EXECUTION OF LNG MEGA TRAINS - THE QATARGAS 2 EXPERIENCE

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Introduction/Background

The world demand for natural gas has renewed interest in the production and transportation of liquefied natural gas (LNG) from resource rich areas in Africa and the Middle East to new markets and customers in Europe and the Americas. Qatar has led the way in meeting this challenge and has become the largest LNG producer in the world. Its vision is to produce 77 MTA of LNG through the continued development of the North Field, the largest non-associated gas reservoir in the world by the turn of the decade. This vision is fast becoming a reality through the development of the world's largest LNG trains (Trains 4 & 5) by the Qatargas 2 Project (QG2), a joint venture between Qatar Petroleum, ExxonMobil and Total.

To achieve the cost reductions required to offset the distance to LNG markets, QG2 developed the world's first fully integrated, value chain LNG venture linking all of the components from wells to markets into a single project. Increased economies of scale also were required which led to the latest generation of LNG production facilities being larger than ever. These large plants are designed with facilities and equipment that dwarf those in plants that are but a few years old. This major advancement in the scale of LNG production facilities was achieved through advancements in process technologies, process integration and the use of large scale equipment.

Successful implementation of this mega project required simultaneous execution of several large scale projects in four countries by a work force of over 35,000 people. All components of the project had to converge at the same time to connect all of the links of the value chain. In addition, the application of large scale technologies and first of a kind equipment applications required a very rigorous and structured approach from project inception through all of the stages of project execution, including stringent equipment testing plans to ensure the facility will achieve a reliable operation.

The first of the large LNG trains, Train 4, began producing LNG in March, 2009 and is approaching full capacity. The second train, Train 5, is being commissioned and will go through startup and production ramp up during the second half of 2009. To complement the trains, QG2's Offshore production facilities, large LNG ships, and the LNG receiving terminal in Wales have all been completed and successfully started up.

Objectives

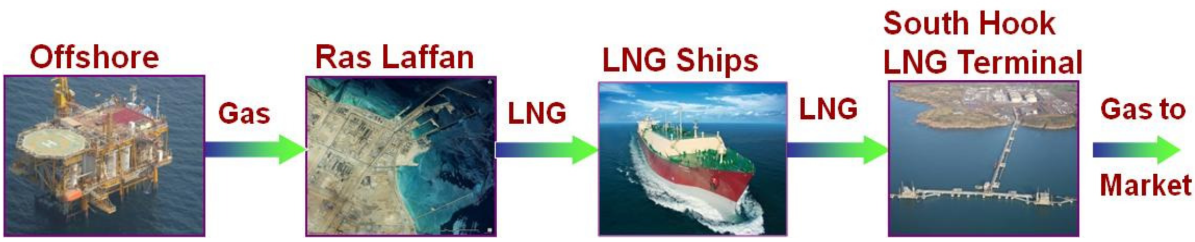
This paper will discuss many of the creative solutions developed by QG2 and the key components that led to a successful project, including;

- Implementation of the full value chain,
- Successful development and integration of major new technology,
- Implications of unprecedented size and scale, in particular, the 7.8 MTA LNG mega trains,
- Meeting the challenges of executing projects of this magnitude.

Lessons learned from the various phases of project execution and perspectives for execution of future mega projects will be discussed.

The Full Value Chain

The most unique feature of the QG2 Project is it represents the first time, on this scale, that anyone has attempted to build a project that encompasses the entire LNG value chain. The QG2 value chain starts with the wellheads located offshore in Qatar's North Field, continues on to Ras Laffan where the liquefaction, storage and export facilities are located, then goes to a fleet of 14 of the largest LNG ships ever built, and finally ends at the South Hook LNG receiving terminal in Wales, UK.



The QG2 Full Value Chain

The scope of the Offshore facilities includes 30 large bore gas wells, 3 Wellhead Platforms and 2 Wet Gas Pipelines (34" and 38" diameter). The drilling program, managed by RasGas, achieved the fastest well ever drilled in the North Field, 14,500 feet in 33 days, and the 30 well program was completed 27 rig-months ahead of schedule. The offshore facilities were built in Abu Dhabi and then lifted into place on jackets that were installed prior to the drilling activities. The two wet gas pipelines gather the gas from the platforms and transport it to the Onshore facilities at Ras Laffan.

QG2 Wellhead Platform 5

The two mega trains located onshore are the heart of the QG2 project, each capable of producing 7.8 MTA of LNG, and represent the largest portion of the project investment. In addition to producing LNG, the Onshore facilities produce LPGs (Propane and Butane), condensate (C5+), and sulfur.

The LNG ships are next on the value chain. QG2 is managing the ship building program in Korea for all the Qatar LNG Ventures, totaling 53 ships in all. The QFlex and QMax class ships, having capacities of 210,000 and 265,000 cubic meters respectively, are the largest ever built compared to the 135-140,000 cubic meter capacity of conventional LNG carriers. These ships are high efficiency, low emission and incorporate onboard reliquefaction, resulting in virtually no LNG losses during a voyage. The design of the reliquifaction system and the ship containment system underwent rigorous assessments and testing to prove their feasibility, including extensive testing of hydrodynamic sloshing

Comparison of QG2 & Conventional LNG Ships implications for the large tanks. All 14 of the ships built for the QG2 Venture have been delivered and are already in service. Of these ships, the "Mozah" was the first Q-Max delivered and she has successfully delivered her first cargo to Wales.

The final component of the QG2 value chain is the South Hook LNG Receiving Terminal in Milford Haven, Wales, UK. This terminal has the capability to deliver up to 2.1 billion cubic feet of gas a day into the UK market. The terminal comprises two LNG receiving Berths, 5 large storage tanks, and the use of Submerged Combustion Vaporizers for regasification prior to sendout into the UK gas grid. One important factor for the local community was to reduce the vertical profile of the facility to help it meld with the environment. This was achieved by building the largest diameter LNG tanks ever constructed to minimize the tank height while still achieving the storage requirements of the terminal. The first phase of the terminal is fully operational and has received several cargoes of LNG.

Storage Tanks at South Hook Terminal

In addition to the main components of the value chain, an equally important aspect is the series of large projects referred to as the Common Facilities projects. These projects involved building common product storage and loading facilities to serve the multiple ventures in Ras Laffan. Four such projects were implemented for each of the main products – Common Lean LNG, Common Sulfur, Common LPG, and Common Condensate. QG2 managed the first two on the list and RasGas managed the remaining two. The Common Facilities are a major success for Qatar and the Ras Laffan ventures due to the large cost savings from the synergy of shared facilities. For example, the eight Lean LNG trains share eight storage tanks and four LNG loading berths. If separate facilities had been built, then as many as 16 tanks would have been required.

Common Sulfur Storage Facilities

The remainder of this paper will focus on the creative solutions to technical and execution challenges for the large LNG trains. Each of the other components of the supply chain are large projects in their own right, and also have numerous examples of technology application and project execution challenges and solutions, but the nature of the challenges and the methods used to address them are most pronounced and therefore best represented by the large LNG trains.

Common Lean LNG Tanks

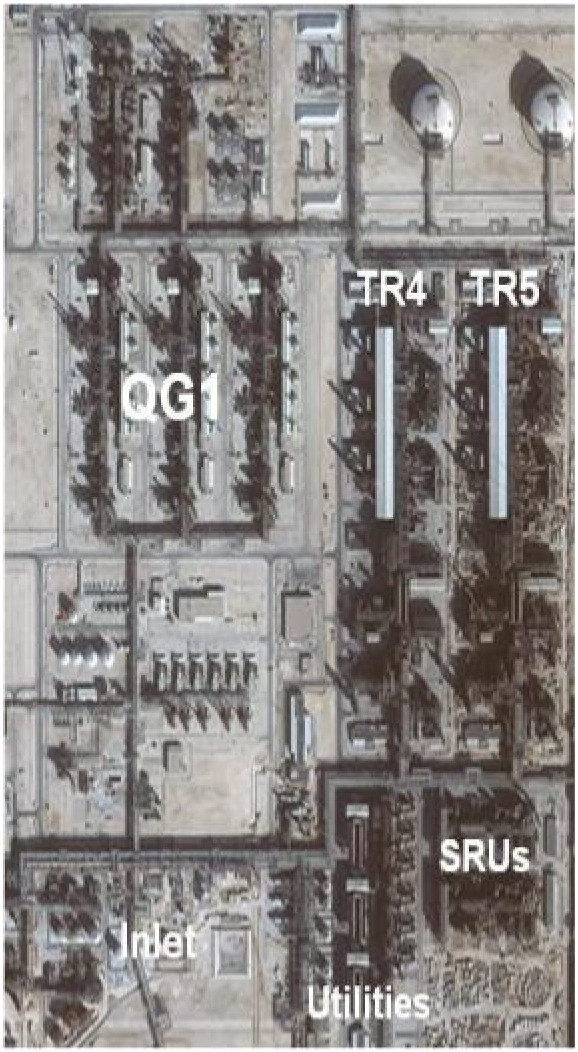
The 7.8 MTA Mega Trains

The two 7.8 MTA mega trains are at the core of the QG2 project and are the largest component by far. The trains are 50% larger in capacity than previously achieved in the industry. The satellite photo shows Train 4, Train 5, Utilities, Sulfur Recovery Unit (SRU), and the Inlet Facilities. By comparison, the three smaller Qatargas 1 trains that were constructed 10 to 12 years ago and today produce a combined total of 10 MTA also are shown in the photo.

To achieve a step change in size, a significant step change in technology was required. The design of the mega trains included more than 40 technologies considered new or step-outs. A few of the key technologies are briefly highlighted in this paper, including a discussion of the challenges associated with implementing this many new technologies at one time. However, this paper will not cover the technologies in detail since several papers have been written on the innovative technologies of the QG2 design. A comprehensive discussion recently was presented at the March 2009 Doha Natural Gas Conference titled "Qatargas 2, the Design and Technologies for a 7.8 MTA LNG Train."

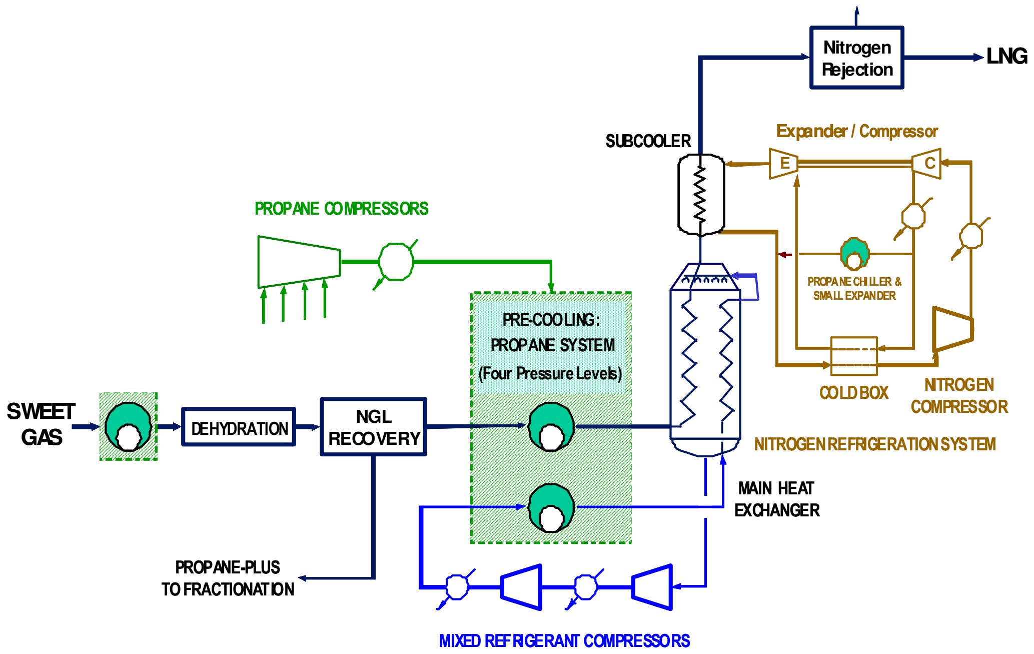
When the gas comes onshore, it enters the Inlet Facilities where the liquid condensate and water are separated from the gas. The condensate is stabilized and treated prior to being pumped to the Common Condensate Storage and Loading facilities where it is exported. The water is treated and disposed of subsurface into two injection wells. The wet, sour gas then flows to Trains 4 and 5 where the acid gas components (CO2, H2S, and COS) are removed, and the gas is dehydrated using molecular sieve. The extracted sulfur compounds are sent the SRU where a recovery efficiency of over 99% is achieved.

The QG2 project is designed to meet the lower heating value gas specifications required by many of the markets in the Atlantic Basin. The "lean LNG" is produced by incorporating an NGL extraction process into the train design upstream of the liquefaction process. The Ortloff SCORE process was selected and has been designed to achieve 99% propane recovery. After the NGLs are removed, they are fractionated into propane and butane products which are pumped to the Common LPG Storage and Loading facilities where they are exported.



Satelite Photo of QG2 Trains 4 and 5

Finally, the gas flows to the liquefaction section which incorporates a few key technological advances developed by QG2 for this first of a kind facility. These advances include the use of General Electric (GE) Frame 9E turbines in mechanical drive application, large scale Siemens variable frequency drives and motor/generators in the compressor strings, the first application of the Air Products AP-X technology in the liquefaction of natural gas which incorporates the novel use of a N2 SubCooling refrigeration loop, and the integration of power and steam generation to achieve a highly efficient and environmentally friendly LNG plant design.



AP-X Process Diagram

The Challenges of Executing a Mega Project

Planning and designing the QG2 mega trains was a major technological success. However, that feat had to be followed by a massive project execution campaign to complete the project safely and to produce a high quality, highly reliable facility. The sheer scale of these trains created monumental challenges. This paper will briefly discuss several of the major challenges listed below, and then address the first two on the list for a more in depth discussion.

- Unprecedented Size and Scale - It is all too easy to underestimate what the size and scale of a mega project can mean. From an execution perspective, size proved to be arguably the most impactful factor on overall project execution results. Although the capacity was a 50% increase from the previous largest train in Qatar (7.8 MTA compared to 4.7 MTA), many of the challenges were not a linear extrapolation but in some respects closer to orders of magnitude.

- High New Technology Content - The QG2 trains also had a high new technology content. Typically a project with a few new technologies to implement would present a major challenge. The mega trains contained more than 40 technologies that were considered new or step-out technologies requiring a very rigorous and structured approach to ensure the design, construction, installation and operations were all successful.

- Project Integration - QG2 involved the simultaneous execution of multiple projects in multiple countries, multiple nationalities (more than 40), numerous Shareholders and Owners, Operators, contractors, subcontractors and vendors, a high degree of interdependency amongst the facilities in Ras Laffan, and more than 200 commercial agreements to address a complex web of interfaces and linkages, physical and commercial. These many layers of complexity required a systematic approach to Interface Management and the close integration of all of the project elements to ensure that projects were completed and facilities were available when needed. This was particularly important because of the full value chain project and the reliance on common facilities.

- Strained Resources and Infrastructure - Most projects executed over the past few years have experienced strained resources in an overheated market environment. This was particularly true in Qatar with several large projects all executing simultaneously which created strains on the infrastructure. There was a very high degree of competition for resources, particularly for skilled labor. In the course of the project, QG2 ran into shortages of numerous commodities – cement, steel, diesel, argon, dune sand - to name just a few. These factors were in part a reason for delays experienced on the project and had to be carefully monitored to predict potential shortages and to implement mitigation plans.

- Assembling the Right Team to Manage Scope and Complexity - Considering the scale and complexity of the undertaking, it was crucial to assemble a team that has both the *Capability* and the *Capacity* to manage it. QG2 was fortunate to be able to draw from very strong shareholder organizations to assemble a team with the experience, wisdom, technical expertise and execution skills to be able to plan, organize and anticipate, as well as having the capacity to respond to challenges and surprises. This was crucial to success.

Managing Size and Scale

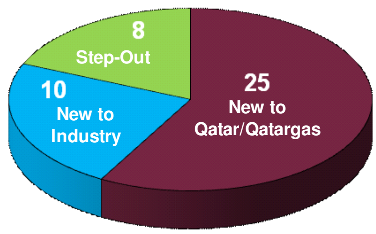
Construction of the Onshore trains involved quantities, weights and sizes on a scale that was unprecedented, and it was quickly realized that project execution on this “mega” scale required different approaches to project execution and management. For example, before construction could go into full swing, one of the first steps was to build the equivalent of a small city to house and ensure the proper welfare of a workforce of almost 30,000. The volumes involved can be overwhelming - for example, each month, QG2 served 2.5 million meals and the workers consumed over a million eggs!

A greater imperative was to quickly train this large group of workers, comprising mostly inexperienced labor with little prior exposure to industrial activity. One measure of the size of this challenge is the number of work hours involved on the project – about 250 million work hours expended to date. Safety at every level was paramount, and safety and training programs were specially tailored both to suit this population of workers as well as to be effective when applied to large numbers of workers. Safely transporting 30,000 workers to and from site each day, ensuring that drinking water is available in a high heat index environment across a large site, and conducting effective Tool Box Talks in multiple languages are a few examples of the challenges in managing safety. The project has a goal of achieving an Incident & Injury Free workplace, and was able to continuously improve safety performance year-on-year, achieving world class safety levels. For more detail on the processes and programs used to manage safety, please refer to a paper presented at the December 2008 International Petroleum Technology Conference on QG2’s experience in Managing The Safety of Large Onshore Workforces.

Thousands Working Safely

The construction activities required more than 300 cranes on site to safely execute more than 1500 major lifts, including the heaviest lift to install the Acid Gas Removal Absorber weighing 1500 tonnes. The Onshore trains construction required more than 43,000 tonnes of structural steel, 245,000 cubic meters of concrete and 4 million meters of cable. Most of the piping is large diameter with some of the largest being seawater supply lines with a diameter of 114 inches. The volumes, sizes, weights and heights involved in this massive construction effort required special planning and attention with respect to construction equipment and materials, laydown areas, workshops, logistics, construction sequence, scaffolding strategies, testing and reinstatement, etc.

Systems completion and pre-commissioning activities was another significant challenge. To effectively manage the effort, the overall facility was broken down into systems. Train 4 contained over 1000 systems which required more that 600,000 tests, checks and inspections to be performed. Enhanced analytical tools were developed to manage the scale of the systems completion effort in order to measure, analyze, and drive progress in an effective manner.



While the QG2 project can lay claim to many "largest" parameters, the key point is not the size of the numbers, but the realization that when a project has numbers of this magnitude, the degree of skill required in execution planning and organization, optimizing, sequencing, prioritizing, and measuring takes on a very different dimension, an altogether different level of project execution.

Many lessons have been learned on Train 4 about how to build a train this big, and these lessons are systematically captured and passed on to the rest of the mega trains being built in Qatar, and they are deriving significant benefits from the "Design One, Build Many" strategy.

Managing High Content of New Technology

These trains would not have been possible without the introduction of new technologies. It has already been mentioned that more than 40 new technologies were required. To manage the implementation, these technologies were divided into three categories, as shown on the pie chart – new to the industry, new to Qatargas, and significant step outs in size. Although this last category may not be new, they represent significant technical challenges since nobody has previously built them on this scale.

With the success of the project and the very large investments hinging on these technologies, a very rigorous and structured approach was developed for the introduction of new technologies, from project inception through all the stages of project execution, and into Operations. The more significant elements were;

- A proprietary Technology Qualification Process, working in close partnership with critical vendors,
- Extensive modeling and testing programs on the major pieces of the mega train, not least of which were full string tests in Massa for the turbine and compressor units of the refrigeration systems,
- A comprehensive review of all 43 technologies using different tools to assess potential issues and mitigation actions. These actions included additional training, procedures, design modifications and ensuring some of the best people from key vendors were heavily involved in final commissioning and start-up.

GE Frame 9E Turbine

This structured approach maximized chances of success. The introduction of major new technologies for Trains 4 & 5 have been relatively trouble free with no major issues, and most of the problems faced during commissioning and startup involved more conventional equipment with a step change in size. The lesson to be learned is significant increases in size may require the same rigor as development and implementation of a new technology, and implications of scale-up need to be fully understood.

Summary and Conclusions

QG2 is a clear example that mega projects can be designed and executed safely and efficiently to produce a high quality, highly reliable facility. For the next mega project, the following lessons learned and perspectives may be useful to keep in mind during planning and execution:

- The more “new”, the more effort, diligence, discipline and rigor are needed, not just at the outset, but throughout all the phases of a project,
- Many of the QG2 experiences, processes, tools and learnings can apply well, not just to LNG projects, but mega projects around the world, especially greenfield projects in remote locations (e.g. managing large workforces, large scale construction, assimulation of new technologies, multiproject integration).
- When “thinking big”, one should be aware on mega projects that a point can be reached where execution challenges are no longer a simple extrapolation but become orders of magnitude more complex,
- Being “first” is great – when the project is done – until then, a team with the experience and capability both to anticipate as well as respond to surprises and complexities is essential. Furthermore, having the depth of technical resources from shareholder organizations that can be called upon to resolve key issues is critical. By definition, attempting something that no one has done before means being the first to encounter any unknowns along the way.