



GASCONSULT FLNG TECHNOLOGY

EXECUTIVE SUMMARY

Gasconsult has developed liquefaction technologies for mid-scale LNG with single train capacities up to ~2 million tpa. ZR-LNG, the core process, uses the feedgas as the refrigerant medium, eliminating refrigerant storage, blending, extraction and handling facilities, providing a significant capital cost reduction. The lower equipment count, ~15% lower footprint and lower weight of the facility is particularly beneficial for FLNG application as it results in a reduced deck area and weight of the host hull or platform, further reducing capex. Alternatively, the reduced footprint allows installation of additional productive liquefaction capacity on an existing hull/platform, enhancing project economics.

The ZR-LNG+ process was recently introduced to meet new market dynamics where LNG buyers are seeking a minimum carbon product accounting for not only CO₂ released during combustion but also during gas extraction, liquefaction and shipping. ZR-LNG+ enhances the core ZR-LNG liquefaction efficiency by incorporation of an integrated cooling circuit using a single external refrigerant.

A summary table showing indicative performance of Gasconsult's ZR-LNG and ZR-LNG+ processes against competing liquefaction technologies is provided below. At the highest efficiency end of the market, ZR-LNG+ achieves an efficiency comparable to the dominant DMR (Dual Mixed Refrigerant) and C3MR (Propane pre-cooled Mixed Refrigerant) base load technologies, but with 30-40% less equipment. For conventional mid-scale plants ZR-LNG has a 5-10% higher efficiency and production capacity than the mainstream SMR (Single Mixed Refrigerant) technology but with a 25% lower equipment count. For small-scale plants ZR-LNG has an equivalent equipment count to nitrogen expander technologies but with a significantly higher efficiency and production capacity.

TECHNOLOGY	SINGLE TRAIN EQUIPMENT COUNT IBL + OBL	RELATIVE POWER DEMAND	RELATIVE REVENUE PER MW OF POWER INPUT
HIGH EFFICIENCY			
ZR-LNG+	27	100	150
DMR/C3MR	37/45	100	150
MID-SCALE			
ZR-LNG	19	117	128
SMR	26	122-129	116-123
SMALL-SCALE			
ZR-LNG	19	117	128
3 X N ₂ EXPANDER	20	134	112
2 X N ₂ EXPANDER	19	150	100

The design and configuration of ZR-LNG and ZR-LNG+ has been independently validated by McDermott a leading engineering company expert in cryogenics. ZR-LNG also won, against international competition, the Petronas Technology Challenge 10 which was seeking a compact, efficient FLNG solution for difficult feed gases. Please see page 4.

The technologies enjoy significant patent protection. Please see Appendix 1.

ZR-LNG – ZERO REFRIGERANT LNG (including its variants)

The ZR-LNG process was developed by Gasconsult to provide a simple, lower cost, lower power demand, easier to operate alternative to SMR processes. ZR-LNG, a methane expander-based process, is self-refrigerating, using the feed natural gas as the refrigerant medium. Equipment for handling, storing and blending refrigerants (including where necessary refrigerant extraction from the feed natural gas) is eliminated. This reduced equipment count provides a significant capital cost saving plus



reduced weight and footprint. Independent analysis by a number of industry players has also confirmed a lower power demand than SMR schemes, the traditionally favoured process for mid-scale liquefaction. Typically, ZR-LNG provides a saving of 5 – 10% of power depending on the SMR variant under review. A 10% power demand advantage at a 2 million tpa LNG capacity level provides over \$100 million p.a. additional revenue from the same compressor driver at an LNG sales price of \$10 per million BTU.

Expander-based processes are also easier to operate than mixed refrigerant schemes as maintaining efficiency at close to design requires ongoing adjustment of the mixed refrigerant composition. Added to improved safety (no liquid hydrocarbon refrigerants), faster start-up (<12hrs vs 24hrs+), elimination of logistics issues around refrigerant supply, and no refrigerant make up costs, ZR-LNG makes a compelling case for application on mid-scale ~2 million tpa liquefaction trains.

Given the highly competitive power demand of the base ZR-LNG process, Gasconsult has, until recently, had limited incentive to further enhance ZR-LNG's efficiency. However, with the current demand by LNG buyers for low carbon product, the market dynamic has changed. Gasconsult therefore developed ZR-LNG+, an integrated cooling variant. This matches the power demand of base load DMR and C3MR schemes and other than the requirement for a single external refrigerant ZR-LNG+ retains all the advantages of the core ZR-LNG scheme in respect of FLNG application.

There is a further variant of ZR-LNG. The IHR (Integrated Heavies Removal) process removes C5+ and aromatics from raw natural gas, avoiding the need to install an upstream NGL recovery unit to prevent freezing and plugging of the main cryogenic exchanger and ancillary equipment. IHR performs the same steps as an NGL unit but using the expander and re-compression facilities already existing in the basic ZR-LNG configuration. This saves ~\$50 million relative to an upstream expander based NGL recovery unit for a 2 million tpa LNG train.

In summary for FLNG applications ZR-LNG, ZR-LNG+ and IHR provide the following benefits:

- Reduced liquefaction plant capex arising from absence of refrigerant infrastructure
- Reduced hull/platform capex arising from reduced weight and footprint of liquefaction plant, or potentially additional productive LNG production from an existing hull/platform
- Reduced capex from IHR avoiding requirement for C5+ removal by an upstream NGL unit
- Reduced capex; for all Gasconsult technologies all equipment is competitively available from multiple vendors and no equipment is tied to the technology licence
- No, or reduced in respect of ZR-LNG+, refrigerant supply issues at remote locations
- Ease of operation; no refrigerant composition adjustments
- Reduced opex; no refrigerant make-up costs (other than for the single refrigerant of ZR-LNG+)
- Safer operations; no liquid hydrocarbon refrigerants
- Higher revenues arising from reduced power demand
- Reduced carbon emissions arising from reduced power demand

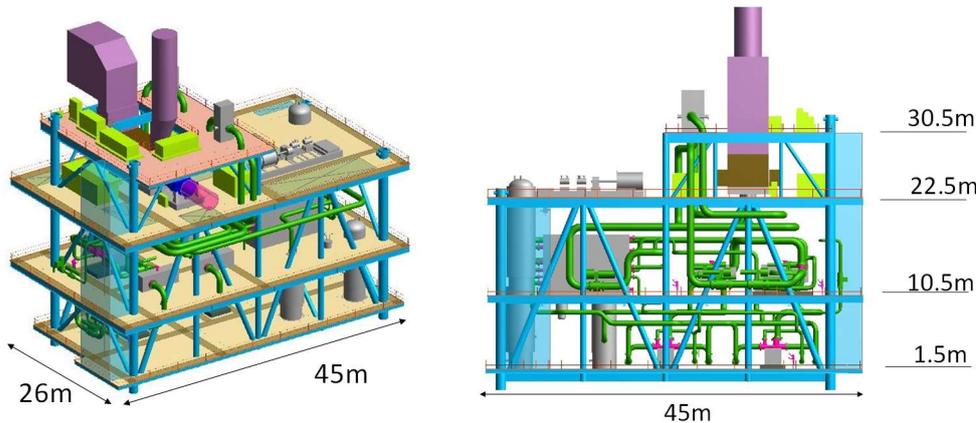
ENGINEERING DEVELOPMENT

The main engineering development of the technology has been carried out by McDermott, who completed a detail study of the technology for a 2 x 1.5 million tpa FLNG facility off the West African coast. Inter alia the work covered process validation and detail engineering work and production of assessment data covering costs, layout, weights, reliability and process comparisons with competing technologies. The full work-scope is covered in the report index on P3, together with drawings of the liquefaction module and the FLNG hull.

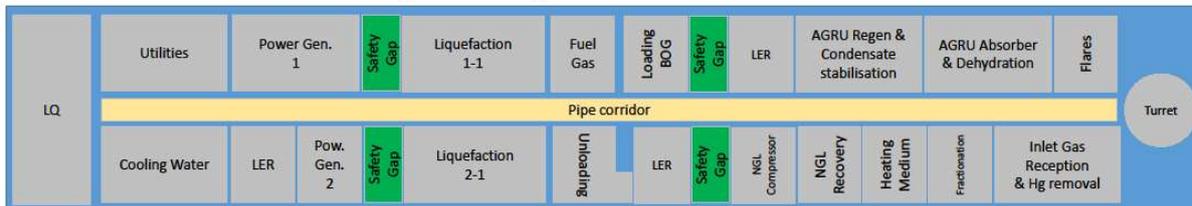
MCDERMOTT REPORT INDEX

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1.5 million tpa module. Weight 4422 tonnes



Custom Hull 2 x 1.5 million tpa trains. 380m x 65m x 33m



A second engineering development programme was carried out with Petronas who through their Technology Challenge programme were seeking an efficient compact FLNG solution. Page 4 shows the Petronas announcement of Gasconsult winning the Technology Challenge against international competition. Subsequent to this Gasconsult performed a number of FLNG studies for Petronas on difficult feed gases containing up to 70% CO₂.



Winners

Technology Challenge 10: GASCONSULT LIMITED

PETRONAS applauds Gasconsult Limited for winning the tenth Technology Challenge namely, Compact Refrigeration System for Natural Gas.

PETRONAS has recognised the issue on large footprint, complex with heavy equipment which are challenging for offshore applications resulting in unattractive economics to overall projects. In our hunt for a compact refrigeration system for natural gas processing, we found Zero Refrigerant LNG (ZR-LNG) proposed by Gasconsult Limited to be the most benefit solution that is compact and comes with minimal equipment count.

Gasconsult ZR-LNG process is highly differentiated; unlike competing processes, it uses no external refrigerants; just natural gas feed as the refrigerant medium in an optimised system of expanders. This eliminates refrigerant storage and transfer systems and the process equipment used to extract refrigerant components from the feed gas as required for mixed and multi-refrigerant cycles. This also reduces equipment count, capital cost and footprint.

The challenge received an encouraging participation from both local and international companies. Upon comprehensive assessment by a panel of internal subject matter experts in PETRONAS, Gasconsult triumphs over many other encouraging participations by proposing ZR-LNG Technology.

Congratulations Gasconsult Limited and our heartiest gratitude to all participants for your continuous support in the PETRONAS Technology Challenge.

APPENDIX 1 - PATENTS

Technology	Awarded Patents	Patents Pending
ZR-LNG	2012 – UK: GB 2486036 2016 – China: ZL 201280027025.X 2016 – Japan: 5984192 2017 – Mexico: 346703 2017 – Australia: 2012270148 2017 – South Korea: 10-1820560 2019 – Canada: 2,836,628 2019 – Malaysia: MY-172653-A	High efficiency ZR-LNG+ GB2404789.6 superseded by PCT/GB2025/000010
IHR (Integrated Heavies Removal)	2019 - EP 3338043 (DE, FR, ES, IT, GB) 2020 – JP 6640886 2020 – US 10641548 B2 2023 – KR 10-2498124	2023 High methane LNG – IHR+ GB2318454.2 superseded by 2024 PCT/GB2024/000053