TEACHING AN OLD DOG NEW TRICKS:
The conversion of the LNG peak shaving plant at the Isle of Grain, UK, into an import terminal

APPRENDRE A UN SINGE A FAIRE DES GRIMACES :
La transformation en terminal d’importation de la centrale de pointe de GNL située a Isle of Grain, Royaume-Uni

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INTRODUCTION

The Transco LNG Storage business has five peak shaving facilities strategically located across the UK on the gas transmission network. It provides services that enable shippers of natural gas to meet peak gas requirements and transmission support to Transco, the owner, operator and developer of the majority of the UK’s gas transportation system.

Advantica provides advanced technology and systems solutions for high performance energy and utility companies worldwide. Advantica's solutions have been valuable - particularly to its largest customer, Transco - and to gas, oil, water and electricity clients in over 50 countries, improving their financial performance whilst maintaining safe and reliable operations.

The UK is undergoing a rapid change in its gas supply and the dynamics of the UK gas market will change considerably over the next decade as demand for natural gas increases and as indigenous production declines. The UK will no longer be self sufficient in natural gas and demand will increasingly be met by importing gas via interconnecting pipelines with Norway and Belgium, and through LNG: the latest predictions show that the UK will be importing 40% of its gas by 2010, increasing to 90% by 2020.

The UK currently does not have import facilities for LNG shipments – the world’s first LNG terminal at Canvey Island, UK, was closed and decommissioned in 1994. The presence of an LNG import terminal in the UK would enhance the diversity of supply of gas into the UK, reducing the reliance on pipeline gas from interconnectors from Europe.

The Isle of Grain peak shaving plant, commissioned in 1981, has 200,000m³ of storage in four double containment tanks, and the send out capacity is comparable in scale to many of the world's import terminals. During the 1980’s, British Gas (the predecessor parent company of Transco LNG), purchased the land surrounding the peak shaving plant and prepared plans to build a greenfield LNG import terminal; this was not progressed due to the deregulation of the UK market and further gas discoveries in the North Sea resulting in poor project economics.

The Isle of Grain is ideally placed for LNG importation, being a remote location but within 50km of London, with a natural deep water berth and existing connection into the UK’s gas transportation system. The present project, which uses the marine element only of the greenfield plans, was initiated in December 2000, as a response to the declining gas supply in the UK, and involves the conversion and extension of the existing peak shaving equipment. The philosophy for the design is to re-use, where possible, existing equipment thus minimising the cost of the project and the lead time, whilst ensuring the infrastructure remains viable for the next 25 years.

The design concept is to connect the existing LNG plant to a new jetty, via an above ground unloading line, convert the existing LNG storage tanks from peak shave duty to accept LNG from ships at far higher flows, install new more efficient vapourisation equipment and larger boil off gas compression to dispose of the flash gas accompanying the ship offloading. A major challenge of the project is the distance of the existing plant to the marine facilities – not only was there an issue to consider concerning the handling of flash gas during ship unloading but also a need to minimise risks and put in place mitigation strategies for the pipeline and road crossings.
The success of the project is influenced by many factors including system design and life extension, operational strategy, equipment reliability and supply contracts, and a key consideration is ensuring that the facility will deliver the required business performance once in operation.

This paper covers the challenges in converting the Transco LNG Storage peak shaving plant at the Isle of Grain, near London, into an LNG import terminal.

1. COMMERCIAL RISK

Risk can be considered to be the combination of the probability of an event happening and its consequence, and the examination of factors that influence operations and business performance early in the decision making process is crucial. It is at this stage that optimal design and planning will have most impact and will help to minimise costs of future operation and minimise risk to commercial performance.

A complex set of relationships exist between:

- Availability / reliability of import terminal equipment
- Storage capacity available
- Shipping (ship size, ship delays)
- Export rate from terminal

These factors have all been considered and decisions have had to be made regarding life extension of existing elements of peak shaving equipment versus new equipment. One major area has been the philosophy for modifying and revalidating the existing LNG storage tanks.

To better quantify the commercial risk, a number of studies have been undertaken including:

- The application of advanced availability modelling techniques to model the performance of different design options for the Isle of Grain conversion.
- Estimating gas export shortfalls based on equipment failures and shipping delays, to provide a recommendation on the gas export rates achievable for various terminal configurations.
- The trade off between storage, shipping and export rates to examine capacity constraints on the existing LNG tankage with recommendations on whether and to what size additional storage volumes are required for different scenarios.

2. AVAILABILITY MODELLING

2.1 Additional equipment

Decisions had to be made during the design phase of the import terminal on a number of capital cost items in terms of existing versus new equipment and the amount of redundancy. For example, the Isle of Grain peak shaving plant has direct fired convection vaporisers (which are not efficient for base load operation) but a decision had to be made on the regasification strategy for the import terminal in terms of the number, type and capacity of new vaporisers and whether to retain any of the existing vaporisers as back up. The choices made during the design process have a primary influence on the ability of the facility to meet future supply contracts and there is a need to ‘optimise’ the design in order to deliver the best life cycle solution. The balance between capital expenditure, future supply contracts and operating expenditure, however, is complex.

Advantica has developed a computer package, OPTAGON, that uses a Monte Carlo approach to predict the supply capability of oil and gas production and storage facilities. This sophisticated package uses a genetic algorithm for identifying the optimal design option, maximising the return on investment and allowing the full spectrum of business risk to be understood. The comprehensive model developed for the Isle of Grain import terminal covers the entire operation of the terminal, including shipping interactions. Failure and repair data have been taken from operational experience at the Isle of Grain peak shaving plant and other LNG terminals, and from collaborative industry databases.
The availability modelling has allowed bottlenecks in the terminal design to be identified, and enabled the potential production benefits of additional equipment to be compared against the cost of providing this equipment for a range of scenarios. As an example, in the case of no additional storage capacity being available, a design of import terminal plant that was predicted to achieve 99.9+% availability for a particular export scenario was predicted to fall to an unacceptable availability of 91.4% when the export rate was increased by 80%. Analysis, however, of the location of pinch points in terminal equipment at the higher export rate indicated that the primary contributors to increased availability were the addition of 1 new submerged combustion vaporiser and 1 new external tank pump. By incorporating an extra vaporiser and an extra external tank pump, the original terminal design for the initial scenario, which represented a possible export rate at the start of import terminal operations, could achieve 99.5% availability at the 80% higher export rate. This is demonstrated in Figure 1.

Figure 1: Elimination of terminal pinch points by identifying additional equipment

2.2 Storage volume and shipping implications

There must be sufficient storage at an import terminal to:

- Receive the whole of a cargo without unnecessarily holding up the vessel.
- Retain sufficient quantity of LNG, between ship deliveries, so not to unnecessarily impact on the downstream market.
- Avoid warming up the storage tanks.

The trade off between availability, storage capacity, shipping and regasification rate is complex. Figure 2 shows a graph of how the normal working volume of LNG in storage can vary with time, for 138,000m³ LNG ship cargoes (assumed to be unloaded in 12 hours) for a particular export scenario. As the send out rate is increased, for the fixed storage capacity, flexibility of operations diminishes. For example, more cargo deliveries are required per year with greater utilisation of the marine facilities and increased scope for shipping delays, either because of terminal unavailability disrupting unloading or the queuing of ships.
By investigating different scenarios, and combining with availability modelling, the risk in meeting different export rates was assessed for the existing storage capacity at the Isle of Grain. A study has also been made of the status of fill of the tanks and the impact on shipping.

Availability modelling has also considered the quantity of LNG in storage because under or overfilling affects the performance of the facility. Figure 3 shows, for four (increasing) export rate scenarios, how the quantity of LNG varies in storage. None of the export rate scenarios result in the storage tanks becoming empty for a significant time span over the duration of one year. However, as export rate increases, the larger number of LNG deliveries required has the consequence that the amount of time that the tanks are full increases and, therefore, a greater risk exists of impacting on operational and business performance.

This type of analysis has also be used to aid with the timing of investment in a new fifth tank; if installed too early before the market is developed, the payback would be poor, against loss of revenues and facility flexibility if the decision is delayed.
3. MODIFICATION OF EXISTING LNG STORAGE TANKS FROM PEAK SHAVE TO IMPORT TERMINAL APPLICATION

3.1 Fill rate

The current peak shave storage tanks are designed to be filled at a rate of 900m$^3$ of LNG per day - this fill rate needs to increase to 12,000m$^3$ per hour upon conversion to import duty, to ensure that a 138,000m$^3$ ship is capable of being unloaded within 12 hours. This step change in fill rates requires that significant adjustments are made to the connections to the existing tanks as well as the instrumentation and safety systems. Furthermore, the modifications to the tanks, two of which were commissioned in 1979 and the other two in 1981, are to current standards which, consequently, has significantly impacted on the design. Figure 4 shows an ariel view of the existing storage tanks.

The modifications to the tanks are the provision of new 24” fill and boil off gas lines (compared to the 3” fill and 12” boil off lines currently fitted), an increase in the amount of available process pressure relief (to handle the fill case) and the provision of three independent level measurement systems. Of particular concern was appropriate overfill protection at the new fill rates and the level of fire protection required on the tank roof.

Figure 4: Ariel view of the existing Isle of Grain LNG storage tanks

3.2 Strategy

It is not technically feasible to modify the tanks whilst in service, and each of the tanks will have to be fully decommissioned and warmed up. This is within the initial design parameters of the LNG storage tanks which have an allowance for 6 warm / cold cycles.

During the tanks modification, the Isle of Grain remains a peak shaving site and, consequently, to maintain security of transmission supplies, two tanks only can be decommissioned at any time. Furthermore, hydrotesting of the tanks after modification is to be avoided due to the complexity and cost involved. No modifications to the tank internals, which would impact upon the integrity of the primary containment vessel, were to be undertaken that would necessitate a further hydrotest of the facilities.
The objective and challenge is to take two of the storage tanks out of commission during 2003 for modification but to have them returned to service as peak shave storage tanks for the 2003/2004 winter. The remaining two tanks are then to be decommissioned and modified during 2004, to allow base load operation to commence in January 2005.

Each of the tanks will be fitted with new fill and boil off lines, new pressure relief systems and new level, temperature, and pressure instrumentation appropriate to importation duty, and while out of service the tanks will be inspected and revalidated for a further 25 years of design life.

Due to the level of uncertainty in the scope of work within the tank modifications, it was decided to remove the work from the fixed price lump sum contract for the conversion of the rest of the terminal facilities to importation duty. Instead a contract was awarded, on a reimbursable basis, to one of the original tank manufacturers. Operational, engineering and health and safety input was provided on a day to day basis, by Transco LNG staff based at the contractors office during the design phase of the project.

3.3 Method

The decommissioning of each tank will follow the following basic steps; pump out, warm up, purge to nitrogen, purge to air, isolation, initial tank entry, inspection and construction, de-isolation, purge to nitrogen, purge to gas, and cooldown.

In order to meet the timescales of the project, a number of methods of reducing the time frame for tank modifications were examined. Two areas of large savings were examined in detail, namely reducing the warm up times of the tank by supplying additional heat input, and reducing the boil off times by insertion of a temporary pump to reduce the level of LNG following pump out to a minimum (heel removal). It was estimated that the heel of the tank would take upto six months to evaporate, thus jeopardising the programme.

For the purposes of tank revalidation, it was desirable for the tanks to warm up at a rate of less than 4°C per hour. To ensure that this was the case, it was agreed to allow the tanks to warm up naturally with no external heat addition.

Decommissioning of the first tank was initiated in December 2002, with the tank level reduced to 380mm via the in-tank pumps. The temporary pump was inserted into the tank in January 2003, where the level was reduced to below 35mm. It was envisaged that the removal of the heal saved one month per 100mm of heel removed, thus saving three and half months from the programme for each tank. This procedure was completed within two weeks with no technical or health and safety issues.

It is expected to take approximately 7 months from beginning the tank pump out to recommissioning of each tank, with 16 weeks of construction within the programme.

4. KEY DESIGN ELEMENTS

4.1 Unloading facilities

A complete new jetty structure, designed to accept ships up to 205,000m³, is to be built in the Medway Estuary. LNG will be unloaded from the ship via three unloading arms and vapour returned from the boil-off compressors through a fourth vapour return arm. The LNG from the arms is to be directed through two parallel lines, a main 36” line and a second 14” recirculation line, 4.5km to the LNG storage tank area at 12,000m³ per hour.

4.2 Handling of flash gas

The unloading of the LNG carrier and the length of the unloading line results in a significant increase in boil off production. The optimisation of the plant compression was significantly impacted by the choice of unloading line configuration which ranged from two 24” lines to a single 42” line. The final modelling of the unloading system resulted in the need for a peak requirement in excess of 70 tonnes per hour with a base load of 6 tonnes per hour. The boil off configuration considered the use of a re-condenser, maximum use of the local 2 bar and 38 bar gas mains and compressor type. The re-condenser was inappropriate due to the warm temperature of the LNG after circulation through the
unloading system to the jetty. The selection of compressor type between reciprocating and centrifugal was assessed and parameters set to allow either solution to be offered by the EPC contractors.

During normal operation two new (cold suction) 2barg boil-off compressors will compress vapour into the local distribution system. Whilst, during unloading operation up to four (cold suction) 38barg compressors are required to dispose of the additional boil-off gas.

A vapour return line will also be installed to let down vapour from the compressors’ discharge to the ship at 7barg during unloading.

4.3 LNG send out system

LNG send out liquid from the storage tanks is carried out in a two stage process from the in-tank and ex-tank pumps. These pumps form part of the original equipment from the LNG site and were subject to extensive modelling to ensure adequate availability was achieved. These pumps will be refurbished during the construction phase.

LNG is presently gasified in six direct fired convective heating vaporisers. These units are adequate for peak shave duty due to the low number of hours of operation per year, however they are far too inefficient for base load operation. They are to be replaced by submerged combustion vaporisers, each with the ability to accept hot water circulation as part of a later combined heat and power development.

5. QUANTITATIVE RISK ASSESSMENT

Advantica has undertaken a quantitative risk analysis for the Isle of Grain import terminal. The risk analysis was produced by identifying a representative set of hazardous scenarios that might result in a release in the jetty area, from the jetty-to-site pipeline or on the Isle of Grain site following its conversion to an LNG import terminal. In consultation with Transco LNG, nine release scenarios were selected for analysis:

**JETTY**
- Large LNG spill at jetty head (PERC valves fail)
- Small LNG spill at jetty head (PERC valves operate)
- Explosion at jetty head

**LNG PIPELINE FROM JETTY TO SITE**
- Rupture of the jetty-to-site line during transfer operations
- Leak in jetty-to-site line during transfer operations
- Leak in jetty-to-site line during cool down period

**LNG SITE**
- Release from thermal relief valve
- Rupture of LNG export pipeline to vaporisers
- Rupture of natural gas pipeline from boil off compressors

The likely frequency of each release scenario was assessed as were the consequences. By combining the frequency and consequences of releases, assessments were made of the risks to individuals at selected locations, and also to society in general, with consideration given to ways in which each scenario could occur. Initially, a preliminary consequence analysis was undertaken using input parameters that erred on the side of caution such that, in cases of doubt, assumptions were made that led to more severe consequences - the advantage of this ‘conservative’ approach was that the scenarios that had the potential to cause severe consequences were identified. As an example, in a worst case screening, it is reasonable to assume that a failure of the LNG transfer pipeline from the jetty to the Isle of Grain terminal occurs where the pipeline is closest to the centers of population and that the wind is directed towards that population.
In cases where a potential to cause a high number of fatalities (more than two) was identified, consequence calculations were performed for a range of possible realisations of the scenario to produce a more detailed and accurate assessment of the scenario. For example, in the case of failure of the transfer pipeline, failure is equally likely to occur anywhere on the pipeline for a range of wind speeds and wind directions allowing a probabilistic picture of a range of possible outcomes to be constructed as a cumulative frequency-consequence, or f-N, curve. Figure 5 shows the f-N curve for pipeline failure of the LNG transfer line and shows the frequency, f, with which a number N or more fatalities are predicted to occur plotted against N.

![Figure 5: f-N curve for failure of jetty-to-site pipeline during transfer of LNG](image)

The quantitative risk analysis has demonstrated that the risks from the scenarios analysed are below the level which would be deemed unacceptable when measured against the risk frameworks developed as part of the on-going operation of the existing process plant.

6. CONCLUSIONS

The combination of detailed modelling and front end engineering design has meant that the Isle of Grain conversion from a peak shaving plant into an import terminal has been able to demonstrate the following:

- The design modifications have been optimised, with unnecessary capital expenditure being removed from the design.
- The reliability and throughput of the site has been proven to a high degree of certainty to meet the commercial requirements.
- The re-use of existing equipment will result in the rapid availability of the plant at a far lower cost than a greenfield project.
- The quantitative risk analysis has demonstrated that the risks from the scenarios analysed are below the level which would be deemed unacceptable when measured against the risk frameworks developed as part of the on-going operation of the existing process plant.