ABSTRACT

With the successful completion of the Ras Laffan LNG Facilities, RasGas entered the LNG market as one of the lowest capital cost per ton producer in the industry. Upon completion of the project in March 2000, the LNG industry is ushered into the new millennium employing several technology firsts.

The objective of this paper is to provide both an overview of the Ras Laffan Onshore LNG Facilities Project and a discussion on the project development and EP&C (engineering, procurement and construction) work.

The specific design, rationale, and subsequent operation will be discussed for the following technology applications employed at the facility:

- Use of two Frame 7 Gas Turbine Drivers with centrifugal LP, MR and Propane Compressor Service,
- Cooling Medium Selection,
- Removal/Recovery of Sulfur,
- LNG Storage Tanks, and
- ICIMS (Integrated Control and Information Management System).

In addition, the following execution issues will be discussed:

- Total Quality Management, and
- Short Construction Schedule.
RESUME


L’objectif de cette présentation est de fournir un aperçu du Projet relatif aux installations onshore de GNL de Ras Laffan et de discuter des travaux de développement, d’ingénierie, d’approvisionnement et de construction du projet.

La conception spécifique, la justification et l’exploitation ultérieure seront discutées dans le cadre de l’application des technologies suivantes dans les installations :

- Utilisation de turbines d' entraînement à gaz Frame 7 pour les compresseurs centrifuges BP/HP MR et de propane
- Choix du moyen de refroidissement,
- Élimination/récupération du soufre,
- Réservoirs de stockage du GNL, et
- Système intégré de contrôle et de gestion des données)

De plus, les questions d'exécution suivantes seront discutées :

- Gestion totale de la qualité, et
- Courte durée de construction.
SUCCESSFUL COMPLETION AND INITIAL OPERATION OF THE
RAS LAFFAN ONSHORE FACILITIES (LNG) PROJECT

INTRODUCTION

In March 1996, the Ras Laffan Liquefied Natural Gas Company Ltd. (RasGas) awarded the Joint Venture of the JGC Corporation and Kellogg Brown & Root, Inc. (JGC/KBR JV) the Engineering Procurement and Construction (EP&C) contract for the two train grassroots LNG Plant Project known as the Ras Laffan Onshore Facilities Project.

RasGas, established in 1993, is jointly owned by Qatar General Petroleum Corporation (QGPC), Mobil QM Gas Inc., Itochu Corporation, Nissho Iwai Corporation and a Korean entity (KORAS) who is in the process of assuming a 5% interest. RasGas is a fully integrated Offshore /Onshore LNG company and the sponsor of the US$ 3.4 billion RasGas LNG Project, a market-driven multi-train LNG project. The onshore LNG Facility, which cost US$1.6 billion, has an initial production capacity of 6.4 Mtpa from two 3.2 Mtpa trains. The project design allows the addition of four individual LNG trains with associated infrastructure to be added incrementally as market demands. The RasGas facility is located in the newly formed Ras Laffan industrial city, 80km north of Doha, in the State of Qatar.

The RasGas' LNG Plant Project comprises three (3) major projects, namely, the Offshore Platform in the North Field, constructed by McDermott, the Pipeline between the Offshore Platform to the Onshore Plant Site, constructed by Saipem and the Onshore Facilities Project, constructed by JGC/KBR JV. Natural gas feed for the project comes from the non-associated gas reserves in the North Field, located off the northeastern coast of Qatar. The North Field contains proven gas reserves of more than 380 trillion cubic feet.

What follows is a synopsis of the process technology development activities and the EP&C work completed by the JGC/KBR JV for the two LNG trains, associated utilities, offsite and offplot facilities. The JGC/KBR JV successfully completed the EP&C and commissioning of both LNG trains February 2000, one month ahead of schedule. Upon successful completion of the LNG trains, RasGas entered the LNG market as the one of the lowest cost per ton producer in the industry incorporating many first-of-a-kind technology applications.

RASGAS’ RAS LAFFAN LNG PLANT DESIGN

A simplified block flow diagram of the Ras Laffan LNG Plant is shown in Figure 1, Appendix A. The facility consists of inlet gas reception and treating facilities designed to handle the two-phase production stream, condensate stabilization, gas liquefaction, sulfur recovery and storage and loading facilities plus all necessary utility and offsite systems and infrastructure. While the Ras Laffan LNG Plant is a totally separate and independent facility from the Qatargas LNG Plant, it is integrated into the infrastructure developed by the State of Qatar for LNG exports, the Ras Laffan Port.

Feed gas from the North Field contains a high percentage of Hydrogen Sulfide (H₂S), and Mercaptans (RSH). Thus the process configuration for Acid Gas, RSH removal, and sulfur recovery is comparatively larger here than at other LNG Plants. In addition to producing 6.4 Mtpa of LNG, the LNG plant is designed to produce 45,000 barrels per day of stabilized condensate and 312 tons per day of solid sulfur. Condensate in the feed gas is separated in the Slug Catcher. Mercaptans in the condensate are removed by the Merichem Unit. H₂S and
RSH, removed in the Acid Gas Removal Unit (AGR), are recovered in the Acid Gas Enrichment (AGE) and Sulfur Recovery Units (SRU). The AGR Unit uses the Shell proprietary Sulfinol-D process; the SRU’s were initially licensed from Comprimo and then later modified by JGC.

Each of the trains has a molecular sieve Dehydration Unit to remove water and sulfur compounds from the feed gas. After the Dehydration Unit, the feed gas is cooled by the propane refrigerant and enters the scrub column where the heavier components are separated and sold as plant condensate. RasGas selected the APCI Propane/Mixed Component Refrigeration (MCR) Process for Liquefaction. After the gas is liquefied, it is routed to the Nitrogen Rejection Unit, and then to Storage and Loading.

Plant Utilities include:
- Four General Electric (GE) Frame 6 Gas Turbine Generators to supply required electric power to the plant. The four turbine generators operate on an N+1 basis. Further expansion capabilities are provided in the generating and distribution facilities for the addition of four LNG trains.
- Two Diesel Generators to supply electricity to start-up the plant.
- Two Diesel Engine Driven Sea Water Fire Pumps to supply cooling water for the start-up of Main Gas Turbine Generators (i.e., Electricity from the diesel Power Generator and cooling water from the Sea Water Fire Pump enable the supply of instrument air for Gas Turbine Generator start-up).
- Fresh Cooling Water is used for Refrigerant Compressor inter/after coolers and other services. Fresh cooling water, used as the cooling media for the plant, is cooled by seawater. RasGas fresh cooling water system consists of Fresh Cooling Water Tanks, multiple Fresh Cooling Water Pumps, and a battery of 16 plate and frame heat exchangers per train for closed circulation of fresh cooling water.
- Other facilities such as Nitrogen Generator, Desalination Plant, HRSG, Waste Water Treatment Units, Boiler Feed Water Treatment, etc. were constructed.

Since the RasGas LNG Project is a grass root LNG Plant, all facilities, including RasGas' Administration Offices and Infrastructure, were included in the Onshore Facilities Project. Altogether 60 administrative and industrial buildings were constructed, i.e., Administration Building, Canteen, Mosque, Clinic, Warehouse, Maintenance Workshop, Fire Station, Laboratory, Central Control Room, Main Substation, Satellite Instrument Houses (SIH), Electrical Substations, Shelters, etc.

In the Ras Laffan Port area, the following facilities are located outside of the plant site (also known as “Offplot”):
- 3 x 140,000 m³ Above Ground, Full Containment LNG Storage Tanks
- 50,000 m³/h Sea Water Intake/Outfall
- 3 LNG Loading Arms, with their Ship-to-Shore Facilities; 1 LNG Vapor Return Line
- Tankage/LNG Loading Flare Stacks
- Condensate Storage Tanks
- 5 km Pipelines for LNG, Condensate and Sea Water

By incorporating specific technology selection strategies, the plant has a high design reliability. Other technology selection strategies are discussed below.
TECHNOLOGY SELECTION STRATEGY

Frame 7 Gas Turbine

The preferred process refrigeration gas turbine for compressor driver until recently has been the dual-shaft industrial gas turbine. The preference over the single shaft machine stems from the ability to control the speed of the power turbine independently from that of the gas generator and therefore providing more process and operation flexibility. The P.T. Arun and Northwest Shelf plants have had good operating experience with the GE Frame 5 dual-shaft turbines.

The available driver power and reliability determines a major part of the plant availability and operating costs. All scheduled shutdowns are driven by gas turbines maintenance cycle. The recent trend in LNG Plants is towards large gas turbines because they have demonstrated high reliability and availability together with high thermodynamic efficiency, lower emissions and easy maintenance.

Selection of the gas turbine drivers takes place during the project formulation phase in conjunction with establishing a LNG production rate design. The choice of drivers and the LNG production rate are integrated with proven Main Heat Exchangers, process and compressor technologies. RasGas adopted Frame 7 gas turbines technology for the Mixed Component Refrigerant (MCR) and Propane compressors. This selection was driven by many factors:

- There was a 20-25% reduction in specific capital cost ($/MW), as well as in the installation cost, as a result of using fewer larger turbines;
- Frame 7 Model 711EA’s have a rating of about 83.4 MW compared with 28 MW for Frame 5 Model C’s;
- There is a 10-15% improvement in specific fuel consumption with a corresponding reduction in emissions.

Table 1 below shows different sizes of gas turbines. The cost per unit of power decreases considerably with size.

<table>
<thead>
<tr>
<th>Frame</th>
<th>Type</th>
<th>Efficiency @ 15C (%)</th>
<th>ISO Power @ 15C(MW)</th>
<th>Relative Cost ($)</th>
<th>Relative Cost ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5C</td>
<td>Two Shaft</td>
<td>29.3</td>
<td>28.3</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Single Shaft</td>
<td>32.4</td>
<td>39.2</td>
<td>1.25</td>
<td>0.93</td>
</tr>
<tr>
<td>7EA (121EA)</td>
<td>Single Shaft</td>
<td>32.7</td>
<td>86.5</td>
<td>1.26</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Industry experience with these drivers in LNG service is good to date. Their record in power generation service and their cost advantage have given a strong impetus for their use as compressor drivers in Natural Gas liquefied processes. The Bintulu plant has been successfully operating a Frame 7 for MCR compression services for approximately five years.

During the conceptual phase of the project, the plant owner must decide on suitable gas turbines that meets its reliability criteria and which are also consistent with a commercially
viable LNG production rate. RasGas chose Frame 7 gas turbines to meet process requirements in a most economical manner.

In addition, RasGas evaluated the option of centrifugal and axial type compressors for low pressure, high volume LP MR service and ultimately selected the centrifugal design. This compressor is arranged for grade installation with inlet and discharge nozzle arranged in upward orientation.

**Cooling Medium System**

In developing the basis of design for an LNG plant, some of the alternative designs most commonly studied are: the use of air cooling, fresh water cooling, seawater cooling or a combination of the above. Many factors have to be taken into consideration in cooling system choice, including material of construction, fouling factor, exchanger’s size, etc. It is critical to be able to quantify the reliability of the plant. As always, reliability includes maintainability either by inspection or prevention, each one with a different associated cost.

The selection of cooling system was determined by the downtime of the Frame 7 gas turbines. The favored cooling process is the one requiring less maintenance time, which does not exceed the Frame 7 maintenance schedule.

Thus, considering only scheduled downtime, the availability of a freshwater cooled plant is greater than seawater cooling due to the fact that the seawater is known for having a relatively high maintenance component, corrosion potential and marine organisms that may create some special problems. A frequent problem in seawater cooling system is reduction in heat transfer due to bio-fouling, calcareous scaling, etc. which contributes to a rapid heat exchanger deterioration process.

During the Front End Engineering (FEED) project phase, RasGas evaluated fresh-water cooling system vs. seawater cooling system to determine the most cost effective and efficient system. Using a fresh water cooling system saves cost in exchanger metallurgy since less expensive materials are used compared to a seawater cooling system. This reduces the maintenance cost of the piping/exchangers network, since the only maintenance needed is for the plate and frame exchangers which are exposed to the seawater medium. Furthermore, it protects the environment from any leakage from the plant process side getting to the open sea.

The initial cost comparison between both systems came close to being equal, but the fresh cooling system has advantages in the long run from the point of view of operation and maintenance costs; hence, RasGas opted for fresh water system. RasGas fresh cooling water system consists of Fresh Cooling Water Tanks, multiple Fresh Cooling Water Pumps, and a battery of plate and frame heat exchangers for closed circulation of fresh cooling water. Seawater is used as the cooling medium for the fresh water system, which is carried out in plate and frame heat exchangers.

In summary, the RasGas fresh water cooling system has an installed cost comparable to direct seawater cooling but is expected to have lower operating and maintenance costs while reducing leakage of material to the environment.
Removal / Recovery of Sulfur

RasGas plant sweetens the dehydrated sour natural gas from the Qatar North Field to produce LNG. The gas composition from the North Field Alpha (NFA) contains contaminants of \( \text{H}_2\text{S} \), \( \text{CO}_2 \), and RSH. The feed gas composition to the AGR unit is shown in Table 2 where the NFA 13 was the original design basis from an offset well and the NFR-1 was the 1st well drilled in RasGas NFR block.

Removal of these contaminants is required for reasons of safety, corrosion control, gas product specifications, to prevent freeze-out at lower temperatures as well as to decrease compression costs, and to meet environmental requirements in both Qatar and in consuming countries.

There are many available processes, which can remove and treat acid gases; however, there are few that have the advantage of removing trace sulfur compounds such as RSH and acid gases in a single step.

A process to remove acid gases and mercaptans was needed. During the process selection phase, a number of processes were looked at such as an activated MDEA for removing the sour gases followed by a molecular sieve drier/mercaptan removal bed before being treated in the scrub column to remove heavy hydrocarbons. The second system was not commercially proven. At that time, there were no LNG commercial units operating with this type of “multiple molecular sieve beds in one vessel” arrangement.

A Selexol system was considered for removing mercaptans from the mole sieve regeneration gas; however, it was not selected because the Selexol process was not commercially proven in the treatment of regeneration gas for LNG plants.

Table 2. AGR Feed Gas Composition

<table>
<thead>
<tr>
<th>Composition</th>
<th>NFA-13 (Mol %)</th>
<th>NFR-1 (Mol %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_2\text{S} )</td>
<td>0.82</td>
<td>0.46</td>
</tr>
<tr>
<td>( \text{CO}_2 )</td>
<td>2.36</td>
<td>2.28</td>
</tr>
<tr>
<td>( \text{N}_2 )</td>
<td>3.97</td>
<td>3.75</td>
</tr>
<tr>
<td>( \text{He} )</td>
<td>0.00</td>
<td>0.04</td>
</tr>
<tr>
<td>( \text{C}_1 )</td>
<td>83.67</td>
<td>84.54</td>
</tr>
<tr>
<td>( \text{C}_2 )</td>
<td>5.29</td>
<td>5.35</td>
</tr>
<tr>
<td>( \text{C}_3 )</td>
<td>2.02</td>
<td>1.98</td>
</tr>
<tr>
<td>( \text{IC}_4 )</td>
<td>0.39</td>
<td>0.34</td>
</tr>
<tr>
<td>( \text{NC}_4 )</td>
<td>0.63</td>
<td>0.54</td>
</tr>
<tr>
<td>( \text{IC}_5 )</td>
<td>0.23</td>
<td>0.18</td>
</tr>
<tr>
<td>( \text{NC}_5 )</td>
<td>0.21</td>
<td>0.15</td>
</tr>
<tr>
<td>( \text{C}_6+ )</td>
<td>0.34</td>
<td>0.31</td>
</tr>
<tr>
<td>Aromatics</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Sulfur Compound</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Based on this concern, a decision was made to select the Shell Sulfinol-D treating process. Sulfinol-D is a mix of physical and chemical solvents consisting of diisopropanolamine (DIPA), sulfolane and water which is suitable for both acid gas and mercaptans removal. Besides that, it is a proven technology with a good operational experience record.
RasGas is closely monitoring the performance and commercial experience of MDEA treating followed by water/mercaptan removal in a combined molecular sieve bed to determine its potential for applying that technology in future trains.

The acid gas removed by the Sulfinol-D process could be flared, incinerated, or fed to a SRU. To decrease Sulfur Dioxide (SO$_2$) emission to the atmosphere and to comply with the local environmental regulations, RasGas decided to select a proven sulfur recovery process.

The basis of selection and size of a sulfur recovery process is always based on composition, flow rate, and the recovery efficiency required. Recovery is often dictated by environmental regulations rather than profit from sulfur sales. RasGas Sulfur Plant design was initially based on the NFA-13 offset well gas composition going to AGR Unit, shown in Table 2 with an H$_2$S concentration of 0.82 mol%. The process selected was SUPERCLAUS™, which essentially is a modified Claus process with a special catalyst in the last reactor to oxidize the H$_2$S selectively to sulfur avoiding formation of SO$_2$.

Right before the EP&C detailed design began, the first test well (NFR-1) drilled in the RasGas contract block showed lower H$_2$S concentration (0.46 mol%) as shown in Table 2. The CO$_2$ concentration remained approximately constant. This new information led to major changes in the sulfur plant design to achieve high recovery with the new composition.

Acid Gas Enrichment (AGE) was added to increase the H$_2$S/CO$_2$ ratio feeding the Claus Plant. The expected sulfur recovery from this arrangement was 95%, which satisfied the local environmental regulation; however, RasGas decided to increase the recovery, and thus reduce further reduce the SO$_2$ emissions.

A Tail Gas Cleaning Unit (TGCU) was added which converts all of the remaining non-H$_2$S, which is recycled to the front end of the AGE unit. The sulfur emissions are reduced as the sulfur recovery from the Claus sulfur plant and TGCU is expected to be 95%.

**LNG Storage Tanks**

Initially two 140,000 m$^3$ storage tanks were constructed, followed by a third tank of the same size, all of which were constructed by the same subcontractor. The storage tanks are Above Ground Full Containment type consisting of a 9% nickel open top inner tank primary container and an outer secondary container with pre-stressed concrete walls and a reinforced concrete roof. The tanks are located in a reclaimed area of the site. Drilled cast-in-place concrete piles were used to transmit tank loads to the underlying bedrock foundation.

When the plant was placed in operation, the 140,000 m$^3$ net capacity tanks were the largest PC-9% nickel above ground, full containment LNG storage tanks constructed.

**ICIMS (Integrated Control and Information Management System)**

The ICIMS system electronically collects and integrates business information, technical information, and plant control information for both onshore and offshore operations of the facilities.

The ICIMS consists of the following three major systems, with listed sub-systems, which are connected together by ICIMS network infrastructure and are accessible from PC/Workstations on the network:
• Plant/Platform Control and Information Management System (PCIMS):
  - Real Time Information System (RTIS)
  - Laboratory Information Management System (LIMS)
  - Electrical Integrated Control System (ELICS)

• Technical Information Management System (TIMS):
  - Engineering Work Environment – Computer Aided Engineering (CAE)
  - Computer Aided Design and Drafting (CADD)
  - Electronic Document Management System (EDMS)
  - Computerized Maintenance Management System (CMMS)

• Business Information Management System (BIMS):
  - BIMS subsystems include systems for: Accounting and Finance; Production Management; Material Management; Human Resources Management; Procurement and Contract Administration; Management Information and Decision Support Tools.

The ICIMS is also accessible from workstations installed in remote locations such as company offices in Doha and the Ras Laffan offshore gas production platform.

PROJECT EXECUTION STRATEGIES

Faced with increasing competition and price volatility in the LNG market, RasGas realized that its opportunities to market LNG are tied to its ability to reduce capital investment cost. In order to obtain the lowest lump sum bids, RasGas minimized EP&C Bidders’ risks by maximizing scope definition in the early stages of the project. The JGC/KBR JV aligned their project execution strategies for the EP&C phase to achieve this objective.

Total Quality Management

Pre-FEED (Pre-Front End Engineering Design). Pre-FEED work on the RasGas Project began in mid-1993. During the definition stage, RasGas worked extensively to develop a well-defined front end design and employed a number of value improvement practices for cost saving opportunities. Among the studies performed, technical studies confirmed the economics of a single two phase (gas and condensate) 32 inch pipeline from the offshore production platform to the onshore plant. These studies also recommended the critical selection of a single shaft Frame 7 gas turbine driver for the Propane and Mixed Refrigerant compressors in the liquefaction trains. Optimum sizing of 140,000 m$^3$ for each of the three LNG Storage Tanks was established with the recommendation to construct above ground full containment concrete tanks. Each of these recommendations was studied further during the FEED work to confirm market capability for the first time application of these technologies.

FEED. FEED work began in early 1994 under separate contracts for the Onshore (Chiyoda Corporation) and Offshore (Hudson Engineering Corporation) facilities, with the firm objective of providing detailed scope definition and bid packages for lump sum bidding for the EP&C phase of the Project. Key initiatives to maximize scope definition in the EP&C bid package included:

• Value Engineering Teams were established among FEED contractor and RasGas Project personnel with the assigned goal of minimizing scope and looking for ways to “do things better.” Critical reviews of plot plan layouts, constructability, equipment design allowances and sparing philosophy resulted in substantial savings to the
Project. Value Engineering also identified cost saving opportunities through the coordinated planning and design of shared facilities for sulfur storage and handling plus condensate storage and loading with the adjacent Qatargas LNG Plant.

- **Design Model** A detailed plastic design model was constructed during the FEED in order to visualize layouts and scope during design development reviews. This model was later made available for review by all EP&C bidders during the EP&C bidding phase to confirm and enhance their understanding of project scope.

- **Engineering Studies** were identified and completed by the FEED contractor to determine optimum economic solutions in the design. Results of each study were included in the EP&C bid packages to advise bidders of work already performed and evaluated during the FEED to reduce EP&C bidding time and costs.

- **Third Party Interfaces** with the Project were fully defined or eliminated to minimize the complexity of external supply and tie-ins with the Project.

- **Options to the EP&C** scope were defined to provide the contractual pricing basis for RasGas to evaluate potential cost savings and to exercise upon EP&C award as appropriate. Options for the EP&C of the second train were developed to accommodate for the conclusion of Train 2 market sales. Four option cases were established. (These cases are further described in the section entitled “Short Construction Schedule.”) These options were valid up to one year after award of the initial Train 1 facilities, with completion dates up to one year after Train 1 completion.

- **Scope Alternatives**. Bidders were encouraged to submit their ideas for scope alternatives as additional cost effective approaches to the defined scope. These alternatives were kept confidential among all bidders with the understanding that RasGas retained the right to incorporate viable alternatives in the design with the successful EP&C bidder. Additionally, Onshore EP&C bidders were compensated for their bid preparation because of the magnitude and complexity of the Onshore work and as an incentive to promote cost saving ideas.

- **Bidder input** was requested to obtain bidders’ perspective on areas where additional information would improve the quality of bid package information thereby resulting in reduced risk and contingency provisions. As an example, additional soil information was identified and further boring work undertaken by RasGas to provide increased definition for the bidders.

- **Critical Path Engineering** work was performed to provide detailed engineering on selected civil, structural and underground designs and specific complex equipment. This information served to advance the successful EP&C contractor's detail engineering effort by placing the contractor in a position of readiness for early procurement, thereby shortening their Project schedule.

- **Long Lead Contracts**. During the Onshore FEED work, RasGas developed, evaluated and awarded four long lead contracts that totaled approximately US$200 million and reduced the overall Project schedule by 6 months. Awarded between October and December 1995, these contracts included: (1) LNG Storage Tanks to the joint venture of Mitsubishi Heavy Industries and Campenon Bernard; (2) Main Cryogenic Heat Exchanger to Air Products and Chemicals Inc; (3) Refrigerant Compressor Packages and Gas Turbines to Elliott Company and General Electric respectively; and (4) Site Preparation work to Atlas Construction Company. EP&C bidders were advised of this early procurement strategy and kept continuously informed of RasGas' technical and commercial requirements on these contracts during the EP&C bidding phase.
This eliminated risks and facilitated the contractual assignment of each contract to the successful EP&C bidder.

- **Contractor-Arranged Financing Proposals.** Overall project costs were minimized by contractor-arranged financing proposals that were obtained from the Onshore EP&C bidders as part of their lump sum bids. In employing this strategy, Onshore EP&C bidders were able to link and optimize their respective procurement and execution plans with their proposed sourcing of funds from the various export credit agencies, commercial banks and other financial institutions.

- **Operations and Maintenance personnel.** As “owners” of the Project facilities, Operations and Maintenance personnel from RasGas joined the RasGas Project Teams during execution of both the FEED and EP&C phases in order to obtain and incorporate their input in the designs.

EP&C Contracts. Following the rigorous bid clarification and evaluation process, the Onshore lump sum EP&C contract was awarded in March 1996 to the JGC/KBR JV. In February 1997, RasGas exercised its options within the Train 1 contracts and awarded the Train 2 facilities to these same EP&C contractors. The RasGas focus of identifying cost saving opportunities continued through Value Engineering practices on each of the projects resulting in a combined savings totaling in excess of US$10 million. Early in the EP&C work, each of the RasGas and Contractor Project Teams conducted a joint Teambuilding Workshop to formulate a common ‘Commitment Statement’ for alignment of project goals and objectives. This effectively served as the platform for Value Engineering Practices and also set stretch targets in areas of project safety and schedule. The various project taskforce teams (located in Yokohama, Houston, Milan, and Jebel Ali in United Arab Emirates) held workshops at defined stages of the work as a means of monitoring ongoing performance against the ‘Commitment Statement’ goals and objectives.

Construction Progress. Construction at the Ras Laffan LNG Onshore Plant site began in late 1995 with the award of the early site preparation contract by RasGas as a cost saving and schedule effective approach which facilitated the mobilization of JGC/KBR JV and its subcontractors onto a fully prepared site. Portions of the site were also mass excavated to facilitate foundation work. By early 1997, JGC/KBR JV was operating a self-sufficient 6,000 bed construction camp complete with power generation, desalination, and waste treatment facilities. Five concrete batch plants and a pre-casting concrete yard were constructed at the site. The pre-casting operation has produced over 3,000 pre-cast concrete structures, including all columns and beams for the process pipe racks. Early construction planning by JGC/KBR JV also identified the cost saving benefits of installing a computer-controlled, high-frequency induction, pipe-bending machine shop at site. This operation produced more than 16,000 pipe bends to decrease the amount of pipe fittings and associated welding costs. Several pipe fabrication shops were in operation at site to fabricate all piping up to 90 inches in diameter.

High quality control in welding was specified in the project scope and achieved in the project execution. A very low welding repair ratio in radiographic examination, both in piping and LNG Tank welding, was achieved (i.e., 0.47% and 0.46% for piping and LNG Tank welding length repair ratio against 1.0% target, respectively).

**Safety Program.** Worksite safety has been a cornerstone to success in the construction of the RasGas Onshore facilities. The JGC/KBR JV and its sixteen major subcontractors have achieved an outstanding safety record throughout the entire construction period and have not compromised adherence to safety regulations to meet an aggressive project schedule.
The project achieved over 34 million consecutive hours without a Lost Time Accident (LTA) and a total of 55+ million hours worked with only two minor LTAs. This achievement is the result of a firm commitment and total team effort by the RasGas Project Task Force, the JGC/KBR JV and all involved subcontractors to create and maintain a safe work environment. The enormity and complexity of the project, with a multinational work force of over 8,000, had created unique challenges to maintain a safe worksite. In anticipation of these challenges, a comprehensive and multifaceted Safety Program was implemented at the start of construction. The Onshore Project Safety Program was a comprehensive amalgamation of the RasGas safety requirements, JGC-KBR's Corporate Construction Program and individual Subcontractor Safety Programs which embodies all of the key safety initiatives proven most effective by the Construction Industry Institute. Principal elements of the Onshore Safety Program include: extensive pre-task planning and risk assessments; continuous safety orientation and training programs; safety performance recognition, incentives and awareness campaigns; daily site inspections, third party audits and thorough incident investigations; and a well established and effective safety committee comprised of all project managers and safety officers on site.

**Environmental Program.** QGPC has introduced a progressive and comprehensive environmental policy for Ras Laffan Industrial City. “Pollution Prevention by Design” and “Environmental Quality Monitoring” were the cornerstone of this policy and translated into the Industrial City’s official marketing line.

RasGas was the first project in Qatar to complete an Environmental Impact Assessment prior to completing detailed engineering; this allowed the project to incorporate many design features that minimized potential environmental impacts, such as:

- The cooling water process was designed to eliminate the risk of an oil discharge in the Arabian Gulf by using a water / water heat exchanger system.
- The cooling water discharge was strategically placed away from the live bottom coral areas.
- RasGas has established an ecological monitoring program with Qatar University to monitor coastal biological health and water sediment quality.
- Waste management and recycling facilities were integrated into plant operation to minimize offsite waste disposal requirements.
- RasGas has taken the lead in design of a new industrial waste management facility for Ras Laffan City.

**Short Construction Schedule.** Effective Schedule Control, with Detailed Resource Planning, allowed the JGC/KBR JV to successfully overcome obstacles arising from the following situations.

- **Soil Condition** Another definitive factor in the delay of mechanical work was the unexpectedly hard ‘weathered limestone’. The plant site was covered by hard limestone which could not be excavated by backhoe alone, and required the use of rock-breakers and/or blasting. (The efficiency of a rock-breaker, as compared with a backhoe, is 3%: a combination of rock-breaker and backhoe could break and remove rock @ 0.9 m³/h, while excavation by backhoe alone would be 30m³/h.) This situation was overcome by mobilizing large numbers of rock-breakers and blasting offsite trenches during holidays.
• **2nd Train Option Exercise**  At the time of the contract award in March 1996, the 2\textsuperscript{nd} Train was handled as an option. (The specific options were: Option-1, Train-2 being awarded simultaneously with Train-1; Option-2, Train-2 awarded within 3 months; Option-3, award of Train–2 at 6 months; and Option-4, Train-2 after 1 year of award of Train-1.) It was widely expected that the Train-2 option would be exercised within 3 months, with 6 months being the latest award date predicted. However due to the economical situation prevailing at that time, Train-2 was actually exercised 1 year after award of Train-1 (Option-4). This resulted in unexpected inefficiency (especially in the simultaneous/separate procurement of two identical equipment for Train-1 and Train-2; construction of underground pipes for Train-1 and Train-2 running parallel to each other; and peak labour manpower control) which all needed to be overcome.

• **Procurement Philosophy and Progress.** JGC/KBR JV was awarded the Project amongst very competitive international bidding. As a result, the project budget was so tight that the project period for procurement took longer than that for other projects in order to solicit vendors for much more competitive pricing. Worldwide procurement of plant equipment was implemented, expanding to include East Europe and South Asian countries. Furthermore, the Sulfur Recovery Process had been changed from what had been included in the 'Invitation to Bid' (ITB). To further complicate the procurement progress, the economical situation in 1996 was worse than before as was proven by the bankruptcy of three vendors from whom important packages were ordered. These three factors greatly influenced the sequential progress of procurement work, subsequently resulting in engineering delay for want of vendor information. This compelled the construction period to be shortened, i.e., construction period after start of mechanical work was shortened by 3 months which is almost 20% of the mechanical work period.

The most important function in construction rests with schedule control and on the Area Superintendents. At the project control level, JGC/KBR JV established a network schedule that enumerated 1,300 activities for Train-1 EP&C. However, during the construction stage of Train-1, this numbered 1,600 activities, which included full supporting programs of resource data and material delivery information system.

In order to overcome the short construction period, interface co-ordination and detailed planning of construction work for the following week was indispensable for areas where two or more categories of work were to be simultaneously carried out, such as, civil with electrical/instrument cable work, civil with mechanical, etc.

The JGC/KBR JV Area Superintendents commendably co-ordinated with their respective subcontractors based on the detailed network analysis of the Schedule Controller, who scrutinised the work of the next week from the viewpoint of available resources and materials.

**ONSHORE PLANT COMMISSIONING, START-UP, AND OPERATIONS**

The successful commissioning, start-up and operations of the plant can be attributed to many factors, the most important of which was adopting a strategy of dealing with the commissioning and start-up activities/personnel as an integrated team. The team had one objective in mind – to achieve start up on or before the scheduled date in the safest and most efficient manner.
Commissioning of the LNG Facility

For the JGC/KBR JV, the commissioning work started in conjunction with the engineering work in early 1996 with establishment of a Facility Commissioning Planning Team. In order to have an effective commissioning and start-up program, three organizations needed to work closely together: the Project Task Force Group, the JGC/KBR JV Commissioning Team, and the RasGas’ Operations Group. The objective of the team was to plan for all commissioning activities and advise engineering and construction of the required completion dates. Drawing from previous project experience, the JGC/KBR JV determined that the best way to plan commissioning of the plant was to be proactive. This entailed developing a commissioning schedule up front, beginning with the facility completion date and working in reverse to determine the individual system commissioning deadlines. (A brief description of each team and their functions is provided in Appendix B.)

Commissioning such a project meant having to start a major recruitment campaign for the RasGas Plant Operations and Maintenance staff. This activity began in mid-1997, six months after construction started on Train 1. Operators and Supervisory staff began mobilization to Qatar in the first quarter of 1998. The staff was put through a rigorous training program which included Pre-Mechanical Completion (PMC) activities on Train 1. The primary focus of these activities was “test pack validations” which involved field verification of P&IDs. Complete staffing and training for Train 1 Operators and Supervisors was completed in the first quarter of 1999.

Facility Commissioning Sequence. Commissioning of the Onshore Plant, and thus transferring systems over from the JGC/KBR to RasGas, followed a stepwise sequence. A detailed outline of the formal commissioning milestones associated with this project is covered in Appendix C.

The first facility to be handed over was the plant condensate storage area in September 1998. RasGas designed this facility to be shared with QatarGas; thus the facility was completed in a timely manner for usage by the QatarGas facility.

The Utilities Plant was commissioned in a stepwise fashion between June and December 1998. As the individual systems were commissioned, they were operated by RasGas’ Operations Group, under the supervision of JGC/KBR.

Train 1, which included two LNG tanks and three condensate tanks, was offered for mechanical acceptance on March 15, 1999 and accepted by RasGas on March 31, 1999. Gas was then introduced into the plant on April 10, 1999. First LNG production occurred on May 23, 1999, with first shipment of LNG on June 21.

Prior to completing construction of the first train, a team building session was held at the site to define roles and responsibilities amongst the three Commissioning Groups. These sessions allowed for each of the groups to exchange views on the commissioning procedure and develop resolutions to be implemented for construction of the second train.

Train 2 and the third LNG tank was planned to follow Train 1 by about a year; however, this part of the project was ahead of schedule. RasGas received the third tank on December 14, 1999 and commissioned it in 5 days. Train 2 was offered for Mechanical Acceptance on March 1, 2000. Commissioning required only 11 days and first LNG was produced March 31, 2000.
Overview and Review of Facility Commissioning Operations

Train 1 Pre-Mechanical Completion (PMC) /PC/Start-up Overview. The three organisations described above all had a different focus and responsibility towards the completion of the project. The challenge was to develop a team philosophy that would define a common objective for all three parties in order to perform the job with high standards, reduced rework and delays, and at the lowest possible project cost.

RasGas did have a successful start-up. Operations maintained high standards of acceptance; therefore, when the plant was handed over it was in good shape from a construction and readiness standpoint.

RasGas had a plan to commission the plant in 13 weeks from Mechanical Acceptance Package (MAP). The first week was used for pre-start-up safety reviews on the inlet facility and condensate storage facilities. Gas was brought in on schedule, April 10, 1999. During the second week of the plan, pre-start-up reviews were performed on the downstream units. RasGas was very successful in commissioning the Sulfinol system, however had problems lining out the Merichem Unit. Here, level control was a problem and required multiple visits from the vendor. As it turned out, some of the level controllers were set up as reverse acting. Additionally, some level bridals were incorrectly located at elevations than specified in the design.

The next big start-up milestone was to start the Propane Compressor (i.e. to begin dynamic dry-out). Operations were well ahead of schedule but experienced plugging of the valve cages in the recycle lines to the compressor. This caused some delay but the machine was finally started within a day or two of expectations. Plugging was found to be the result of inadequate line blows and the lack of start-up cages in the valves.

Six weeks were scheduled for dry-out based on experience from previous start-ups at other locations, however actual defrosting occurred in about three weeks. This reduction in schedule is attribute to a well thought out defrost system. A significant number of vents/drains were installed as changes to the original design.

On May 12, 1999, RasGas began bringing propane over from QatarGas to fill the refrigerant storage tanks. Pre-cooldown and final cool-down occurred without incident and first LNG was produced on May 23, just eight weeks after MAP.

Post Start-up Mechanical Problems – Train 1. After the successful start-up of Train 1 in May 1999, RasGas did experience some mechanical problems resulting in either shutting down the plant or significantly impacting production. A brief summary of these problems follows.

- **Cryogenic Valve Failure** A number of cryogenic valves failed shortly after initial use. The failures were in some cases complete seizures of the valves and in others, erratic valve movement. The vendor was brought in and they very quickly determined that they had not specified the materials of construction of the bushing material correctly. Replacement of the valves became a challenge. All the affected Train 2 valves were removed and repaired. A short shutdown of Train 1 was necessary to replace those valves with the repaired Train 2 valves. Probably the most challenging area was fixing the valves in the LNG storage area. These valves are always in flowing LNG service. Repair work had to be scheduled around windows in the growing shipping schedule.
• **Frame 7 Speed/Stop Ratio Valve Failures** Six instances on both Train 1 and Train 2 occurred where the Speed/Stop Ratio Valve (SRV) on both the Propane and the MR turbines seized. The seizures were all associated with turbine trips. The particular valves were an integral design, having the Ratio and Gas Control valves housed in a single valve body. The material of construction for these valves was in accordance to NACE specification because sour fuel gas was used during commissioning. The root cause of the failures is believed to be two-fold. First, NACE valves are softer and more prone to scoring in the event foreign matter gets into the valve. This facility does not employ a fuel gas filter skid up stream of the valves, therefore foreign matter is a real possibility. Second, RasGas owns five of the eight valves of this design in the world. Upon visiting the manufacturer, a serious fault was found with their QA/QC and construction techniques. To alleviate this problem, the valves were changed from NACE to Non-NACE, which resulted in a harder material of construction in the stem and other moving parts. Since these changes were made, no other failures have been recorded.

• **Control Valve Actuators** In many applications, control valves were designed with actuators that are more suitable for Emergency Shutdown (ESD) service i.e. either open or closed. These actuators are horizontal with a spring to shut on one side and air to open on the other. In applications such as air control to the SRU reaction furnace, this type of actuator was completely inadequate. Subject actuators were identified and replaced with more fit for purpose designs.

**Train 2 PMC/PC/Start-up Overview.** Although the start-up of Train 1 was considered to be successful, the commissioning operation was reviewed to extract lessons that could be employed during the commissioning of Train 2 thereby increasing the efficiency and reducing costs. The impact of these lessons learned in organization and project co-ordination was a dramatic improvement in the start-up of Train 2 as compared to Train 1. The most significant outcome was the ability of Operations to influence the Contractor Commissioning Group to optimise the availability of unit areas with their Construction Group. As such, Operations had access to parts of the plant well in advance of MAP. This enabled Operations to start performing some commissioning activities such as hot nitrogen drying well in advance. In some cases hot nitrogen drying was initiated 2 months early.

By taking advantage of the fact that the first LNG train was in operation, the Commissioning group utilised cross connections to facilitate both drying and cool-down. This resulted in production of LNG just 11 days from introduction of gas.

**Post Start-up Mechanical Problems – Train 2.** Many of the problems encountered on Train 1 were corrected on Train 2 prior to MAP. As such, Train 2 start-up went much smoother from a mechanical standpoint. In fact, as of July, Train 2 has had an availability factor of over 99%.

• **Frame 7 Stop Ratio Valves** The problem on the stop ratio valves has been solved. One failure on Train 2 has occurred; however, this again was on a valve that had not been changed over to Non-NACE material. The valves were rebuilt under close scrutiny of RasGas personnel.

**Summary of RasGas Facilities Commissioning.** RasGas, although not immune to problems, had a successful start-up of the first LNG Train. Through a commitment to improvement by the Contractor, the Project Task Force and the Plant Operations Group, the
commissioning of Train 2 dramatically improved. By aligning the goals of the three parties, all those involved were able to work closer and develop synergies that were not possible with the various groups working in isolation. Activities were planned sufficiently in advance, along with contingency plans, that enabled the optimal use of resources. This project broke the paradigm that Construction/PMC and Commissioning need to be sequential events. By working together, they were able to overlap some activities that ultimately left the plant in virtually a dry state at MAP.

**CONCLUSION**

With the successful completion of the Ras Laffan LNG Facility, the industry has entered the new millennium debuting new and improved technology applications and execution strategies. As the industry continually strives to reduce cost, maximum definition is the key to reducing the project investment costs. EP&C execution of the Ras Laffan LNG facility by the JGC/KBR JV affirmed that job site safety is the cornerstone to successful construction execution of a project.

With RasGas’ entry into the LNG market, it is well positioned to help fulfil Qatar's objective of becoming the world’s premier supplier of LNG.
APPENDIX A

FIGURE 1. SIMPLIFIED BLOCK FLOW DIAGRAM OF RAS LAFFAN LNG TRAINS
APPENDIX B

RASGAS FACILITY COMMISSIONING PLANNING TEAM

The Project Task Force (PTF) team consisted of RasGas personnel. This group was accountable for the overall project and was the primary interface with the JGC/KBR JV. Their role was to sign off for the completion of Pre-Mechanical Completion (PMC) activities (such as rotating equipment alignment, instrument loop checks, etc.) on behalf of RasGas. The PTF group had a Mechanical Acceptance Package (MAP) Co-ordination Superintendent who acted as the primary interface between the Contractor and the RasGas’ Commissioning Group.

The RasGas’ Operations Group consisted of a Superintendent, two Co-ordinators, and a Start-up specialist. These people oversaw the PMC activities, approved operations cleanliness, approved and assisted in Pre-Commissioning of Utility System start-up.

The JGC/KBR JV Commissioning Group consisted of a Superintendent and a group of field supervisors and technicians that performed most PMC activities, generally with the assistance of RasGas Operating personnel. In addition, the four permanent staff members in the commissioning group looked at the coming workload, borrowing operators and supervisors from the Plant Operations Department as necessary to handle the workload.
APPENDIX C

RASGAS FACILITY ACCEPTANCE PROCESS

Following is a brief discussion of the facility acceptance process.

The JGC/KBR JV Construction Group performed construction of the onshore plant. Once the physical assets were installed, they were handed over to JGC/KBR for commissioning. The Commissioning Group then carried out Pre-Mechanical Completion (PMC) activities such as line blows, refractory dry-out, steam-out of vessels and lines, hydraulic flushes, vessel boil-outs, etc. These activities were done in close co-ordination with RasGas’ Operations Group.

Once PMC was completed, the first formal acceptance between JGC/KBR and RasGas took place. This first step was referred to as the Ready for Mechanical Acceptance Certificate (RFMAC). This step was RasGas’ confirmation that the facility was built as designed with a large percentage of the “punch-listing activities” completed. When the RFMAC was issued and approved, the care and custody of the facility still remained with the JGC/KBR JV. The RFMAC was issued to show RasGas agreed that the facility was safe to start up for use by the JGC/KBR JV. Specifically, it allows the contractor to operate various parts of the utility plant and distributions systems for their use and bring fuel gas into the plant for turbine testing with the assistance of the Plant Operations Department. At this point, JGC/KBR is no longer operating with construction permits but with an operating permit, which allows the contractor to work the system’s agreed upon by the RasGas Operations Group.

The next step, the Mechanical Acceptance Package (MAP), consisted of pulling together logical groupings of RFMACs and formally handing them over to RasGas for their care and custody. Upon completion of this activity, the RasGas plant rules became effective (such as permit to work, safety standards, plant security, etc.).

At this point, with completion of the PMC activities, the RasGas operating staff began their final commissioning activities which consisted of final control valve function checks, ESD testing, high pressure gas testing and ultimately introduction of gas.

Two more acceptance steps occurred after the plant has been commissioned. The first was the Operational Acceptance Certificate (OAC). (Operational Acceptance occurs when RasGas is satisfied that the Plant is operational. Performance testing is not a requirement for Operational Acceptance; however, the plant needs to be in a state that it can pass the performance test prior to OAC.)

After the plant was commissioned, a Performance Test Run (PTR) was run for a period of 72 hours. (During this time, all licensor guarantees are validated. This test is witnessed by the individual licensors, the Lenders Technical Representative and the Contractor Technical Representatives. Once completed, the Final Acceptance Certificate (FAC) is issued and the official warranty period begins.)