EGYPTIAN LNG

THE VALUE OF STANDARDIZATION

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GASTECH 2005

Abstract

Key decisions at the beginning of any grassroots LNG project critically impact the ultimate success of the project. The variables to consider are numerous but from a high-level perspective, commercial variables such as available gas reserves, financeability, corporate objectives and market penetration must be considered in combination with project related variables such as schedule, capital expenditures, and life cycle costs. The ultimate objective is to develop a strategy providing the highest rate of return to the owners whilst taking full account of the risks that can be managed by the owners.

Shipping logistics, pre-investment for expansion trains, safety and environmental impact, technology selection and EPC contracting strategy all come into consideration early on in the process. One of the factors that most shape a LNG project is train capacity. Given the importance of economies of scale, the LNG train size that is chosen, along with the associated refrigeration turbine/compressor configuration, is a key decision that impacts almost all other variables. However, since the train capacity impacts so many project factors, the correct choice for one project is not necessarily the correct choice for another. The unique challenges that each project faces must be considered in order to arrive at the best decision for a given project.

This paper draws on the experience of the Egyptian LNG project which is one of several grassroots projects started in the 2000's that remained with the nominal train size of 3.6 MTPA that became standard in the last half of the 1990's. It should be noted that 3.6 MTPA is an annualized FOB rate - the actual PFD rate or design rate of the facility is over 4 MTPA. Some other contemporary projects have designed at 5 MTPA and one recent project has announced a 7.5 MTPA train. Is it possible for smaller trains to compete in today's LNG business?

The overall strategy for the Egyptian LNG project has been to standardize on the design developed for Atlantic LNG Trains 1 – 3. In this paper, we will provide an evaluation of the key considerations leading to this strategy and show that highly competitive capital costs can be achieved with smaller trains whilst also significantly reducing project schedule and minimizing owner risk.

1.0 Introduction

One of the authors at LNG 12 in 1998 pointed out that the LNG industry has for many years focused almost solely on larger trains and the associated economies of scale as the main means of reducing unit cost. (1) More recent papers at LNG 14 in March 2004 revealed no change in this trend with three papers claiming construction of the largest train in the world, Atlantic LNG, SEGAS and announcements from RasGas. (2, 3, 4) In fact, each one is likely to be the largest only for a short time after startup. There were at least six or seven additional papers espousing the benefits of 7-10 MTPA trains. (5, 6, 7, 8, 9, 10, 11) Papers by Shell and ConocoPhillips/Bechtel/GE did sound some cautionary notes about the value of such large trains but noted their readiness to build one when the climate is right. (9, 10) A review of the remaining LNG 14 papers reveals very few references to other means of reducing liquefaction costs.

The Egyptian LNG project owned by BG, Petronas, EGPC, EGAS and with GdF in Train 1 adopted a different philosophy. Building on the highly successful Atlantic LNG projects, Egyptian LNG adopted an existing nominal 3.3 MTPA design and standardized it as much as possible. The trains were carefully optimized based on experience from Atlantic LNG with "lessons learned" incorporated wherever possible. The end result for the Egyptian LNG project was a nominal 3.6 MTPA train.

It should be noted however that apart from optimization and incorporation of specific "lessons learned", there are minimal changes to the design. The adoption of essentially a standard product helped establish the Egyptian LNG Project as one of the fastest and most cost-effective LNG projects to date. Refer to Figures 1 & 2 for an industry comparison. Egyptian LNG has the shortest project schedule as well as the lowest owner's cost in this comparison. Although not specifically shown, the Egyptian LNG project maintains one of the lowest EPC costs. In this paper, we explore the value of a standardized approach from the perspective of the owner, the technology licensor and the EPC contractor. The results reveal how multiple smaller trains may provide a better fit than a single large train for many LNG projects.

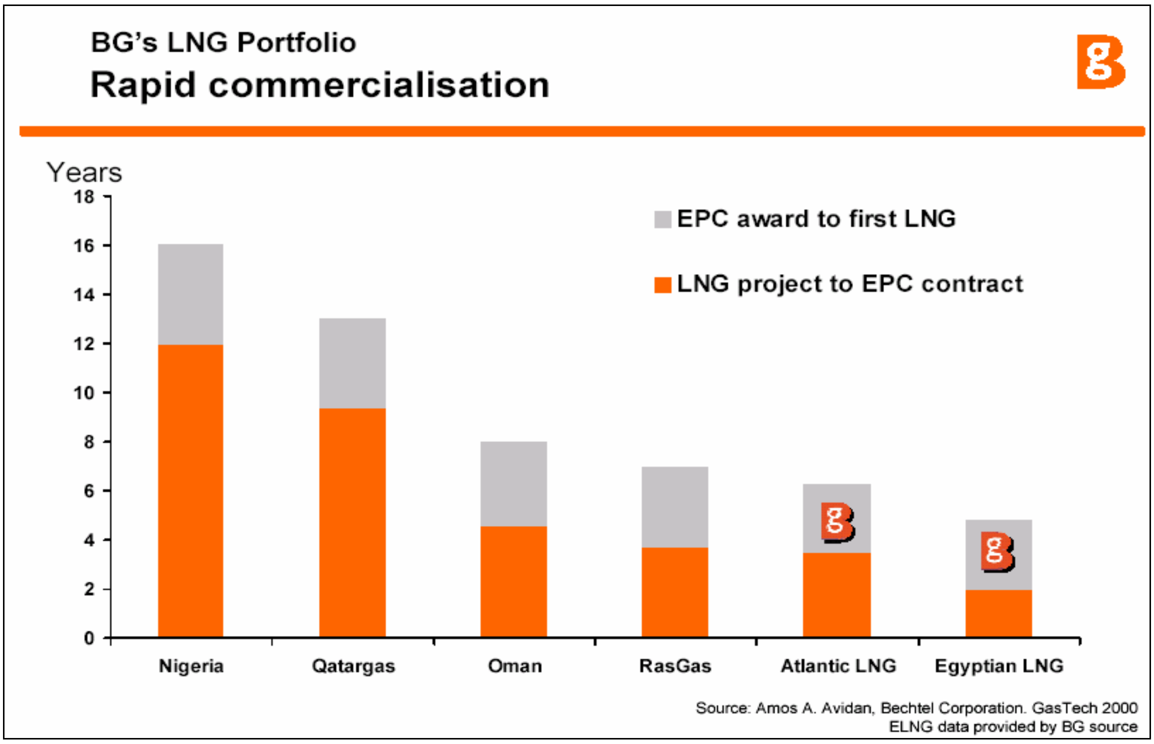

Figure 1: Commercialization Schedule Comparison for Egyptian LNG

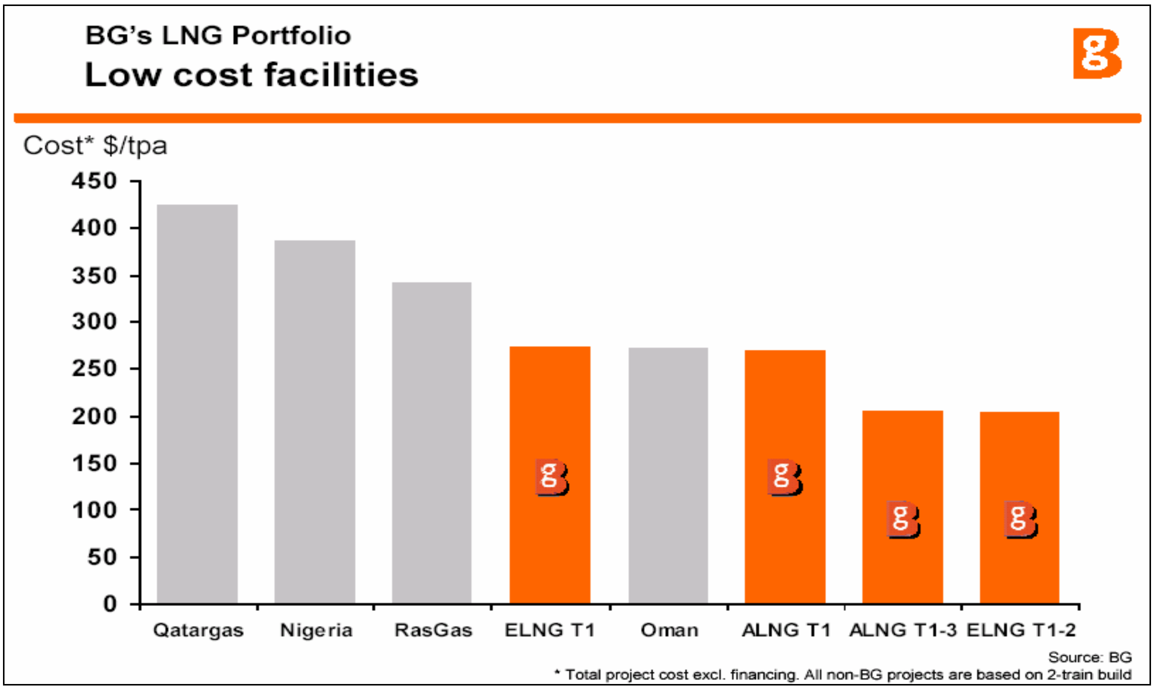

Figure 2: Commercialization (owners) Cost Comparison for Egyptian LNG

2.0 Project Development

Gas market demands, gas reserves and the host country business environment drive LNG projects. Of course, projects must also be economic. This means that projects must be sized and timed correctly for both gas reserves and the market, and must be priced right. The initial size of the overall facility and individual train capacities within the facility are two of the most critical decisions of an LNG project, decisions that must be made in the very early project stages.

Due to large infrastructure requirements for LNG storage, marine facilities, civil works, construction facilities and the like, there are nearly always economies of scale that lead to greater cost effectiveness with increased LNG production. However, it is interesting to note that while LNG train capacity has increased steadily from the inception of the LNG industry, total initial production capacity has increased much more quickly. This can be seen in Figure 3, which shows the increase in train capacity over time alongside initial total production capacity. Whilst train size rose steadily through the 70s and 80s from less than 1 mtpa to over 2 mtpa, initial total plant output rose dramatically from just over 1 mtpa to more than 8 mtpa. Whilst total initial capacity has tailed off, train capacity has continued to increase.

The Algerian GL1Z and GL2Z facilities in the mid 1970's began with six trains around 1.3-1.4 MTPA for a combined production of approximately 8 MTPA. It is interesting to note that these facilities compare favorably in terms of cost with many larger LNG facilities of similar total production. (12)

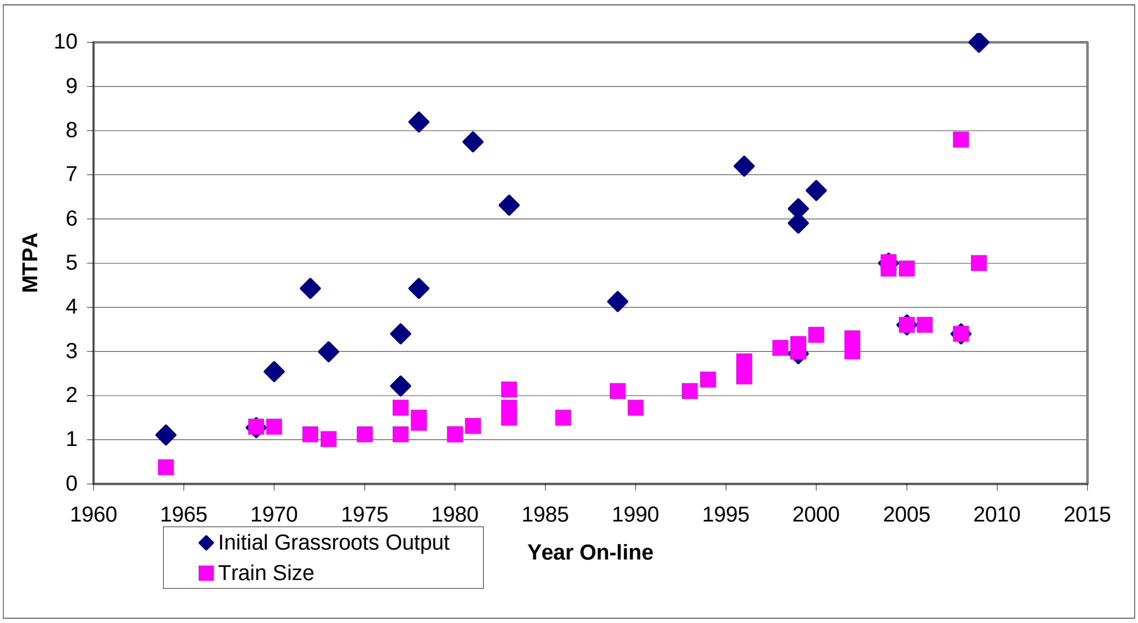

Figure 3: Growth in Initial Production Compared to Train Size

Low capital cost is critical to most LNG projects but simply increasing train size does not necessarily lead to a successful project. In order for a project to proceed successfully, gas reserves, train capacity, market conditions and project costs must all align. Mismatches in any of these elements may result in project delays or may require owners to undertake significantly increased risks. Many LNG projects have been delayed, primarily waiting for markets, while some owners have undertaken significant risks by progressing LNG projects with insufficient gas supplies or without firm LNG sales contracts.

Large LNG projects require substantial gas reserves. A 3.5 MTPA train requires around 4 tcf in proven gas reserves to support a 20-year LNG sales contract and around a 10-13 year tenor on financing. Likewise, a 5 MTPA train requires close to 6 tcf and an 8 MTPA train around 9 tcf. Proven reserve requirements are even greater if the gas field contains significant Natural Gas Liquids (NGL's). There are few large proven gas reservoirs in the world such as Qatar's North Field that can support very large LNG trains. Many other reservoirs are likely to contain large amounts of gas, but proven reserves may be lagging. A high degree of confidence is required for the development of a LNG project and the associated large capital requirements. Furthermore, host governments are often looking for additional reserves to support domestic gas sales before allowing LNG projects to proceed.

Finding and proving the quantity of reserves necessary for large LNG trains may become expensive and time consuming. In locations such as Trinidad and Egypt, several reservoirs supply each LNG train. The high cost of exploration can lead to a "chicken and egg" situation where there is reluctance to spend money to prove reserves until there is a proven outlet for the gas, while at the same time, there are not sufficient reserves to fully underpin to the development of an expansion train or another LNG project.

A similar case can be made for markets, as it is difficult to find outlets for large volumes of LNG entering the market all at once. It may be easier to progressively enter the market with production from multiple smaller trains than to enter all at once with production from a single large train. Early revenue can significantly impact project economics. Multiple smaller trains may provide a better match for markets that have a slow ramp-up over time as opposed to matching production from a single large train. (10) Full project economic models are required to evaluate this properly. Merely considering simple unit cost of capital measures may lead to the wrong answer.

With Egyptian LNG, gas reserves and markets were critical issues from the outset of the project in April 2000. While there were sufficient proven reserves for a 3.6 MTPA or perhaps a 5 MTPA train with the potential for more, all that could be immediately guaranteed was 3.6 MTPA. At that particular time the US and UK gas markets had yet to undergo a remarkable revival. While Spain and France were interested buyers, there was an excess of supply chasing those markets. Therefore, the key to capturing the market was a combination of speed and confidence in delivery. Proving sufficient reserves for a 5 MTPA train would have delayed the project and placed Egyptian LNG behind other projects seeking the same markets. A larger train would also have created difficulty in finding a single buyer, again delaying the entire process.

Given the relatively high marine costs for the Egyptian LNG project at Idku (a 2.5 km jetty and a 1 km breakwater, as well as significant dredging) the economics of a single 3.6 MTPA train were challenging. However, synergies with domestic upstream development and changes to the cost recovery mechanism agreed with the Egyptian government, which made the project feasible provided that construction was cost effective. Given the high fixed-infrastructure costs, a 5 MTPA train did appear economically more attractive. However, the additional production of a second 3.6 MTPA train proved even better. This was especially true when the two 3.6 MTPA trains could be completed within 6 to 12 months of one another. Close coupling the two trains enabled a single integrated project with all the consequent savings in mobilization and execution synergies. In effect, Egyptian LNG chose to build a nominal 7.2 MTPA (over 8 MTPA design rate) LNG facility with half the capacity coming on stream 6 months after the first half. Marine costs were about $200 million and total Train 1 and 2 EPC costs (including all marine costs) were about $170/ton – a favorable comparison to a single large 7.5 MTPA train.

Another factor to consider is non-recourse project financing. Financing for Atlantic LNG Train 1 and Egyptian LNG Train 1 was among the highest required for their respective areas of the world. Successful project financing over the short time periods allowed was a major achievement in both cases.

With the Egyptian government keen to generate additional foreign income and the need to capture an available market, a fast track schedule became imperative. Additionally, since upstream partners made significant pre-investments in pipeline infrastructure, accelerating the project schedule would result in a better return on their investment. It ultimately became clear that a single 3.6 MTPA train followed closely by a second identical train best fitted the needs of the Egyptian LNG project. This approach allowed the project to proceed at an accelerated pace without delays to find more reserves or locate additional buyers. In addition, the combined nominal capacity of 7.2 mtpa for the two trains effectively captured the desired economy of scale.

3.0 Technology

The Egyptian LNG project provides an excellent example where adopting a more standardized approach to LNG plant design and remaining within proven ranges of experience has resulted in a very successful approach that led to a world-class facility.

3.1 Reduced Technology Development Cost and Schedule

While developing ultra-large LNG trains there is often a natural requirement to push the envelope of proven technology. The tendency is for everything to increase in size, including equipment such as driver turbines and/or electric motors, refrigeration compressors, heat exchangers, vessels, pumps, piping, valves, etc. However, much of the equipment used in current LNG train designs is already at the upper range of proven experience. Thus, if any of the items cited fall outside of the proven range of experience, there is an increased need to provide technical due diligence. This requires manpower and time, which translates into engineering expense that reduces the economies of scale and quite often leads to a negative impact on the overall project schedule.

From a development cost and schedule perspective, adopting a more standardized approach provides an attractive alternative. A proven standardized design provides the ability to fast track projects, while adding little associated risk. With the current gas demand, as owners race to capture as much of the market as possible, reduced schedule becomes critically important. As mentioned earlier, only a nominal 3.6 MTPA could be guaranteed based on proven reserves at the outset of the Egyptian LNG project. Others were racing to capture the same market. Given that situation, the technology configuration employed at the highly successful Atlantic LNG facility, multiple trains based around 6 frame 5D gas turbines, was very attractive.

In fact, the Egyptian LNG team carefully considered a literal copy of the Atlantic train design. The feed gas compositions for Atlantic LNG and Egyptian LNG were similar enough such that this approach was certainly feasible. The flexibility of the process technology allowed for a literal copy without redesigning anything and merely re-rating for Egypt process conditions. Apart from the LNG tanks both sites also enable similar foundation designs. However, while a literal copy held some attraction, it was ultimately rejected in favor of an optimized design more suitable for the Egypt conditions. Redesigning and optimizing for the Egyptian LNG feed gas composition and ambient temperature conditions allowed for a LNG production increase to a nominal size of 3.6 MTPA.

3.2 Reduced Equipment Costs

Utilizing equipment within a proven range of experience has multiple advantages. Equipment vendors, contractors, and the technology licensor are all less likely to include excess design margin and/or contingency. There is simply an improved comfort factor with the equipment for all parties. This has the direct advantage of reducing equipment cost while also providing owners with a design closer to the desired capacity. This allows more certainty in contract negotiations, which helps avoid overselling or underselling production. In addition, larger equipment sizes can sometimes result in reduced vendor capabilities. Remaining within well-established and accepted experience ranges allows contractors an increased ability to select multiple equipment bidders, which also aids in driving down equipment cost.

While it is easy to understand relationships between cost and size for individual pieces of equipment, it becomes much more difficult when an entire LNG facility is considered. One must perform a detailed study consisting of multiple options that incorporate the entire LNG train in order to determine the best economy of scale. The equation becomes even more complex for differing feed compositions, product slates and inlet gas pressures. With this in mind, the ConocoPhillips and Bechtel LNG Collaboration Product Development Center (PDC) completed a large train study using a typical LNG feedstock at typical feed pressures for multiple process configurations. The study was intended to assist owners with understanding the available choices within the ConocoPhillips LNG Process, formerly known in the LNG industry as the Phillips Optimized Cascade LNG Process. Some of the results of this study, shown in Figure 4, reveal some interesting points. In general, as would be expected for the range of production studied, the cost per metric ton of production decreases as train size increases. However, one will note that on a total direct cost basis, the cost for 2 – nominal 3.6 MTPA trains is fairly close to that of a single 7.2 MTPA plant.

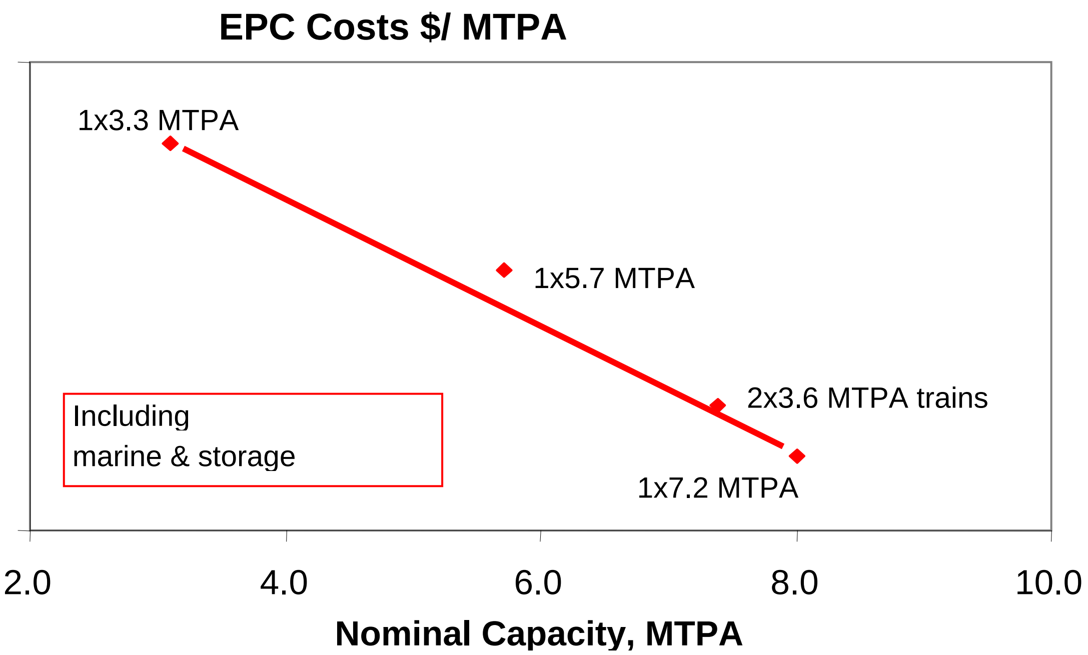

Figure 4: Total Direct Cost Comparison for Large Trains - Courtesy of The ConocoPhillips and Bechtel LNG Collaboration Product Development Center

This trend is confirmed by a comparison of the Egyptian LNG project with recent LNG projects that selected 5.0 MTPA trains. For instance, the SEGAS project at Damietta in Egypt has reported unit EPC costs of $200/tonne for a single 5 MTPA train. (3) Egyptian LNG EPC costs are significantly lower at about $170/tonne. The recent announcement for very large 7.5 MTPA trains in Qatar reports EPC costs of $255/tonne. Whilst the scope of these projects are significantly different, and while there have been significant changes in steel prices and exchange rates over the last few years, this price may not result in a significant reduction from the SEGAS and Egyptian LNG costs.

3.3 Reduced Technical Risk

In addition to reduced financial risks as discussed earlier, there are also reduced technical risks to consider. Adopting a standardized approach has the advantage of insuring that one stays within the proven range of experience for all, or at least most critical equipment. While this reduces technical risk, it also provides the owner team with the ability to better predict actual operation over the life of the project. This in turn aids in the marketing effort by providing the owner with the ability to comfortably demonstrate a consistent LNG supply. Financial lenders are more likely to recognize a lower risk situation. Thus, from a technology as well as commercial perspective, there is simply less risk associated with adopting a standardized approach.

While there is less risk associated with a standardized design for lenders, buyers, and owners, the same is true for the technology licensor and for the EPC contractor. The result is synergistic. For example, contractors will be more willing to accept a lower contingency, which can provide owners with significant savings. Likewise, a proven operational history provides the technology licensor with more comfort with regard to the risk they are willing to accept with performance guarantees.

3.4 Incorporation of Lessons Learned and Optimization Ideas

A standard design does not mean standing still from a technology perspective. The ConocoPhillips and Bechtel Global LNG Collaboration has implemented a formal "lessons learned" process. Lessons from previous projects are considered for each additional project. While these lessons are not necessarily limited to projects with the exact same production and process configuration, they are certainly more applicable if that is the case. It should be noted that while all ConocoPhillips and Bechtel LNG projects to date have all exceeded their performance targets, and came on stream ahead of schedule, results have also improved significantly with each successive project (3,4). This is directly attributable in large part to the "lessons learned" process. The Egyptian LNG team recognized a distinct advantage early in the project in capturing and capitalizing on this experience and knowledge. As a result, the Egyptian LNG project incorporated many lessons learned from the Atlantic LNG experience into the Egyptian LNG design.

ConocoPhillips and Bechtel recognize the value of continuous improvement and jointly maintain a database of lessons learned. The database includes items and improvement ideas that arise throughout all phases of all LNG projects. In fact, an entire "template" design, complete with P&IDs and all lessons learned is continuously maintained. This "template" design was fully utilized for the Egyptian LNG project. Consider that part of the success of Atlantic Trains 2&3 are the result incorporating lessons learned from the Atlantic Train 1 experience. (15) Building on this success, Egyptian LNG has incorporated those same Atlantic Train 1 lessons learned but also added those of Atlantic Trains 2&3. In fact, the Egyptian LNG design now serves as the "template" design for the ConocoPhillips/Bechtel Collaboration.

The Egyptian LNG project team visited with the technology licensor as well as Atlantic LNG personnel on several occasions. The performance of the Atlantic trains was explored extensively, openly discussing any problems experienced during the first few years of operation. Only a few significant items were noted, demonstrating that the original Atlantic LNG design was quite sound. Some of the ideas noted for improvement are included below.

- A gear was added to the propane compressor trains, allowing operation at reduced speed while also allowing improved operation over the full range of ambient temperatures. Since temperature variations are greater in Egypt than Trinidad, this was considered significant.

- The Heavies Removal Column was modified to include a rectification section, allowing for greater NGL recovery.

- The amount of information from the compressor control room to the main control room was increased to include additional items required for smoother operation and improved turbine/compressor optimization.

- Navigational information for the marine jetty was increased. This was considered a particularly important area, since the Idku jetty presents a more challenging marine environment.

- Additional pre-investment was included in the storage and loading area to allow for easier incorporation of a second train. Given a very likely second train in a short time period, the additional ideas were included within the Egypt Train 1 design.

3.5 Reliability and Availability

As LNG train sizes increase, availability and reliability become increasingly important. As train sizes increase, exposure to a single failure is greater. For single train LNG projects this is especially critical, which helped in the decision process for Atlantic LNG Train 1 to adopt a *"two-trains-in-one"* approach. (1) This configuration of the ConocoPhillips LNG Process has historically provided a production efficiency of greater than 96% with an availability of greater than 98.5%. Rigorous RAM analyses of various configurations of the technology utilizing a *"two-trains-in-one"* approach confirm significantly higher reliabilities as compared to configurations that do not adopt the approach.

4.0 Project Execution

4.1 Contract Strategy

Another critical element in any project is contract strategy. Most LNG projects are financed through a combination of equity capital and non-recourse financing. In order to achieve an attractive financeable package, owners require a firm lump-sum turnkey (LSTK) bid from a financially stable and reputable contractor with a reputation for certainty of outcome. This is usually supported by an EPC contract with significant liquidated damages (LDs) provisions.

A small number of global EPC contractors possess the ability to provide credible LSTK bids capable of attracting favorable financing terms. For this reason, most contractors other than Bechtel form consortia of 2 to 4 companies to share the risk of billion dollar plus LSTK LNG contracts. Typically, only 2 to 4 credible global consortia can be formed to bid on these large EPC projects, depending on location and technology.

Owners can achieve a LSTK contract in a variety of ways. In the "traditional" approach the owners first study and select the liquefaction technology, apply their engineering standards, and bid out feasibility studies and the front-end engineering definition (FEED) phase. This step can last a year or more and cost the owners 10 to 30 million dollars. The owners then bid the FEED package - a process that takes several additional months and involves extra costs. The traditional approach is the longest and usually the most expensive in terms of upfront owners costs. In addition, the EPC contractor chosen may not have had an impact on the FEED phase of the process, which is so important to overall project execution and has so much impact on ultimate project quality.

In an attempt to improve on this approach, several owners have used a parallel FEED design competition. In this option, it is not required to choose liquefaction technology up front and bids are only received from those undertaking the FEED competition, which saves bidding time. These owners find that the additional expense of a second parallel FEED may be justified if the end result is a much lower cost with a shorter schedule project, as demonstrated by the Atlantic LNG Train 1 project owners in 1995. The use of such a competition was particularly effective for Atlantic LNG because until that time, there was in effect only one proven liquefaction technology commercially available. The use of a design competition allows the EPC contractor to lead the front-end loading step. Care is required to ensure that value added specifications are used consistently and do not overly impose unneeded or arbitrary restrictions. (17)

A third approach is the "Open Book", integrated project team concept. The owners choose to work with one technology and one EPC partner early in the scoping phase, and progressively negotiate the FEED and the LSTK contract for EPC. This approach is commonly used for expansions of existing trains where there are significant synergies to be gained from working with the initially successful contractor. However, this approach has also been used for an increasing number of recent grassroots projects such as Egyptian LNG, Darwin LNG, and Equatorial Guinea LNG. The benefits are the ability to cut development costs and schedule and achieve certainty of outcome early on. This approach requires more innovative and advanced contracting skills, but when properly used can lead to the lowest price and shortest schedule, with the lowest risk to the owner. The integrated team approach and its advantages over the other two major project execution options are illustrated in Figure 5.

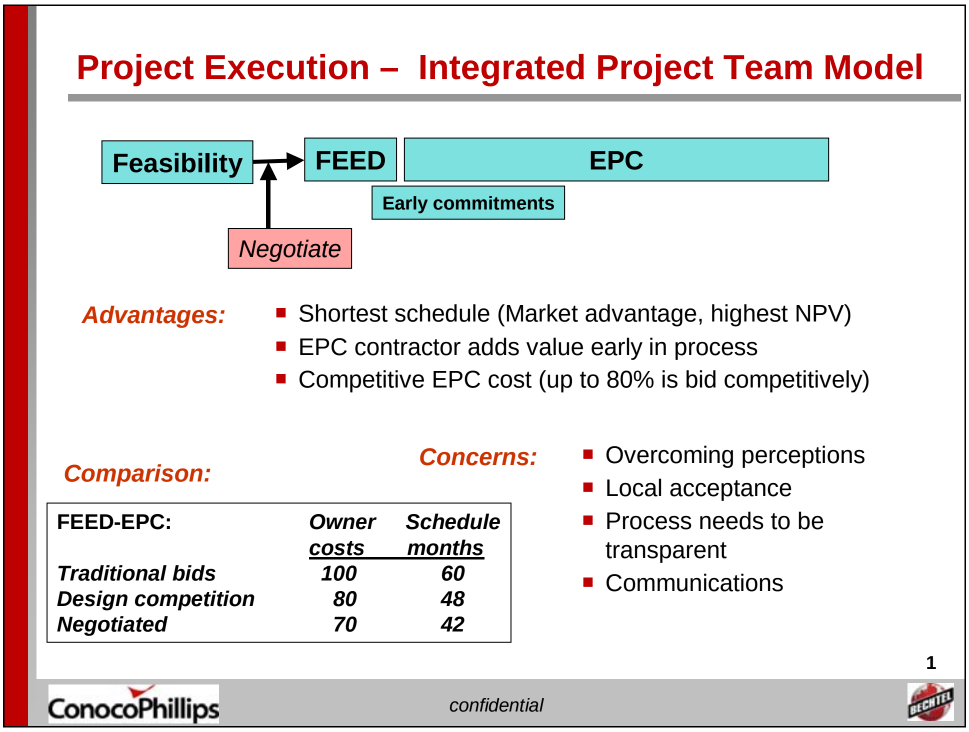

Figure 5: The Integrated Team – Open Book Method to LSTK Price

For Egyptian LNG taking the standardized train approach supported the integrated team contract strategy, reducing schedule further and mitigating much of the cost risks.

4.2 Schedule

The Open Book approach, coupled with the benefits of a standardized approach, can shave from 9 to over 18 months off the overall project schedule as compared to the "traditional" bid-evaluate-negotiate-award cycle and from 6 to over 12 months as compared with the dual FEED approach. This is illustrated in Figure 6.

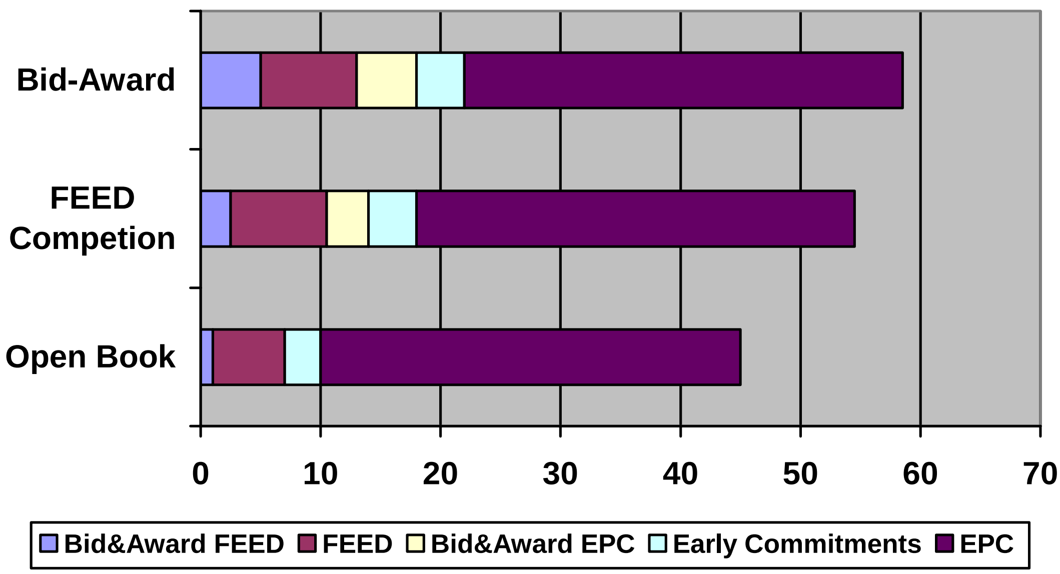

Figure 6: Schedule Comparison for FEED Contracting Strategies

A shortened schedule not only allows owners to capture markets ahead of the competition but also results in significant revenue earlier in the life-cycle analysis, while also reducing owner's costs. This is an important fact for both owners and host countries. Whilst reduction in front-end schedule may not significantly improve project economics, due to the relatively small expenditure as compared to overall project costs, the reduction in the EPC schedule and associated early production can significantly enhance project economics.

Building on the Atlantic LNG project allowed completion of the Egyptian LNG Front End Engineering Design (FEED) in a very short time period. The FEED process began in mid September 2001 and was completed in March 2002 with the delivery of a LSTK price. The engineering part of the FEED was essentially completed in just four months to allow for equipment pricing and estimation of bulks. Because fairly precise numbers were available from the recent Atlantic LNG Projects, the work was completed with a high degree of confidence in a relatively short period of time, without introducing significant risk and contingency.

The timely completion of preliminary engineering allowed for early commitments on storage tank design, compressor designs, as well as an early start on site preparation. These items progressed while the EPC terms and price were finalized. While early commitments may begin in a similar manner under a more competitive EPC approach, the actual award of these commitments and other long lead items must eventually be assigned to an EPC contractor, as has been done on a number of projects. This adds to contract complexity was well as overall risk to the project.

Standardization also allows improvements in EPC schedule. Orders for equipment and bulks may be placed earlier, greater confidence may be provided with preliminary vendor data to allow faster engineering progression, and well-known construction sequences may be optimized based on prior experience. A methodology for this is discussed in more detail later.

Comparing Egyptian LNG with the SEGAS project demonstrates a schedule savings from the Open Book approach. SEGAS was also a fast track project that used an innovative contract strategy compared with other more typical LNG projects that have usually relied on the "traditional" project execution approach. SEGAS based the contract strategy around dual FEEDs using the same liquefaction technology. (3) The following table compares some of the key milestones for the two projects.

Table 1: Schedule Comparison Between the SEGAS and Egyptian LNG Projects

	SEGAS	**Egyptian LNG**	**Difference (months)**
FEED Award	1st Nov 2000	1st Sept 2001	10
Long Lead Commitments	1st Jun 2001	1st May 2002	11
EPC Award	26th Nov 2001	1st Sept 2002	9
First Shipment	January 2005	May 2005	4

Whilst FEED and long lead items on the SEGAS project began approximately 10 to 11 months before the Egyptian LNG project, the first cargo is scheduled only 4 months ahead. This comparison of Egyptian LNG to another fast tract project demonstrates a shorter schedule through utilizing the integrated team, open-book approach.

4.3 Cost

The schedule savings of the Open Book approach are fairly obvious and readily acknowledged. However, the big question with this approach is how owners ensure a competitive price. One of the authors was asked this question by a past director of a major Middle East LNG project. That project used the "traditional" approach to project execution, with a schedule that was two years longer than Egyptian LNG. They received two competitive offers from EPC consortia. In addition to not showing an EPC cost savings, the end result was a missed opportunity to capture markets two years earlier, losing hundreds of millions of dollars in net present value. Considering the small number of qualified contractors that can competently plan and execute billion plus dollar LNG projects, we question whether the traditional approach or a FEED competition really ensures the lowest life-cycle costs or even the lowest EPC costs.

Open Book contracting is a relatively simple and transparent process by which contractual and commercial terms for project execution are mutually agreed upon between owner and contractor during front-end engineering design (FEED). Almost all equipment, materials, and key subcontracts, such as LNG tanks and marine facilities are still priced in competitive quotations by the contractor with full participation by the owner. Bidding of bulk items is also possible, if required. The owner reviews all bids with the EPC contractor as the price is developed. We estimate that about 70 to 80% of the value of the final EPC contract may be competitively bid. Items that are not bid may be readily benchmarked against industry norms and other similar projects. The owners and the contractor mutually agree to contractor overhead and fair profit. To minimize risk this may be agreed upon before committing to the Open Book process. Contingency will be determined based on scope definition and a detailed risk analysis, (with a range set upfront). This process is illustrated in Figure 7.

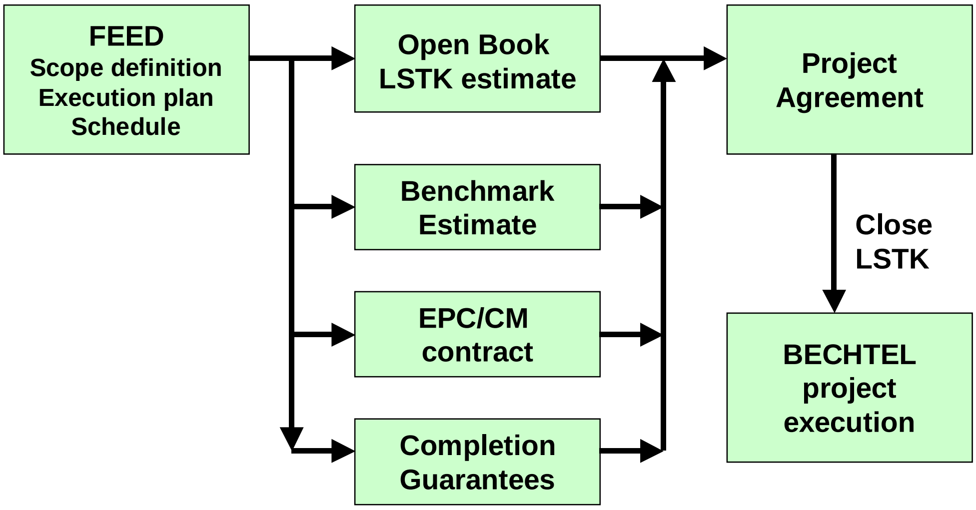

Figure 7: Open Book LSTK Methodology

After final determination of the open book estimate and agreement on the lump sum price, the contractor will close the book and execute the project on a lump sum turn key (LSTK) basis. The contractor will provide appropriate performance and schedule guarantees that will ensure low-cost project financing.

For Egyptian LNG the standardization extended to the Open Book process. The main EPC terms and conditions were replicated with key issues such as liquidated damages (LD's) agreed based on the Atlantic LNG contracts. A similar strategy was adopted with overhead as well as profit and contingency, allowing these areas to be agreed with minimum negotiation. The technical standardization enabled bulk quantities and prices to be readily verified and agreed between the parties. Again it may be seen how adopting a standard product approach minimized execution risk.

4.4 Improving Project Execution using 6-Sigma

Bechtel Corporation has applied 6-Sigma to improving its work processes for the past 3 years. 6-Sigma is a statistically based methodology that allows one to solve business problems and hence improve results. The key to 6-sigma is identifying, measuring, and eliminating defects and errors. The use of 6-Sigma has been shown to:

- Improve customer satisfaction
- Reduce defects in the delivery of goods and services
- Reduce cycle times
- Improve profit margins
- Increase pride and satisfaction for project people

Since the activities occurring during the process dictate the final outcome, 6-Sigma focuses on the process rather than the final outcome. It achieves results through Process Improvement Projects (PIP's), which utilize the Measure, Analyze, Improve, and Control phases:

- *Measure* benchmarks the process and helps select the critical-to-quality characteristic that is to be made defect-free.
- *Analyze* reviews when and where defects occur.
- *Improve* screens potential causes of defects, discovers variable relationships among those causes and establishes operating tolerances of the solutions.
- *Control* sustains improvements and includes validation of the metrics and implementation of process controls.

Sigma is the value of the process standard deviation for a given characteristic. A process with more variation around a mean has a larger standard deviation than a process with less variation relative to the same mean. The term 6-Sigma refers to six standard deviations between the mean (where the data is centered) and the most precise specification (customer requirement). In manufacturing a 6-Sigma level relates to a 99.9997% customer satisfaction and has become the term used for processes and systems used to approach this level of satisfaction.

Figure 8 shows how this process was applied to the Egyptian LNG project. The process included:

- Utilization of 6-Sigma tools to identify strategic gaps and develop process maps to improve work processes.
- Projects integrated Suppliers/Subcontractors/Engineering/Procurement and Construction in "Cost of Poor Quality" (COPQ) teams.
- Improved work process integration with sub-suppliers
- Improved communication between all groups early on to understand expectations and deliverables.

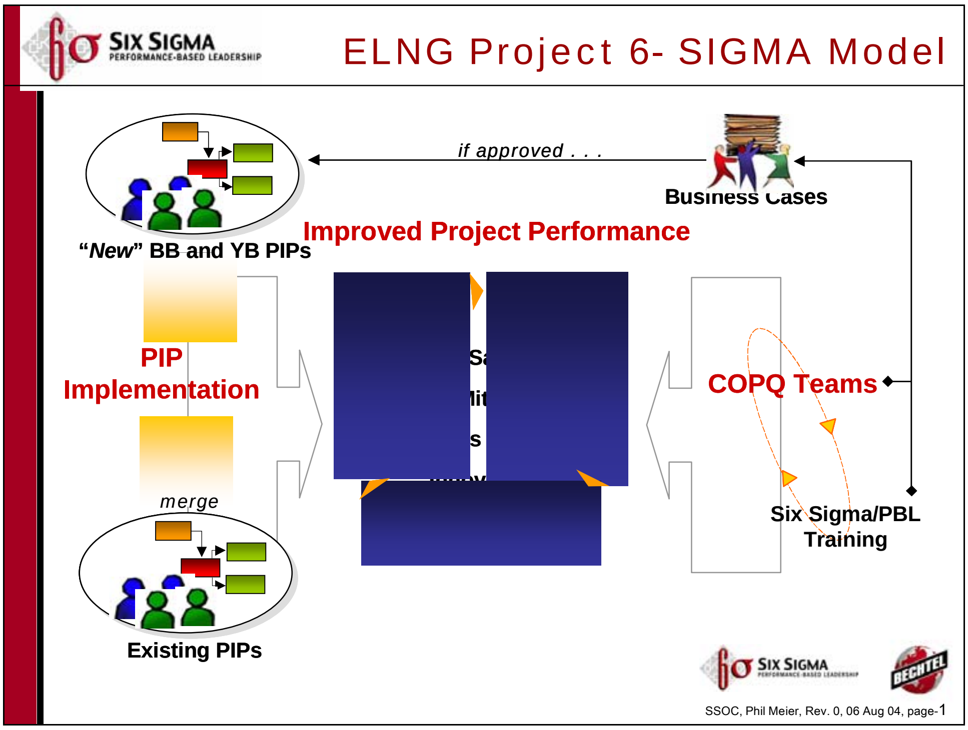

Figure 8: Bechtel's ELNG EPC project's Sigma Model

A critical factor in implementing 6-Sigma activities is reliable data. In order to identify and track improvements in the work process, it is important to know exactly what is being achieved presently by the process and then to monitor what happens as changes are implemented. Data must be gathered from previous projects and results of new processes must be compared with earlier ones.

Adoption of the Six-Sigma practices on Egyptian LNG enabled improvements in the following areas:

- Faster delivery of major equipment
- Increased rate of pipe spool fabrication
- Shorter engineering schedules
- Replicated construction execution methods

These methods may of course be applied to future trains and other future projects to increase the value of the standardized approach.

One of the major advantages of the use of the 6-Sigma process for the Egyptian LNG project was the fact that the two trains were designed using a standard template and were constructed with only about 6 month interval between them. This allowed maximal synergies and savings in engineering and implementation of the results of 6-Sigma teams from Train 1 on Train 2, and the flexibility of shifting procurement and construction resources between the two trains to optimize overall schedule, cost, and use of resources. The application of 6-sigma has resulted in lower costs, faster schedules and reduced risk.

6.0 Conclusions

We believe that all major popular LNG train sizes (3.5, 5, and 7.5 MTPA) are viable and likely to be utilized by LNG project developers over the coming decade. Smaller train sizes, around 3.0 to 4.0 MTPA, may provide a better fit for gas reserve availability and market requirements as well as enable faster project development. Furthermore, as Egyptian LNG demonstrates, multiple smaller trains may be developed more cost effectively than larger single trains. This is especially true when two such trains are designed using a standard template and constructed in close proximity. Through innovative contracting strategies and rigorous value engineering of all aspects of the design and construction of a standard product, highly competitive costs may be achieved without the greater technical and commercial challenges of larger LNG trains. The use of 6-Sigma has shown significant value in supporting the standardized design approach, while the open-book negotiated project execution approach has complemented these two methodologies. The combined result is a world-class LNG project in Egypt with one of the shortest implementation schedules and lowest capital, owner, and projected life-cycle costs of any other contemporaneous LNG project.

References

1. Jamieson, Johnson, Redding, - “Targeting and Achieving Lower Cost Liquefaction Plants”, LNG 12 May 1998
2. Diocee, Hunter, Avidan, Eaton, - “Atlantic LNG Train 4- The Worlds Largest LNG Train”, LNG 14 March 2004
3. Fernandez, Villanueva, Mayer, Hill, Durr, - “Egypt’s Premier LNG Project Establishes New Industry Benchmarks”, LNG 14 March 2004
4. Daily News, LNG 14 March 2004
5. Paradowski, Bamba, Bladanet, - “Propane Pre-cooing Cycles for Increased LNG Train Capacity”, LNG 14 March 2004
6. Sawchuk, Jones, Durr, Davis, - “BP’s Big Green Train: Benchmarking Next Generation LNG Plant Designs”, LNG 14 March 2004
7. Roberts, Liu, Bronfenbrenner, Petrowski – “Reducing LNG Capital Cost in Todays Competitive Environment”, LNG 14 March 2004
8. Thompson, Adams, Hammadi, Kabbi, Sibal – “Qatargas II – Full Supply Chain Overview”, LNG 14 March 2004
9. Buoncristiano, Camatti, Salvadori, Avidan, Martinez, - “New Generation of LNG Plants Based on Innovative Liquefaction Train Configurations”, LNG 14 March 2004
10. Pek, van Driel, de Jong, Klein Nagelvoort, – “Large Capacity LNG Plant Development”, LNG 14 March 2004
11. Metais, Garcel, Bladier, - “Large Capacity LNG Trains”, LNG 14 March 2004
12. DiNapoli, Yost, “LNG Plant Costs: Present and Future Trends” LNG 12 May 1998
13. Qualls, Hunter, “A Focus on Balance – A Novel Approach Taking the Phillips Optimized Cascade LNG Process Into the Future”, AIChE 2003 Spring National Meeting
14. Avidan, Varnell, Martinez, “Natural Gas Liquefaction Process Designers Look for Larger, More Efficient Liquefaction Designs”, Oil & Gas Journal, August 2003
15. Richardson, Hunter, Diocee, and Fisher, J., “Passing the Baton Cleanly”, GASTECH 2000
16. Hunter and Andress, “Trinidad LNG – The Second Wave”, GASTECH 2000
17. Durr, Hill, Shah, - “LNG Project Design Competition – A Contractors Viewpoint”, LNG 14 March 2004