Bill Howe, Geoff Skinner and Tony Maunder, Gasconsult Ltd, UK, show how new methane expander liquefaction technology can improve floating LNG project returns.

EXPANDING RETURNS

Floating LNG (FLNG) schemes are increasingly being considered for gas monetisation. Given on-board space constraints, remote locations and personnel safety in the event of fire or explosion, special design considerations are applied to FLNG projects. The exploitation of smaller size offshore reserves with reduced economies of scale also demands innovative design to ensure commercial viability.

Safety and process technology issues

LNG producers typically strive to enhance project returns through higher plant capacities and co-product recovery. Complex liquid refrigerant configurations have been deployed to achieve this objective for onshore base load facilities. Post Piper Alpha and more recently the Deepwater Horizon incidents, good offshore practice indicates a need to minimise staffing levels and associated helicopter transfers. Also, following the 2004 Skikda incident, a marked preference has developed amongst some operators for elimination of liquid hydrocarbon refrigerants on FLNG plants. A level of support has thus developed for nitrogen expander processes for FLNG application, despite their low cycle efficiency.

There are compelling arguments for pursuing high liquefaction efficiency. LNG plant design tends to centre on the selection of a specific gas turbine driver and building around this an economically matched configuration of the other process equipment. Once the turbine is selected, the power available for driving the liquefaction cycle is largely fixed. Higher efficiency liquefaction cycles provide higher LNG production from the selected gas turbine driver; enhancing project Net Present Value (NPV) and Internal Rate of Return (IRR); and also reducing associated CO_2 emissions.

Table 1. BP design basis

	PGT25+G4 driver 27.7 MW output
Feed gas composition mol%	C_1 88.5%; C_2 10.3%; C_3+ <0.1%; N_2 1.1%
Gas pressure at liquefaction inlet	80 bar
Sea water temperature	23°C
Process streams cooled to	31°C

Table 2. Capex and Opex parameters

5 x train FLNG - PGT25+G4	ZR-LNG™	SMR	Dual N_2
Field development (US$ million)	1500	1500	1500
Hull + topsides (US$ million)	2390	2390	2390
Base Capex (US$ million)	3890	3890	3890
Nominal (kWh/t)	329	384	439
Output (tpy from 5 x PGT25+G4)	3 906 000	3 348 000	2 930 000
Field life (years)	9	10	12
Online availability (days)	345	345	345

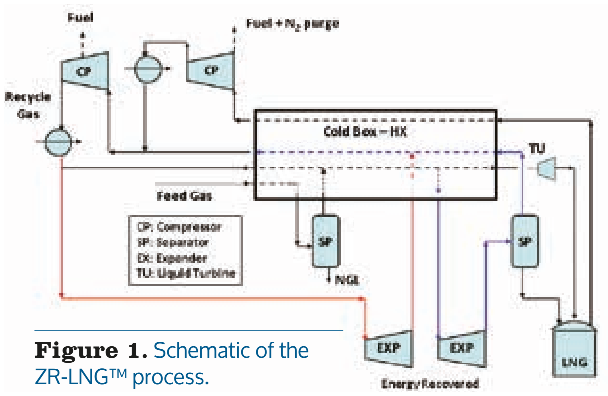

Figure 1. Schematic of the ZR-LNG™ process.

Indeed, liquefaction efficiency is the major driver impacting project returns and is particularly relevant on FLNG schemes where deck space constraints limit the ability to increase available power by process nuances such as waste heat recovery or combustion air and/or feed gas pre-cooling.

Technology

The need to reduce the power demand for an expander-based process while preserving the safety and simplicity of the nitrogen cycle led to the development of the Gasconsult ZR-LNG™ process. ZR-LNG™ liquefaction technology, based on a high efficiency dual methane expander refrigeration configuration, provides a step change improvement in economics for single train liquefaction capacities up to 2 million tpy of LNG. The process uses the feed natural gas as the refrigerant medium. This ensures security and simplicity in respect of refrigerant supply and avoids the use of heavy liquid hydrocarbons. Avoiding an external refrigerant inventory eliminates associated storage, production and transfer systems; reducing cost, complexity and footprint. These factors make ZR-LNG™ particularly relevant for FLNG applications where its high efficiency and the freed up deck space can be utilised to maximise LNG output.

Process scheme

In the ZR-LNG™ process a net drive shaft power of close to 300 kWh/t of LNG with 20°C 'cooled to' temperature is achieved, depending on the feedstock composition, pressure and ambient conditions. This low power demand is achieved without the complexity and cost arising from feed gas pre-cooling and is only marginally inferior to complex onshore base load schemes. A schematic of the ZR-LNG™ process is shown in Figure 1.

Liquefaction is achieved through the use of two expander circuits indicated in red and blue. The low temperature blue circuit expander performs a partial direct liquefaction of its feed. Typically, 35% of the compression power required to operate the process is supplied by the gas expanders. A further reduction in power demand is effected by an expander-turbine providing significant chilling on the LNG run down to storage.

The technology is simple; a 1 million tpy train comprises only two compressor packages plus eight major equipment items. The cold box can comprise as few as three passages (or four when pre-condensation of natural gas liquids is necessary); and all passages in the heat exchange cores have vapour phase feeds. The focus on simplicity and elimination of refrigerant preparation/storage equipment achieves a significant reduction in capital cost and also, importantly, frees up deck space on FLNG facilities. This deck space may be utilised to house productive liquefaction equipment, thereby enhancing project returns.

Several factors contribute to ZR-LNG™'s lower power requirement. The main factor is the higher molar specific heat and lower molar compression power requirement with methane. Other factors include the specifics of the patented process configuration and that partial liquefaction of the feed gas occurs in the liquefying gas expander, converting latent heat directly into mechanical work.

FLNG case study

BP recently conducted an internal study on inherently safer FLNG processes, using individual nitrogen cycle modules based on PGT25+G4 gas turbines, with the intention of eliminating fire and blast risk from the liquefaction section of the topsides. As part of this work, BP invited Gasconsult to develop a mass balance for a ZR-LNG™ module for comparison.

BP found that, compared to processes based on mixed refrigerant, ZR-LNG™ had the advantage of eliminating LPG refrigerant components as well as their processing and storage. Compared to processes based on nitrogen, ZR-LNG™ has favourable specific power but may require greater separation gaps for risk management due to the presence of hydrocarbon leak sources in the congested areas (though this is offset by eliminating the space needed for nitrogen manufacture and storage).

Gasconsult used the mass balance prepared for the BP study to generate a financial comparison of ZR-LNG™, dual nitrogen and single mixed refrigerant (SMR) processes, all based on a 5 train plant.

Design basis

The design basis provided by BP for the case study is shown in Table 1.

Gasconsult has evaluated the impact of liquefaction process selection by constructing a financial model for a 2 trillion ft^3

integrated stranded gas field development. This assumes a project financed venture based on the following parameters:

- Debt-equity ratio of 70:30.
- Loan interest rate – 8%.
- Discount rate – 10%.
- Loan repayment period – 7 years.
- Depreciation rate – 5%.
- Tax rate – 30%.
- Gas sales price – US$ 10/million Btu.
- Shipping cost to market – US$ 2/million Btu.
- Interest during construction capitalised.
- O&M costs – US$ 1/million Btu

The relative liquefaction efficiencies and other data in Table 2 have been sourced from literature searches supplemented by internal Gasconsult analysis and simulations.

Capital costs for the liquefaction trains have been assumed equal for all schemes to provide a level playing field; and also reflecting that the liquefaction schemes are only a relatively small percentage of the overall scheme cost.

Based on the above, project NPVs were calculated for a 2 trillion ft^3 field. For evaluation purposes the calculations assume exhaustion of the gas reserve on a constant output basis throughout its life, probably an unlikely occurrence unless later phase inlet compression equipment is installed.

The outcome, showing cumulative NPV10, is shown in Figure 2, which illustrates the relative financial returns of the candidate liquefaction technologies.

In evaluating Figure 2, an important point to consider is that the higher capacity ZR-LNG™ scheme earns its full project return in a shorter time period. For FLNG applications, returns would be further advantaged by earlier redeployment to another stranded gas opportunity. On a 24-year gas production evaluation the NPV10 advantage of ZR-LNG™ over the dual nitrogen process increases from US$ 560 million to US$ 1.66 billion and over the SMR process from US$ 395 million to US$ 1.06 billion. This assumes two new 2 trillion ft^3 field developments for the ZR-LNG™ and SMR schemes and a single new field development for the dual nitrogen process (arising from its longer period to exhaust the gas reserves).

The financial return data reflected above assumes an integrated gas field and FLNG development, with the developer bearing the full cost of the gas production and FLNG facilities. This data will not be relevant to scenarios where a stranded gas field has already been discovered and is owned by others. Under these circumstances, the owner of the gas will require payment for its off-take by the FLNG developer.

It is clear that selection of the ZR-LNG™ process allows payment of a higher gas price to secure a target IRR return. This is illustrated in Figure 3. For example, if a 30% IRR is the investment hurdle, ZR-LNG™ can afford to pay US$ 3.1/million Btu vs. US$ 1.7 for the dual nitrogen scheme. This increases the return to the holder of the gas reserve from US$ 253 million to US$ 624 million/year; an incremental benefit of US$ 370 million/year. This may be a critical factor in negotiating a 'go forward' for the project.

Impact of capital cost

Given the relative lack of available data from constructed and commissioned FLNG facilities, some considerable uncertainty exists over final installed costs. For the 5 train single 2 trillion ft^3 field study presented above, Gasconsult investigated the sensitivity of final capital cost; Figure 4 reflects the impact of over-runs on the estimates used in Table 2 vs. NPV and IRR for the ZR-LNG™ process.

Conclusion

ZR-LNG™ is positioned as a simple and energy efficient process in the mid-scale single train capacity range up to 2 million tpy. A significant reduction in complexity and cost can be achieved with limited sacrifice of energy efficiency compared to existing base load plants.

The process offers improved project returns when measured on the basis of extracting maximum output from an installed quantum of refrigeration compression power.

The ZR-LNG™ economic advantages are secured whilst preserving the well established operational benefits of nitrogen cycles for FLNG applications. These include safety through reduced complexity and the elimination of liquid hydrocarbon refrigerants, tolerance to ship motion with its impact on multi-phase flows, rapid start-up and reduced flaring.

The technology has the potential to further enhance returns by utilising freed up deck space occupied by refrigerant preparation, storage and offloading systems required by SMR and nitrogen expander schemes. **LNG**

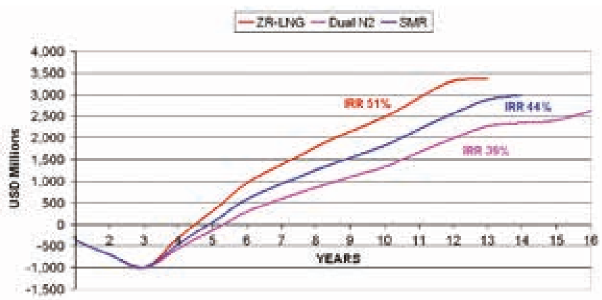

Figure 2. Cumulative NPV10 (2 trillion ft^3 field).

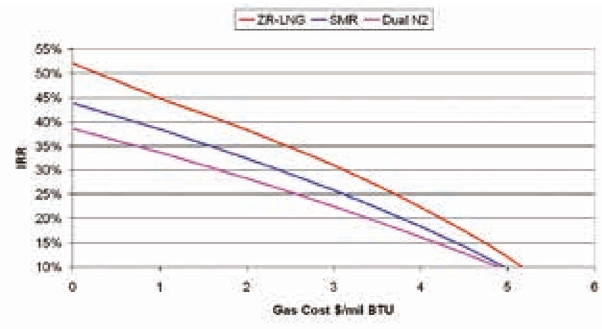

Figure 3. IRR vs. gas purchase cost.

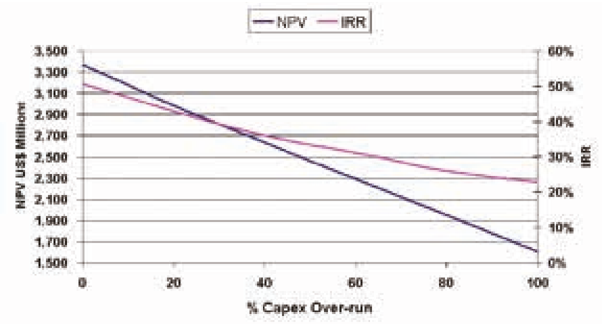

Figure 4. ZR-LNG™ Capex sensitivity (2 trillion ft^3 field).