Rice Global E&C Forum
Engineering & Construction

BRAEMAR ENGINEERING

FLNG Liquefaction Technology

Considerations Influencing LNG Technology Selection

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Agenda

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- Introduction to Braemar Engineering
- Characteristics of LNG
- Factors Influencing FLNG Technology Selection
- FLNG Technology Selection Criteria
- Conclusion

Focus on Mid-Scale Size Production Facilities (1.0 to 3.0 Mtpa)

Agenda

Introduction to Braemar Engineering

Braemar Shipping Services PLC

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Divisional Service Overview

Technical

- LNG vessel consulting
- LNG facilities engineering & consulting
- FSRU / FLNG / FPSO engineering and consulting
- Ship construction supervision
- Marine warranty surveys
- Energy loss adjusting
- Marine engineering & naval architecture
- Vessel and condition surveys
- Failure mode and effect analysis
- Marine cargo surveys
- DP audits
- Shipyard risk assessments
- Towage approvals
- Expert witness services

www.braemar.com

Shipbroking

- Tanker chartering – Crude oil, Clean Petroleum Products, LPG, LNG, Chemicals
- Sale & purchase – second hand, new building, demolition
- Dry Bulk chartering
- Offshore – chartering and sale & purchase
- Container – chartering and sale & purchase
- Research and valuations

www.braemarseascope.com

Logistics

- Port & Liner agency
- Hub agency
- Ship to ship transfers
- Customs clearance
- Freight forwarding
- Project cargoes
- Cruise ship support

www.cory.co.uk

Environmental

- Incident response
- Pollution control
- Salvage services
- Accredited training and environmental consulting
- Crisis management and emergency response advisors
- Industrial services and tank cleaning

www.braemarhowells.com

Braemar Engineering at a Glance

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- Established as Wavespec 1993 in Maldon, UK
- Since 1997 part of the Braemar Shipping Services Plc, a leading international provider of engineering and consultancy services to the shipping, marine, energy, offshore and insurance industries with 400+ engineers in offices worldwide
- Core business:
  - LNG carrier design review, construction oversite & operation consultancy
  - Floating LNG: LNG FSRU, FSU, FLNG
  - Marine engineering & naval architecture
  - Engineering services for LNG projects (Owner's Engineering, Permitting, Engineering & Consulting)
  - FMEA studies and audits for DP vessels
- Member of SIGTTO and founding member of SGMF

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Characteristics of LNG

Natural Gas Markets

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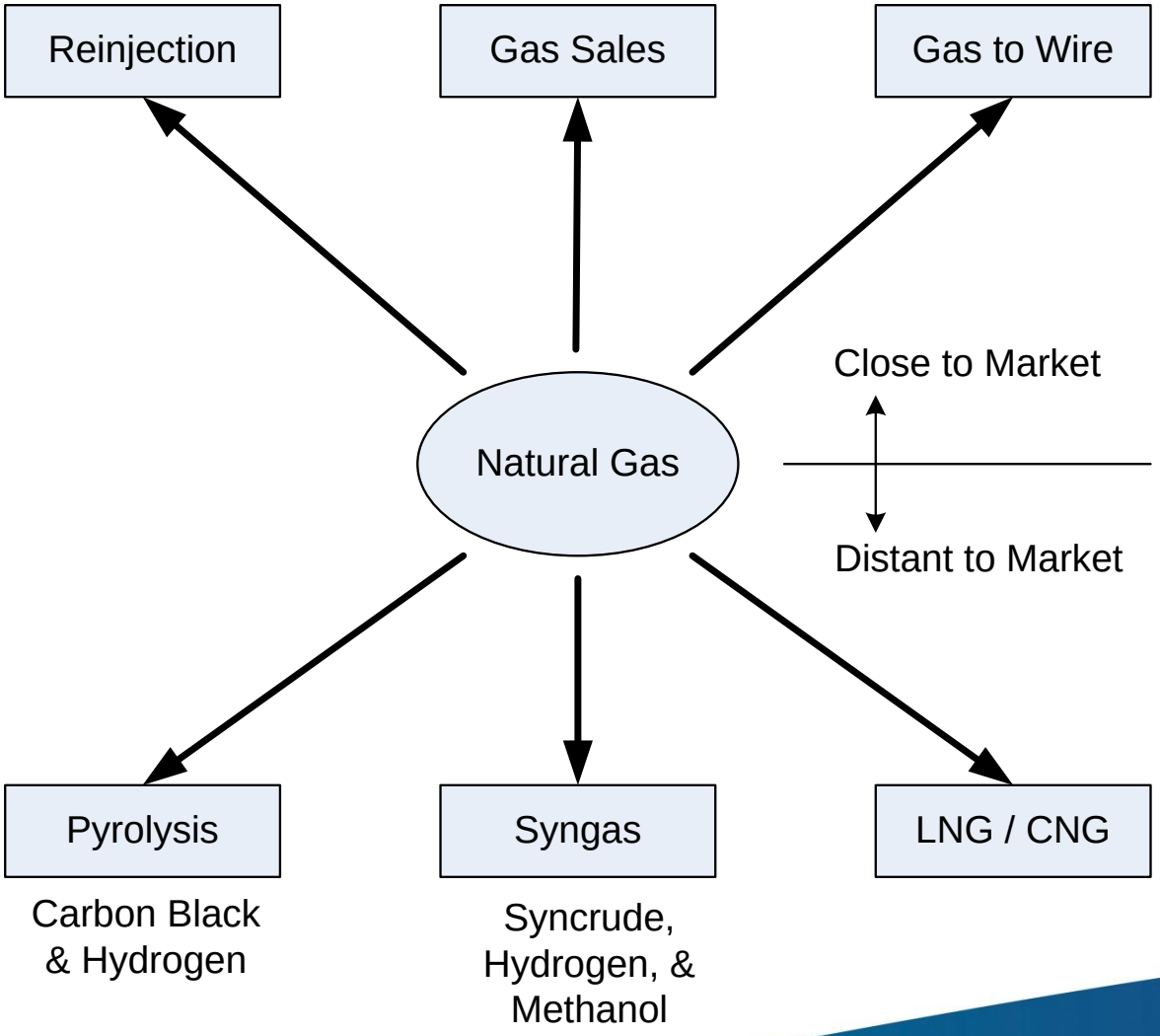

Natural Gas Markets

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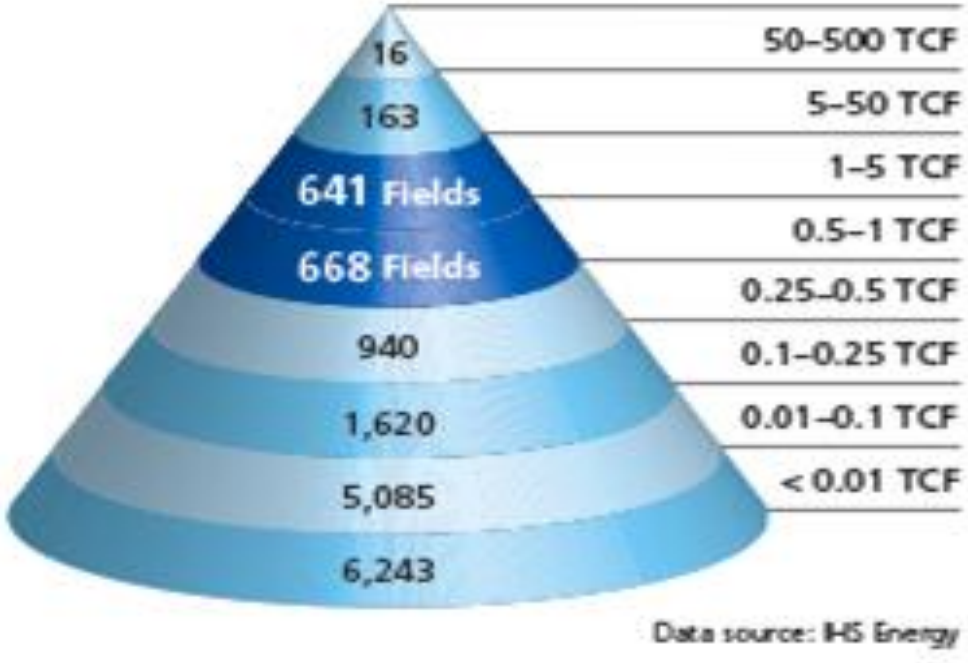
1 TCF Approximately
140 MSCFD (1.0 Mtpa)
over 19.5 years

1 TCF Approximately
280 MSCFD (2.0 Mtpa)
over 10 years

1 TCF Approximately
420 MSCFD (3.0 Mtpa)
over 6.5 years



Natural Gas to Market Cost

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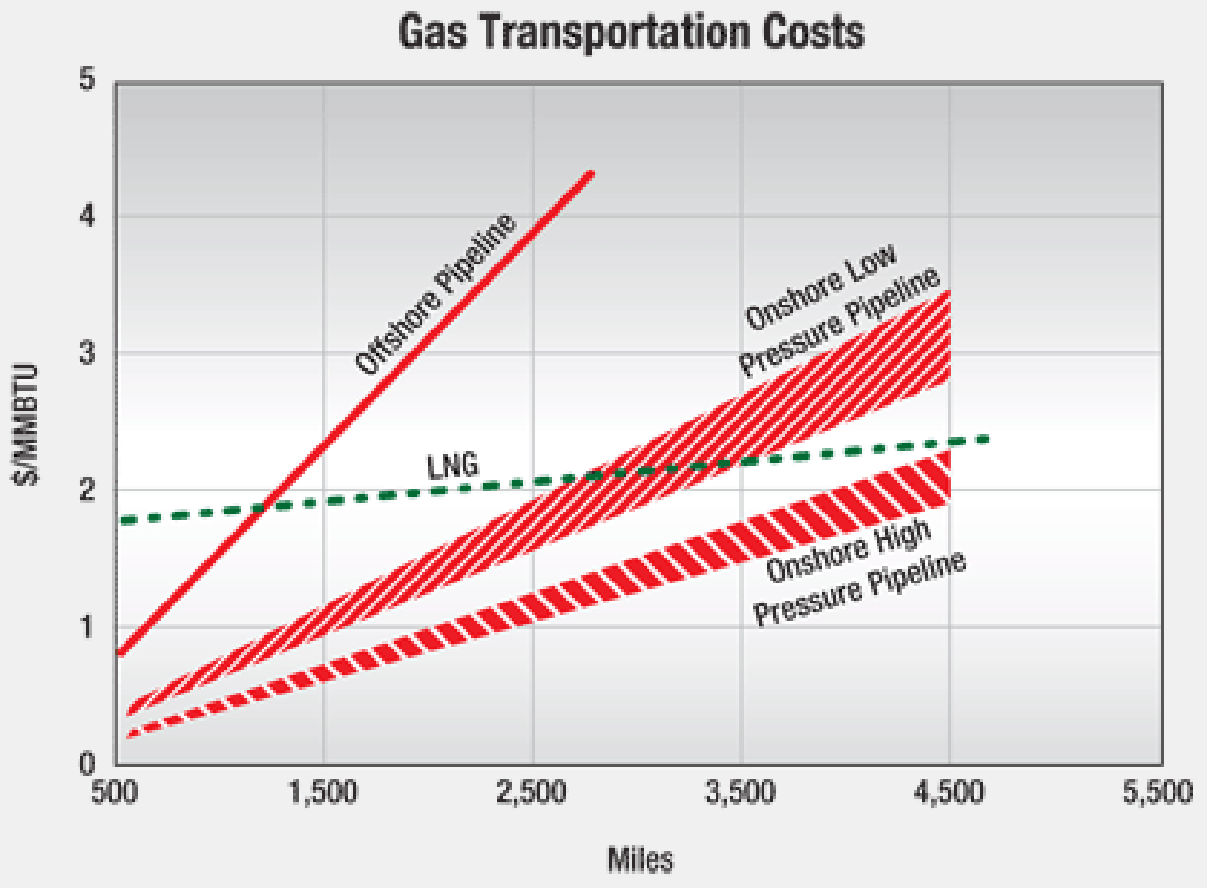

Source: energytribute.com

Liquefied Natural Gas Terminology

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- LNG is Natural Gas that has been super cooled to a liquid at -260°F (cryogenic) at pressures near atmospheric conditions.
  - Must be Water/CO_2 free
  - Colorless
  - Odorless
  - Non-toxic
  - Non-flammable (in liquid state)
  - Non-explosive (in liquid state)
  - “Environmentally Friendly” Fossil Fuel

Liquefied Natural Gas Terminology

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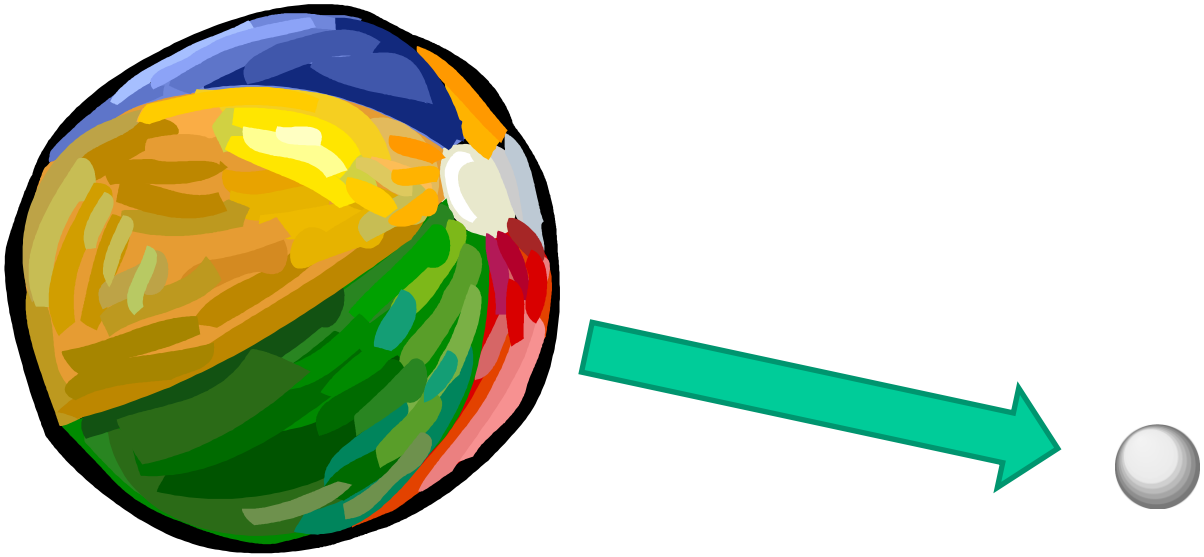
- Why Use LNG? Significant Volume Reduction (600 to 1)



Beach Ball (gas)

Ping Pong Ball (liquid)

Economically feasible to ship in Atmospheric Storage Containers.

Main Systems Required for FLNG

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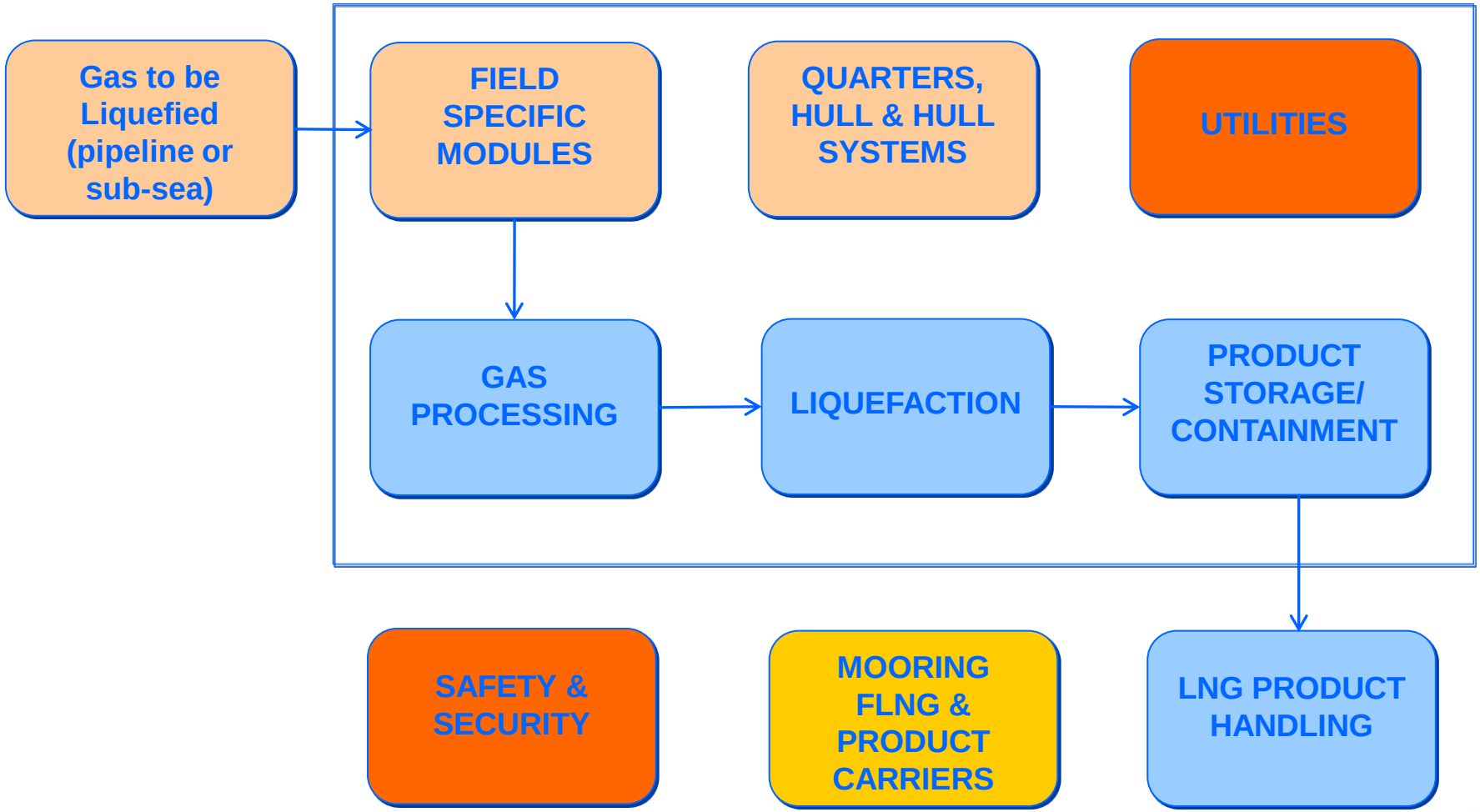

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Factors Influencing FLNG Technology Selection

(In no particular order)

Source and Quantity of Gas

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- Pipeline Gas feedstock will favor high efficiency processes because gas is purchased at “competitive” pricing.
- Wellhead or stranded feedstock will favor less capital equipment (acceptance of a lower efficient process) as natural gas is “below market price”.
- Limited quantity (volume) of feedstock will favor higher efficiency processes (example Canadian project limited to 300 MMSCFD or ~2.0 Mtpa)

Compositional Variation

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Suppliers view of NG Streams…

Component	Mole %
Nitrogen	0.500
CO2	0.500
Methane	>96.5
Ethane	<2.50

Devil is in the Details!

This doesn't include trace contaminants water, mercury, H2S, mercaptans, and Oxygen!

Actual Abbreviated Extended Analysis of a NG Stream…

Component	Mole %	Component	Mole %
Nitrogen	0.500	Mcyclopentane	0.020
CO2	1.000	Neo-Pentane	20 ppmv
Methane	90.009	N-Hexane	0.064
Ethane	4.079	C6 Components	0.108
Propane	2.495	Toluene	100 ppmv
Iso-Butane	0.645	N-Heptane	0.056
N-Butane	0.621	C7 Components	0.061
Iso-Pentane	0.146	Xylene	50 ppmv
N-Pentane	0.140	Ethylbenezene	25 ppmv
Benzene	200 ppmv	N-Octane	0.057

Solubility of HHC in LNG

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Component	Estimated Solubility (ppmv)
Neo-Pentane	5
Iso-Pentane	1000
N-Pentane	1000
Hexane	150
M-cyclopentane	550
Benzene	0.5
Cyclohexane	100
N-Heptane	50
M-cyclohexane	300
Toulene	20
N-Octane	0.5
N-Nonane	0.1
N-Decane	0.0

- Heavy Hydrocarbon Concentrations in excess of the estimated Solubility Limits should be avoided
  - Excess heavy hydrocarbons could cause structural damage to equipment due to the formation of "hydrates or solids" (remote)
  - De-rimming process resulting in a loss of availability and overall production (highly likely)
- Gas chromatography is very difficult in the <100 ppm range
- Note that the Guidelines includes approximately times two (X2) safety margin over empirical data

Must Remove C_5+ Components!

Typical Feedstock Phase Envelop

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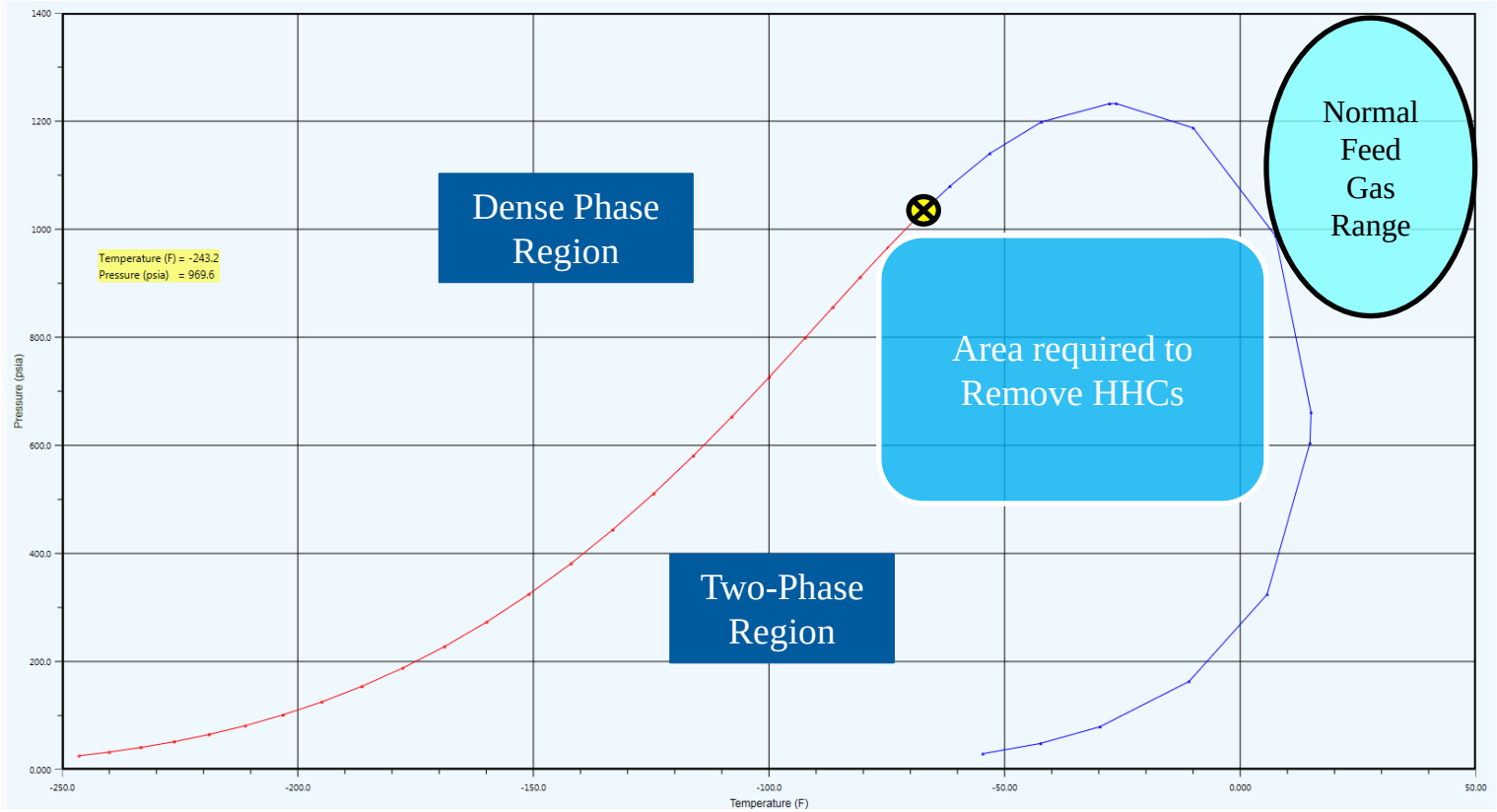

To Remove Heavy Hydrocarbon Components, Facility Must Operate in the Two-Phase Region (Not the Dense Phase Region)

Method of Removing HHC

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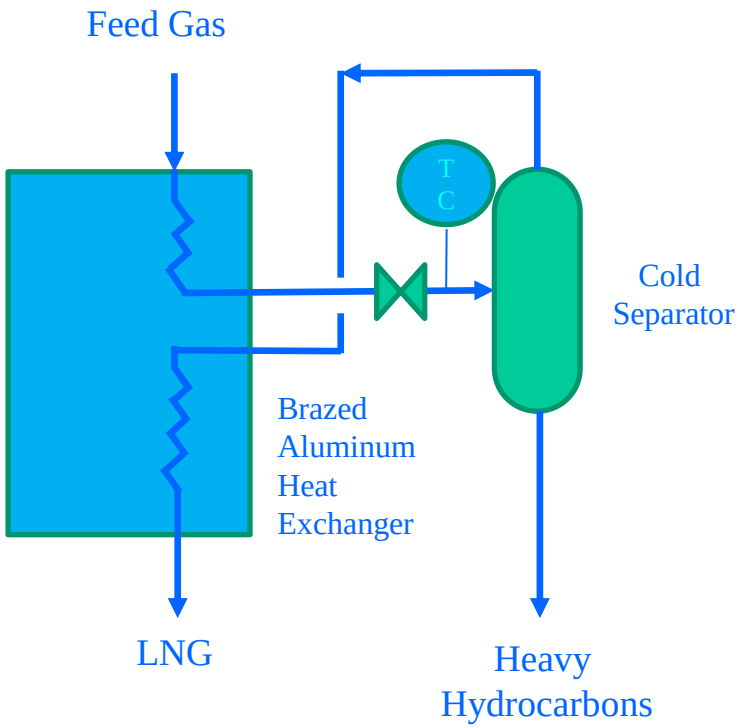
Flash Method

- Simple flash to remove heavy hydrocarbons
- Control the flash temperature to knock-out the required HHCs
- Dispose of HHCs in un-stabilized condensed flash stream
- Significant loss of methane and lighter components (typically 60% of HHC stream is C_2 or lighter)
- Ideal if you have a hydrocarbon "waste" stream (straddle plant)



Simple, Inefficient, and Non-selective Process.

Method of Removing HHC

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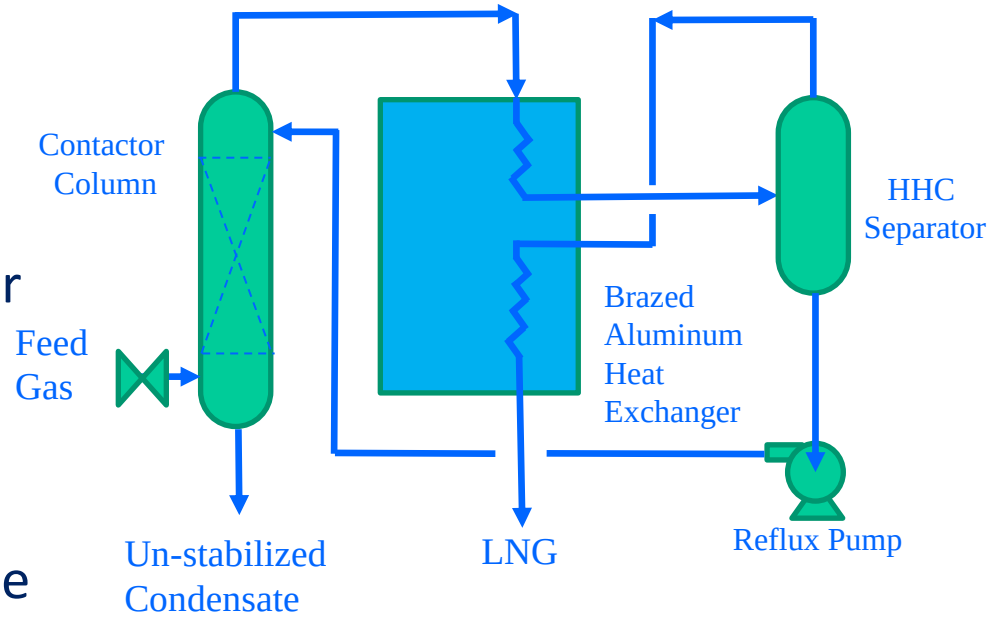
Scrubber Method

- Refluxed Column to strip out heavy hydrocarbons
- Dispose of HHC in un-stabilized condensate stream
- Small loss of methane and lighter components (typically <10% of HHC stream is C_2 or lighter)
- Feed gas must be "rich" in C_3+ components (otherwise would be enriching feed gas with C_3+)



Moderate Simple Process for Rich Gas Does NOT work for Lean Gas

Method of Removing HHC

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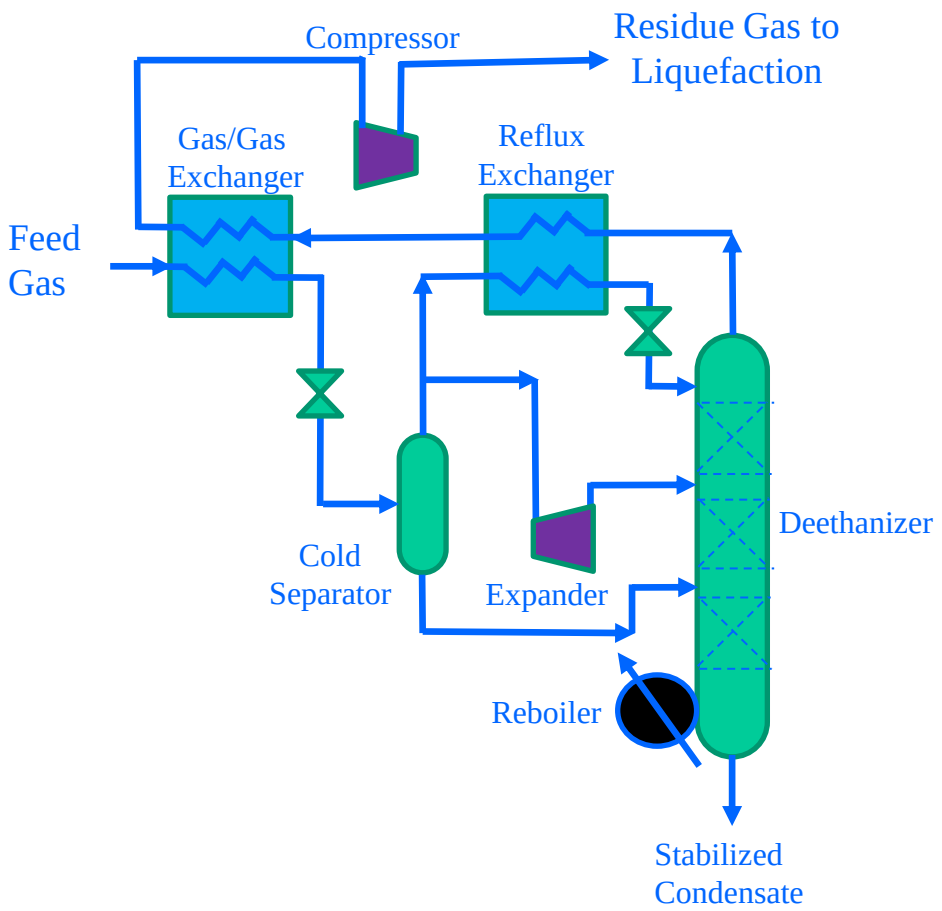
Gas Subcooled Method

- Conventional open art, gas plant technology
- High Capital Expenditures (CapEx) and Operating Expenditures (OpEx)
- Recompression typically required
- Produces a stabilized condensate (adjust to meet product specs)
- Works with any and all gas compositions
- Can be integrated into the LNG liquefaction process.



Complex, Highly Selective Process.

Oxygen Dilemma

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- Pipeline specifications (tariff based) might allow up to 0.4 mole % Oxygen (typically N.A. problem)
- Problems caused by Oxygen:
  - Non-condensible that concentrates in the BOG system (up to 2%)
  - Potential to react (oxidize) and form water during regeneration
  - Poison to the Molecular Sieve beds during regeneration (coking or S species)
  - Salt formation in Amine system
- UOP, BASF, and others have oxygen removal technology but it's expensive, potential high operating costs, and takes up space.
  - <20 ppmv – Typically OK
  - >20 ppmv – Treatment Might Be Required

Is Oxygen content is real? Solution? (future or pre-investment).

Inlet Pressure Variations

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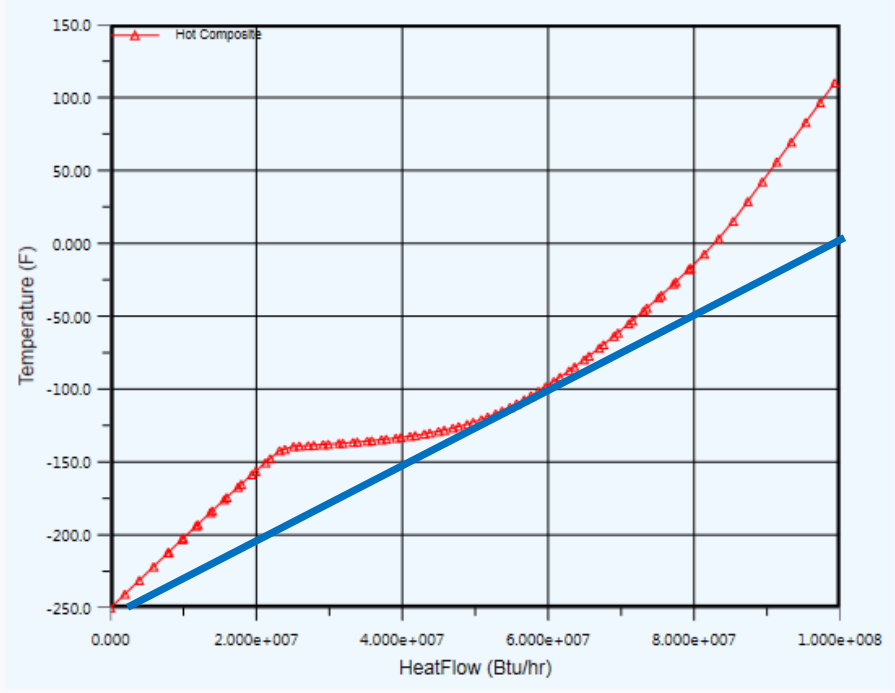
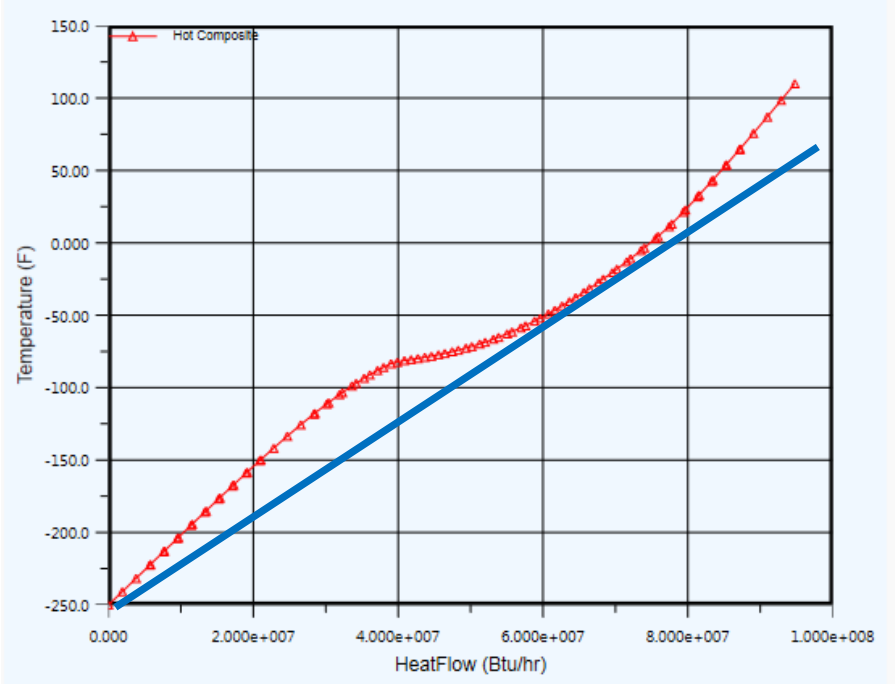
Cooling Curve for Low Pressure Gas (400 psia)



Cooling Curve for High Pressure Gas (900 psia)



High Pressure "Flattens" the Natural Gas Cooling Curve Which Can Effect the Technology Selection (also makes additional J-T refrigeration at End-Flash Drum)

Type of Storage

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- Adjacent Carrier Storage (FSO)
  - Range of Storage – Unclassified (True “Bulk” Storage on Adjacent LNG Carrier)
  - Large Available Topside Space – Dependent on Topsides and LNG Technology Selection
  - Storage independent of topsides (minimal changes)
- Moss Carriers
  - Range of Storage (120,000 m^3 to 170,000 m^3)
  - Limited Available Topside Space (approximately 1200 m^2 to 1500 m^2)
  - Limited Technology Options (Nitrogen, Open cycle)
- Membrane / Prismatic Carriers
  - Range of Storage (87,000 m^3 to 250,000 m^3)
  - Larger Available Topside Space (approximately 6,000 m^2 to 18,000 m^2)
  - Relatively unlimited LNG Technology Options
  - Must span entire breadth of carrier (unless purpose built with port and starboard storage and center line coffer dam)

Marinization of Design

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- Modularization is a key component for all off-shore projects (simultaneous path of topsides and hull)
- Equipment modules sizing limitation and weight are generally set by the coffer dam spacing (bulkhead spacing) between the LNG storage tanks located in the hull.
- Numerous Equipment limitations/Marinization required (size of brazed aluminum cold box, CWHE “tube settling”, pump seals and bearing able to take the wave action, etc.).
- Typically shipping to site is more stringent than operating loads (accelerations due to gravity during shipping).
- Maintainability (simple or complex)
- Multi-phase refrigerant cycles are more sensitive to vessel motions (must minimize impact during the design phase – i.e. headers, manifolds, and baffles, etc.). Mal-distribution of refrigerant can make or break process guarantees.
- Large refrigerant liquid inventories should be minimized due to the potential for leaks leading to explosions / BLEVE.
- Quick / ease of start-up (minimum start-up time from the ambient conditions to operations). Generally governed by the cool down rates of the main cryogenic heat exchangers.

Space Requirements

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- Off-Shore Space is a premium commodity. General Comparison:
  - Premium Land in Singapore ($500 to $1500/sq ft)
  - Premium Land in New York City ($500 to $2000/sq ft)
  - Typical Off-Shore “land” ($2500 to $3500/sq ft)
- Layout facilities to separate personnel and living quarters from main process facility. Typically include the utilities and power generation as a buffer.
- On land, if the risks are unacceptable as determined during the HAZOP or QRA, solution was to spread out the facility (example - moving the Control Room at ACCROVEN to 300 feet).
- Requirements for large safety gaps has a significant impact on space required.
- Off-shore, late significant changes in the Hull or layout can undermine or invalidate the entire project.

Schedule

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- Hull Construction
  - *"Dumb Barge" – Typically 12 to 18 months*
  - *Conversion – Typically up to 18 months*
  - *Custom Built FLNG with In-House Storage – Typically 28 to 36 months*
- *Modular Construction*
  - *Typically have five (5) to eight (8) modules for 2 Mtpa facility*
  - *With long lead items, modules are available 12-30 months*
- *Must sync the base (hull) construction with the topsides*

Transfer of Cargo

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Traditional LNG Transfer Arms

Cryogenic Hoses

Transfer of Cargo

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- European standards do not fully embrace hoses at LNG transfer points.
  - ISO 28460:2010

    15.2.1 General

    Marine transfer arms shall be used for the transfer of LNG at conventional onshore terminals. These shall be equipped with an emergency release system.

    For the transfer of small quantities of LNG, hoses may be used if the total volume of LNG in the hose transfer system does not exceed 0.5 m3 and the length of hoses does not exceed 15 m.
  - EN1473:2007

    9.5.3 Flexible hoses

    Flexible hoses may be used to make small temporary connections for the transfer of LNG and other cryogenic liquids such as refrigerant and liquid nitrogen, for example when emptying or filling road tankers of LNG or liquid nitrogen and they can also be used for transfer operations between small LNG carriers and LNG satellite plants.

    Flexible hoses shall not be used for the routine transfer of LNG between large LNG carriers and shore at conventional LNG Terminals.
- CAN-CSA and NFPA 59A allow for hoses but has very specific requirements (must be designed for purpose, 5X bursting pressure, yearly testing, proper isolation if the event of a failure, etc.).

Transfer of Cargo

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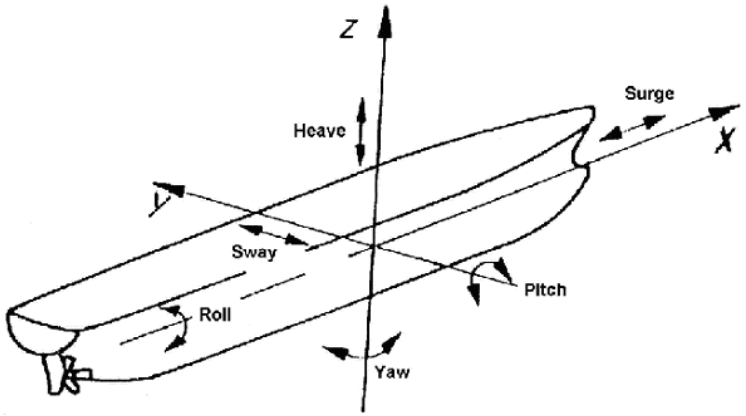
- Cryogenic hoses are limited to <2 meter seas (side by side transfer) and cargo flow rates of about 4,000 m^3/hr (with six 8" parallel hoses). "benign waters transfer"
- Traditional LNG transfer arms can handle up to 12,000 m^3/hr (generally required to load an LNG carrier in less than 24 hours) with wave action up to 2.5 meter.
- To date, there are no operating systems that can transfer LNG in greater than 2.5 meter seas. Multiple technologies are under development (TORP HiLoad, FMC Tandem Transfer, etc.) but do not have experience with operating units.



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FLNG Technology Selection

Technology Available for Mid-Scale

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Potential FLNG Liquefaction Technology Vendors[1] :

- LNG Limited — OSMR (Optimized SMR)
- Linde: — LIMUM (SMR), DMR, Linde's N2 Expander Cycle
- Black and Veatch: — PRICO (SMR), DMR, Nitrogen, Open Cycle
- Air Products: — C3MR, DMR, AP-N™, AP-HN™, SMR, Nitrogen, Open Cycle
- KANFA Aragon: — Dual Nitrogen, SMR, Open Cycle
- Chart Industries — IPSMR®, Dual Nitrogen, Open Cycle
- Mustang — Dual Nitrogen, Open Cycle

1. *Some IOCs use their own developed technologies for their own projects (e.g. Shell, ConocoPhillips) but they are not evaluated as direct competitors*

Single Mixed Refrigerant (SMR)

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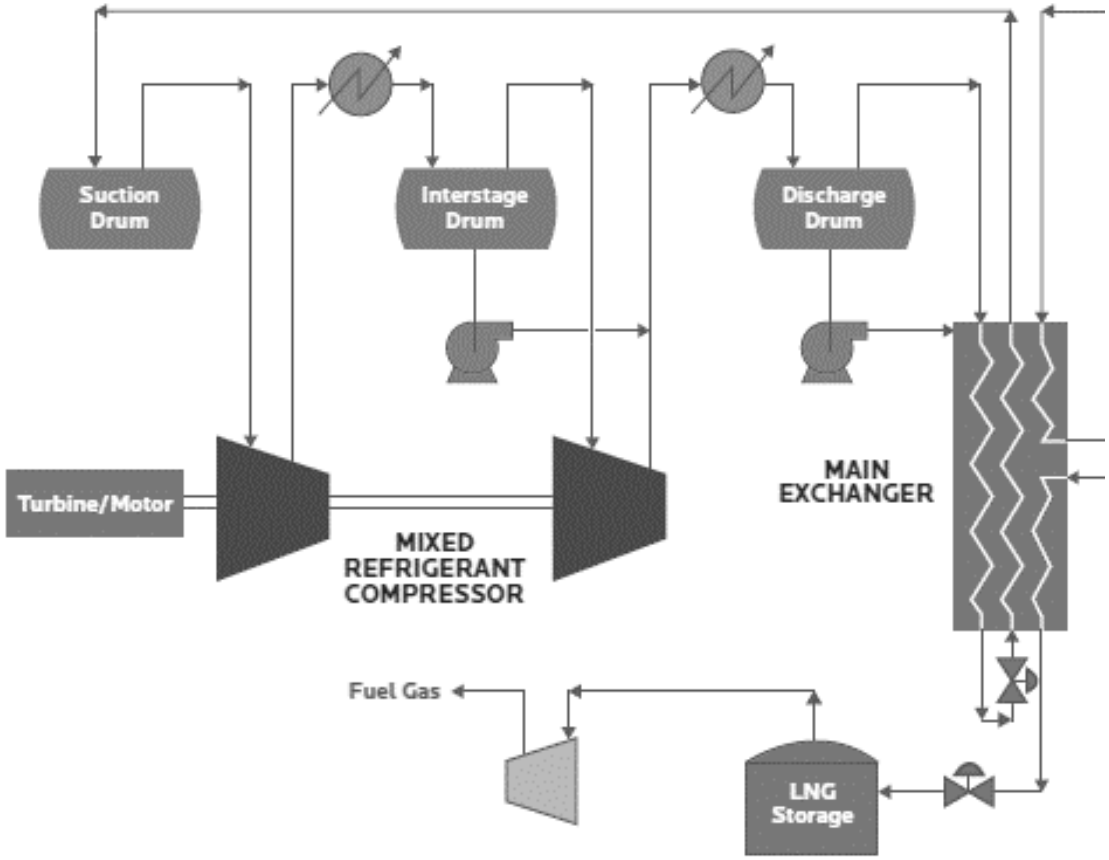

- Large refrigerant vessels
- One Compressor (two-stages)
- Multi-component phase change

Dual Nitrogen Expansion

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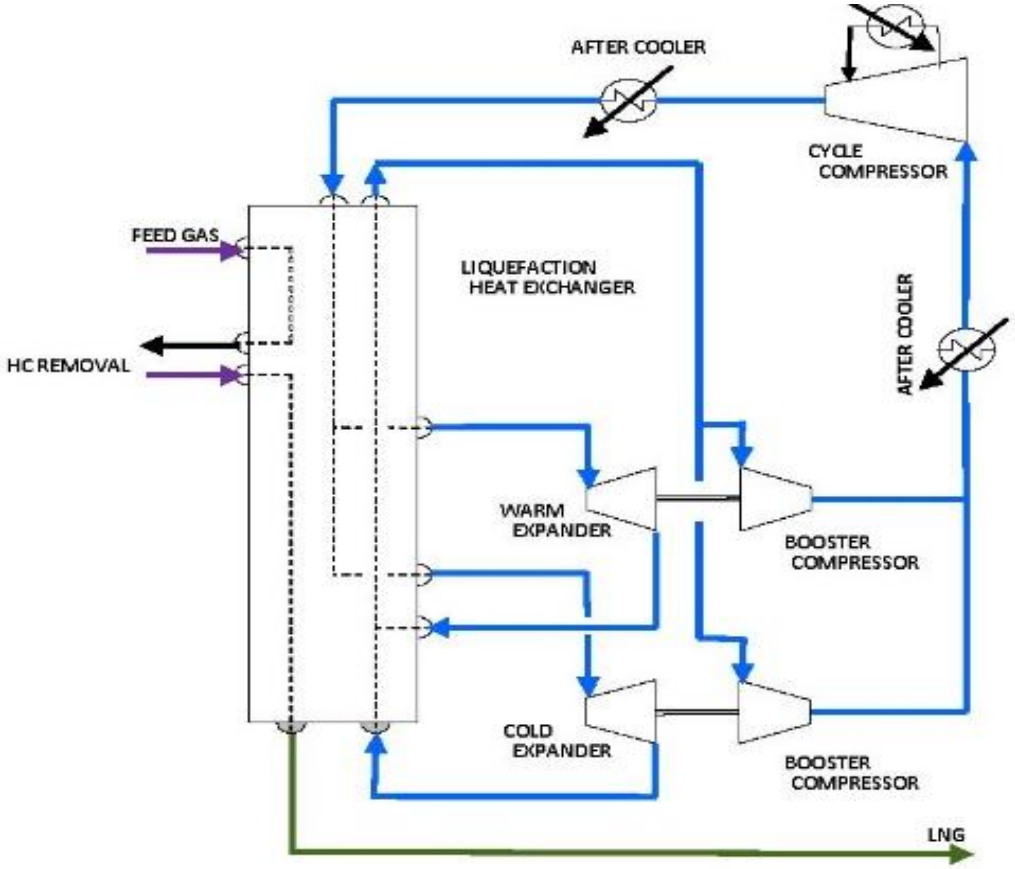

- No Vessels (small footprint)
- Multiple rotating equipment
- No phase change in refrigerant (all sensible heat), i.e. “all vapor all the time”

Propane Pre-Cooled Mixed Refrigerant

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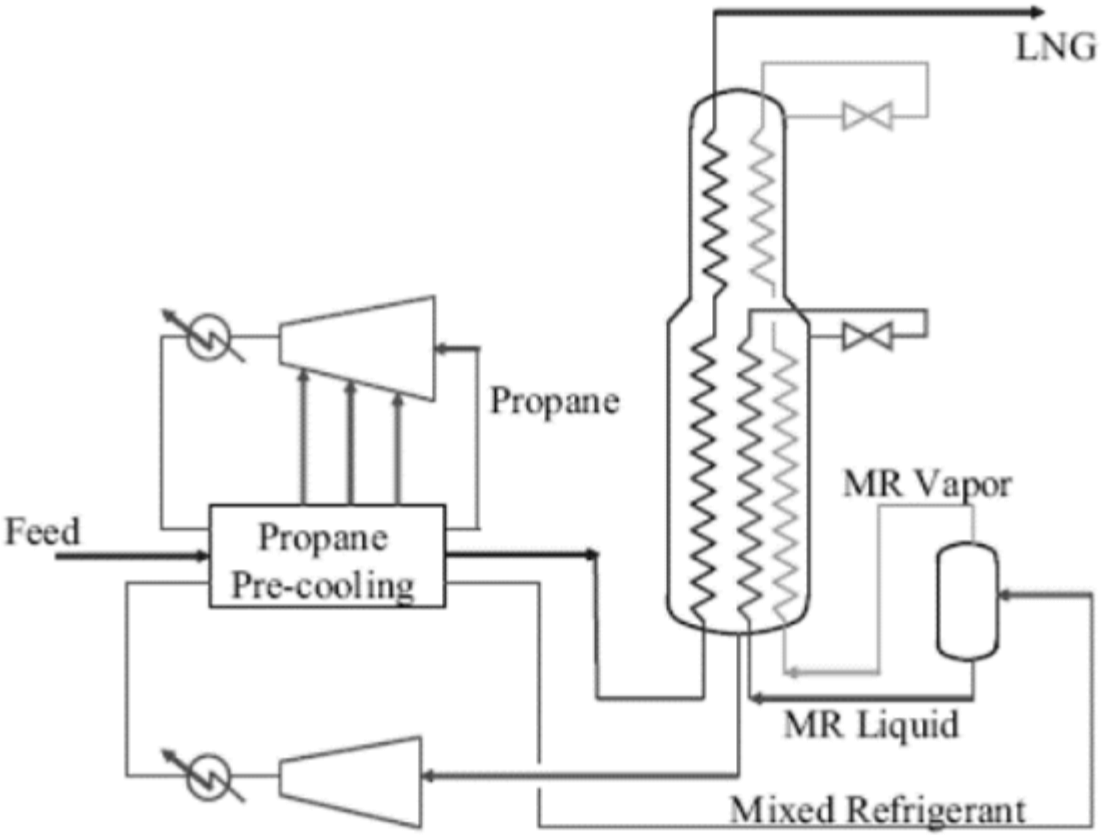

- Large vertical heat exchanger
- Two-levels of refrigerant
- Multi-component phase change

Technology Cooling Curve Comparison

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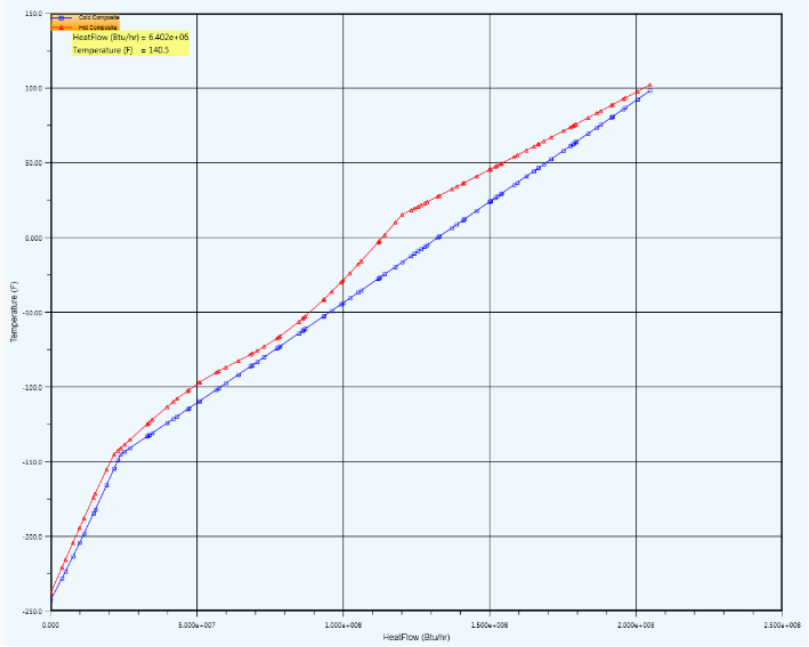
Single Mixed Refrigerant

Dual Nitrogen Expansion



Closer the cold stream to the hot stream, the better the efficiency.

Different Technologies Approach the Cooling Curve Differently

Key Criteria for Offshore FLNG

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CRITERIA	C3MR	SINGLE MIXED REFRIGERANT	DUAL NITROGEN EXPANSION
QUANTITATIVE			
Uses proven technology	Yes	Yes	Yes
Typical Process Efficiency Number (kW-hr/kg LNG)	0.278	0.334	0.447
Estimated Footprint (Liquefaction Only – 2.0 Mtpa)	6,500 m^2	4,600 m^2	3,000 m^2
Weight (2.0 MMTPA Production- 2 Trains)	+30,000 tons	~25,000 tons	~20,000 tons
QUALITATIVE			
Hazardous Refrigerant	Yes	Yes	No
Requirements for Refrigerant Import and/or Storage	Yes	Yes	No
Explosion/BLEVE Hazards	Moderate	Moderate	Low
Flare Capacity	High	High	Low
Sensitivity to vessel motion	High	Moderate	Low
Simplicity of operation	Low	Moderate	High
Total Capital Cost	High	Moderate	Low

Agenda

Conclusion

Conclusion

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No technology is a perfect fit for all applications!
Different factors heavily influence the technology selection including:

- Quantity and Quality of Natural Gas Availability
- Client Approach to Storage*
- Efficiency of Process Desired*
- Safety Concerns
- Dockside, Near-shore, or Off-shore
- Space Requirements and Availability (typically dependent on Storage approach)
- Schedule*

Conclusion

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Thank You!

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