# ZR-LNG – Dual Methane Expander LNG Liquefaction Process

## 1 Introduction and Process Configuration

The patented GASCONSULT ZR-LNG (Zero Refrigerant LNG) process is highly differentiated; unlike competing processes it uses no external refrigerants, using the natural gas feed as the refrigerant medium in an optimised system of expanders. This eliminates refrigerant storage and transfer systems and for mixed refrigerant cycles, the process equipment used to extract refrigerant components from the feed gas. This reduces equipment count, capital cost and footprint. Make-up refrigerant is low cost natural gas as opposed to nitrogen or a mixture of liquid hydrocarbons; reducing operating cost. The absence of liquid hydrocarbon refrigerant also makes for a safer operating environment. A simplified schematic of the process is provided in Fig 1.

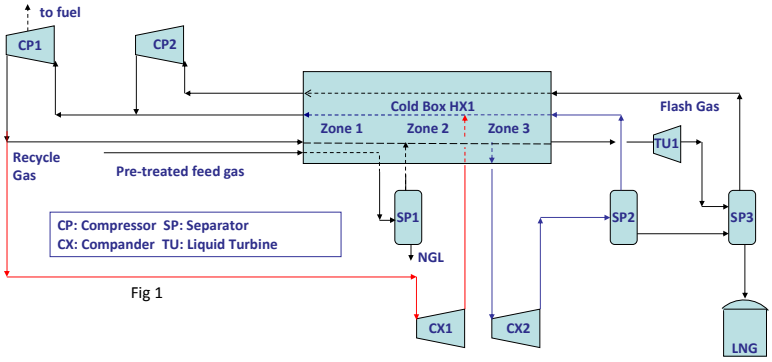


Fig 1

Refrigeration is effected in two expander circuits, a high temperature circuit indicated in red and a low temperature circuit shown in blue. Chilled gases from expanders CX1 and CX2 are routed to the cold box for cooling duty and then returned to the expanders by the recycle compressor CP1. Flash gas is also routed through the cold box and recaptured to the system by a small compressor CP2 which feeds the suction of the recycle compressor. The expanders are configured as companders and operate in series with the recycle gas compressor (Fig 2), recovering approximately 35% of the power required to run the system.

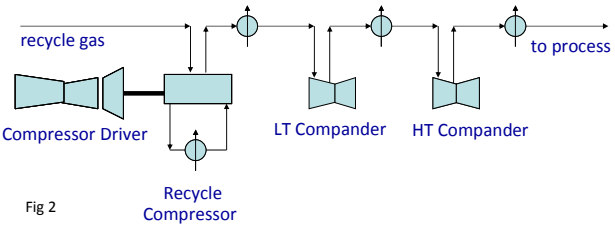


Fig 2

ZR-LNG is similar in concept to nitrogen schemes. However it enjoys a fundamental advantage as methane has a higher specific heat than nitrogen. This significantly reduces circulating flows which in turn reduces power consumption and pipe sizes.

A patented feature is that a partial liquefaction takes place in the low temperature expander CX2 – this very efficiently converts latent heat directly into mechanical work and also permits a reduction in heat transfer area and cost of the main heat exchanger HX1. An optional liquid turbine TU1 in the LNG run down line also improves efficiency by providing a significant chilling effect.

These features, together with the optimised distribution of flows, temperatures and pressures in the expander circuits makes for a highly efficient system, around 300kWh/tonne in temperate climates; equivalent or better than single mixed refrigerant processes, and 25-30% lower than dual nitrogen expander schemes. ZR-LNG achieves this without feed gas pre-cooling, providing a very simple low equipment count facility. The low power demand also reduces $CO_2$ emissions.



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## 2 Technology Advantages

In addition to its low power demand and reduced equipment count a further set of advantages stems from the Zero Refrigerant concept:

- There are no refrigerant logistics issues in remote or offshore locations. Shipments of light and heavy hydrocarbons; and segregated storage to facilitate blending a mixed refrigerant are not required; and absolute security of refrigerant supply is also assured
- There are no propane or other liquid hydrocarbon refrigerants – a major safety plus relative to mixed refrigerant schemes, particularly for FLNG where personnel exit options are limited
- Single phase refrigerant makes the system motion tolerant and well suited to FLNG
- Reduced footprint from the absence of refrigerant infrastructure and simpler C5+ removal makes the system particularly suited to FLNG
- Several operational benefits relative to mixed refrigerant schemes; no refrigerant make-up cost or composition adjustments, shorter start-up time, reduced flaring

## 3 Alternative Configurations for Low Pressure Feeds and Heavies Removal

Being an open methane cycle ZR-LNG also lends itself to very useful alternative configurations in respect of low pressure feed gases and removal of heavy hydrocarbons.

Integrated Pressure Liquefaction for Low Pressure Feed Gases

All liquefaction technologies consume more power at lower feed gas pressures. ZR-LNG can boost low pressure feed gases by routing feed gas after liquids separation in SP1 back to an inter-stage suction point of the recycle gas compressor, instead of to Zones 2 & 3 of the liquefaction section of the cold box (Fig 3). This provides a higher liquefaction pressure decoupled from the feed gas pressure, enhancing liquefaction efficiency without need for a separate feed gas compression plant.

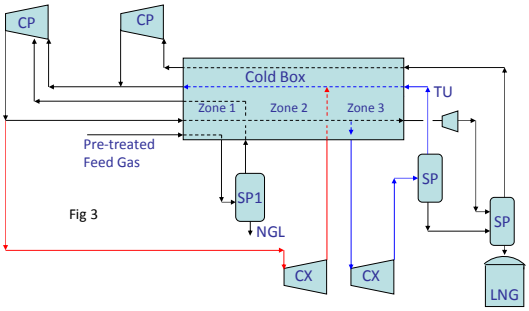

Fig 3

Integrated Heavies Removal

To achieve satisfactory C5+ and aromatics removal may require expansion of the feed gas to a lower pressure, condensing the heavy material and recompressing the depleted gas for liquefaction. This pressure reduction can be required to effect satisfactory vapour/liquid separation with feed gases close to their critical pressure. With the ZR-LNG process heavy components are removed by passing the feed gas plus recycle gas through the high temperature gas expander CX1 (Fig 4) and separating the condensed heavy material from the expander outlet at around 10-15 bar. This solution de-couples the vapour/liquid separation and feed gas pressures and saves a large part of the equipment and cost of a separate expander based NGL removal unit. It also reduces footprint which is particularly relevant to FLNG applications.

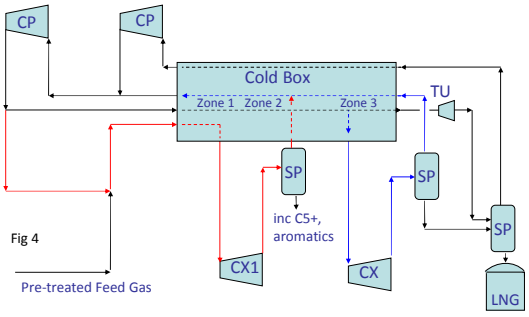

Fig 4

## 4 Technical Validation

All equipment in the ZR-LNG configuration is fully proven in operation and the process steps are well established in dozens of cryogenic gas processing plants. BP and 3 engineering companies have audited ZR-LNG and confirmed its process integrity and energy efficiency. GASCONSULT has also worked closely with many leading equipment vendors to confirm the design viability and ensure that all equipment operates within a window of proven operating experience. As an example Table 1 provides a summary of economically matched rotating equipment for various single train capacities.

| Major Equipment | 0.9 Mil TPA | 1.1 Mil TPA | 1.5 Mil TPA | 2.2 Mil TPA |
|---|---|---|---|---|
| Gas Turbine | PGT25+G4 | LM6000PF | LM6000PF+MD | Frame 7 |
| Compressor Model/Abs Power MW | 2BCL800 / 29.8 | 2BCL1007 / 34.8 | 2BCL1400 / 46.7 | 2BCL1400 / 81.5 |
| Expander LT Model/Power MW | EC50-1 / 5.4 | EC50-1 / 6.7 | EC50-1 / 9.5 | EG50-1 / 13.4 |
| Expander HT Model/Power MW | EC60-1 / 11.1 | EC50-1 / 13.8 | EC50-1 / 8.6 | EC60-1 / 13.8 |
| Expander HT Model/Power MW | | | EC50-1 / 8.6 | EC60-1 / 13.8 |

## 5 Project Returns

Most liquefaction schemes are built around a pre-selected compressor driver around which is assembled an economically matched set of ancillary process equipment. Once the compressor driver is selected the power available for liquefaction is set and the overwhelmingly dominant factor determining LNG production is the liquefaction cycle efficiency. Relative to competing mid-scale technologies ZR-LNG's superior efficiency provides a significant increase in project returns. Fig 5 shows relative returns for a 4 mil tpa FLNG project monetizing a 2 TCF gas field subject of a recent GASCONSULT Case Study.

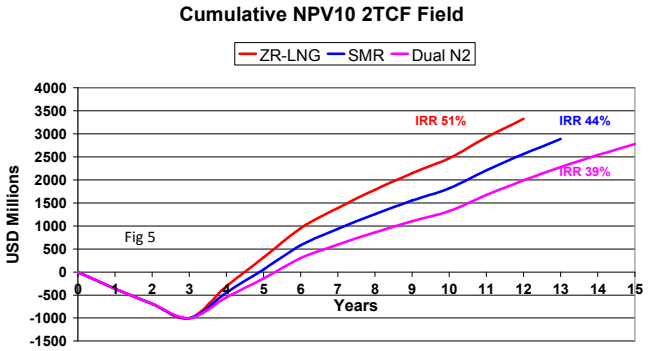

Fig 5

## 6 Commercial Basis of the ZR-LNG Offering

GASCONSULT offer the technology on a licensed basis through provision of front end design packages of flexible scope to suit client's requirements. Licenses are available to LNG producers directly who may then arrange for plant design and installation by an Engineering & Construction (E&C) company of their choice. Licenses are also available to E&Cs who may wish to offer the technology on a case by case project basis or secure a specific geography for exclusive marketing. Under these circumstances GASCONSULT will, if required, provide full technology transfer around the design to the licensee.

GASCONSULT is an independent company, has no ties to equipment manufacturers and no manufacturing shop to sustain. All equipment in the ZR-LNG process is available from multiple vendors and can thus be sourced competitively, providing opportunities to reduce project costs and schedule.