FLNG Liquefaction Technology

Considerations Influencing LNG Technology Selection

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

Introduction to Braemar Engineering
# 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

## 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

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

## Environmental
- Incident response
- Pollution control
- Salvage services
- Accredited training and environmental consulting
- Crisis management and emergency response advisors
- Industrial services and tank cleaning
Braemar Engineering at a Glance

• 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
Characteristics of LNG
Natural Gas Markets

- Reinjection
- Gas Sales
- Gas to Wire
- Pyrolysis: Carbon Black & Hydrogen
- Syngas: Syncrude, Hydrogen, & Methanol
- LNG / CNG

Close to Market
Distant to Market
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

Source: energytribute.com
Liquefied Natural Gas Terminology

- LNG is Natural Gas that has been super cooled to a liquid at -260°F (cryogenic) at pressures near atmospheric conditions.
  - Must be Water/CO₂ free
  - Colorless
  - Odorless
  - Non-toxic
  - Non-flammable (in liquid state)
  - Non-explosive (in liquid state)
  - “Environmentally Friendly” Fossil Fuel

![Image of LNG](image.png)
Liquefied Natural Gas Terminology

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

Economically feasible to ship in Atmospheric Storage Containers.
Main Systems Required for FLNG

- Gas to be Liquefied (pipeline or sub-sea)
- Field Specific Modules
- Quarters, Hull & Hull Systems
- Utilities
- Gas Processing
- Liquefaction
- Product Storage/Containment
- Safety & Security
- Mooring FLNG & Product Carriers
- LNG Product Handling
Factors Influencing FLNG Technology Selection

(In no particular order)
Source and Quantity of Gas

- 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

### Suppliers view of NG Streams…

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.500</td>
</tr>
<tr>
<td>CO2</td>
<td>0.500</td>
</tr>
<tr>
<td>Methane</td>
<td>&gt;96.5</td>
</tr>
<tr>
<td>Ethane</td>
<td>&lt;2.50</td>
</tr>
</tbody>
</table>

### Actual Abbreviated Extended Analysis of a NG Stream…

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

*Devil is in the Details!*  

This doesn’t include trace contaminants water, mercury, H2S, mercaptans, and **Oxygen**!
Solubility of HHC in LNG

**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 C₅+ Components!**
To Remove Heavy Hydrocarbon Components, Facility Must Operate in the Two-Phase Region (Not the Dense Phase Region)
Method of Removing HHC

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 C₂ or lighter)
- Ideal if you have a hydrocarbon “waste” stream (straddle plant)

Simple, Inefficient, and Non-selective Process.
Method of Removing HHC

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 C₂ or lighter)
- Feed gas must be “rich” in C₃+ components (otherwise would be enriching feed gas with C₃+)

Moderate Simple Process for Rich Gas **Does NOT work for Lean Gas**
Method of Removing HHC

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

- Pipeline specifications (tariff based) might allow up to 0.4 mole % Oxygen (typically N.A. problem)

- Problems caused by Oxygen:
  - Non-condensable 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

- 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

- **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 m³ to 170,000 m³)
  - Limited Available Topside Space (approximately 1200 m² to 1500 m²)
  - Limited Technology Options (Nitrogen, Open cycle)

- **Membrane / Prismatic Carriers**
  - Range of Storage (87,000 m³ to 250,000 m³)
  - Larger Available Topside Space (approximately 6,000 m² to 18,000 m²)
  - 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

- 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

- 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

• 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

Traditional LNG Transfer Arms

Cryogenic Hoses
Transfer of Cargo

- 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

- 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.
Agenda

FLNG Technology Selection
Potential FLNG Liquefaction Technology Vendors:

- 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)

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

- 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

- Large vertical heat exchanger
- Two-levels of refrigerant
- Multi-component phase change
Closer the cold stream to the hot stream, the better the efficiency.

Different Technologies Approach the Cooling Curve Differently
## Key Criteria for Offshore FLNG

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>C3MR</th>
<th>SINGLE MIXED REFRIGERANT</th>
<th>DUAL NITROGEN EXPANSION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QUANTITATIVE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uses proven technology</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Typical Process Efficiency Number (kW-hr/kg LNG)</td>
<td>0.278</td>
<td>0.334</td>
<td>0.447</td>
</tr>
<tr>
<td>Estimated Footprint (Liquefaction Only – 2.0 Mtpa)</td>
<td>6,500 m²</td>
<td>4,600 m²</td>
<td>3,000 m²</td>
</tr>
<tr>
<td>Weight (2.0 MMTPA Production- 2 Trains)</td>
<td>+30,000 tons</td>
<td>~25,000 tons</td>
<td>~20,000 tons</td>
</tr>
<tr>
<td><strong>QUALITATIVE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazardous Refrigerant</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Requirements for Refrigerant Import and/or Storage</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Explosion/BLEVE Hazards</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Flare Capacity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Sensitivity to vessel motion</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Simplicity of operation</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Total Capital Cost</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>
Conclusion

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

Thank You!