incorporated into the design of the fourth LNG Train. With Trains 1, 2 and 3 producing at approximately 3.3 mtpa and Train 4 at 4.8 mtpa the total LNG production from Trinidad is 15 mtpa.

Train 1 is currently undergoing debottlenecking and studies are underway to further increase the capacity from the existing LNG Trains. The fourth LNG Train will be completed and started up by the 4th quarter in 2005; Figure 11 depicts what the Atlantic LNG complex will look like in 2005. The efforts of the Atlantic LNG, ConocoPhillips, and Bechtel integrated team allowed for the concept of a large train to come into fruition. The end result of the team's success is the worlds largest LNG train.

Figure 11: LNG Complex with Conceptual Train 4