Floating LNG: Origins and Future Impact on the LNG Industry

SPE Gulf Coast Region

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Floating LNG (FLNG) was conceived as a means of developing stranded gas reserves offshore where pipelines became uneconomic, either by reason of distance or available reserves.

The early concepts were developed along these lines but in the process the other economic benefits came to light. These were controlled yard type construction versus stick built onshore projects with very high costs and poor schedule outcomes in isolated onshore locations.

Ultimately the potential for redeployment after field depletion with relatively minor modifications associated with pre-treatment was another upside.
The early developments were definitely true LNG liquefaction FPSOs and designed along similar lines taking the raw product including condensate, LPG and gas directly from seabed wells.

They included turret systems to take the risers and required condensate removal pre-treatment and fractionation. They were effectively Onshore LNG plants transferred on to a barge (a massive one).

Shell Prelude as the largest FLNG to date is simply massive. It is the largest floating structure ever built.
**SHELL PRELUDE FLNG FACILITY**

- Boeing 747 (71m long)
- Queen Mary 2 (345m)
- Shell Prelude FLNG (488m)

**KEY FACTS**

- The Prelude facility will be 488m long and 74m wide
- It will stay moored in water 250m deep for 25 years
The parallel development in thinking on liquefaction technology and the liquefaction plant size “bigger is better paradigm” began to turn the industry to the consideration that “mid-scale is more manageable.”

Taking the thinking on FLNG hull/storage further the consideration of building a less complex mid-scale LNG liquefaction plant on a barge (ship shaped or not) into a shipyard, appeared to provide an alternative to onshore development.

The impact on cost paradigms has been immense and this in turn has influenced thinking on onshore developments where mid-scale offers good economics and smaller parcels of LNG to sell.
Liquefaction Process Capacity Ranges

At-Shore LNG is at a scale of proven technology and low cost.

Sweet spots:
- 5 mtpa
- 3 mtpa
- 1 to 1.5 mtpa

LNG Technology Summary

- AXENS - LiquefinTM
- Shell - PMR
- Shell - DMR
- APCI - AP-X
- APCI - C3MR or DMR
- APCI - C3MR or DMR with SplitMR
- Conoco Philips-Optimised Cascade Process
- Linde - MFC
- B&V - Prico
- APCI - AP-M (For FPSO's)
- ABB- Niche LNG
- Chart Industries
- Kryopak
- Linde
- Chicago Bridge& Iron
- Hamworthy
- Cryonorm
- BOC

Frame 5, 6 or 7
Frame 7 or 9
Frame 5/LM2500
Frame 5D, 7 or 9

BOC
Cryonorm
Hamworthy
Chicago Bridge& Iron
Linde
Kryopak
Chart Industries
ABB- Niche LNG
APCI - AP-M (For FPSO's)
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AXENS - LiquefinTM

Million Tonnes Per Annum
Floating Liquefaction Systems

- Floating Liquefaction Process Systems
  - Dual Mixed Refrigerant (Most cost-effective & thermally efficient process for >2.0MTPA)
  - Single Mixed Refrigerant (Most commonly considered due to simplicity, hence low cost)
  - Nitrogen Expansion (Safest process, lowest cost but least efficient)

- Refrigeration Compressor Drivers for LNG
  - Steam Turbines
  - Electric Motors
  - Gas Turbines:
    - Industrial
  - Aero derivative
  - Turbo-Expanders

<table>
<thead>
<tr>
<th>Project</th>
<th>LNG Capacity, MTPA</th>
<th>Driver Selection</th>
<th>Total Installed Power, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFLNG1</td>
<td>1.2</td>
<td>Gas Turbine, Electric motors</td>
<td>70</td>
</tr>
<tr>
<td>PFLNG2</td>
<td>1.5</td>
<td>Gas Turbine</td>
<td>78</td>
</tr>
<tr>
<td>Exmar NV</td>
<td>0.5</td>
<td>Gas Turbine</td>
<td>25</td>
</tr>
<tr>
<td>Shell Prelude</td>
<td>3.6</td>
<td>Steam Turbines</td>
<td>Not Known</td>
</tr>
</tbody>
</table>

At-Shore LNG has access to a wide range of proven technologies for mid scale production.
The nearshore concept can take the form of a jetty head as shown here or could be a spread mooring with no jetty.

The next slides show various configurations for various water depths depending on location.
Mooring Systems

Disconnectable Buoy Mooring

- FLNG is able to disconnect and sail away from site
- Suitable for water depth over 55m

Soft Yoke Mooring

- FLNG moored to site; can weathervane to prevailing weather conditions
- Suitable for water depth 20m – 40m
What is At-Shore LNG?

- At-Shore LNG is a further refinement of Nearshore FLNG and uses much of the same topside building blocks and configuration.

- The key cost improvements reside in the simplification of the barge concept to reflect the immediate proximity to land and the benign met-ocean environment. It also facilitates the potential to either bargeside or landside, elements of the facility.

- An At-Shore LNG unit is depicted in the next slide but is essentially an integrated LNG facility on one unit.

- It comprises an 8 module facility to include all pre-treatment, utilities/power and 3 liquefaction units.

- It utilises the lowest cost fabrication concept for LNG storage in a barge concept which considerably reduces material requirements.
Schematic: At-Shore LNG Facility
## What are the Key Differences for At-Shore LNG?

<table>
<thead>
<tr>
<th>Feature</th>
<th>Offshore FLNG</th>
<th>At-shore LNG</th>
<th>Inshore FLNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feedstock</td>
<td>Subsea Production (raw gas)</td>
<td>Pipeline Specification Conditioned Gas</td>
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</tr>
<tr>
<td>Upstream Architecture</td>
<td>Subsea Gathering System</td>
<td>Interstate and intra-state grid</td>
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</tr>
<tr>
<td>FLNG Substructure</td>
<td>Shipshape (FPSO)</td>
<td>Barge or ship shape vessel with integrated storage</td>
<td>Shipshape (FPSO)</td>
</tr>
<tr>
<td>FEED Gas Treatment Requirement</td>
<td>Acid Gas Removal, Dehydration, Hq Removal Required</td>
<td>Required, but to a lower duty specification due to (a) gas pre-conditioning and (b) benign motions</td>
<td>Required, but to a lower duty specification due to (a) gas pre-conditioning and (b) moderately benign motions</td>
</tr>
<tr>
<td>Feed Gas Pre-treatment Location</td>
<td>On FPSO</td>
<td>On Barge or (optionally) at-shore</td>
<td>On FPSO</td>
</tr>
<tr>
<td>LNG Liquefaction</td>
<td>On FPSO</td>
<td>On Barge</td>
<td>On FPSO</td>
</tr>
<tr>
<td>FLNG Liquefaction Cycles FEED Matured</td>
<td>Turbo-expander, SMR and DMR</td>
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</tr>
<tr>
<td>MCHE</td>
<td>PFHEs are robust, SWHEs require enhancement for structural integrity and performance</td>
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<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
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<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>AGRU Columns and Scrub Column</td>
<td>Significant design margins required to ensure onspecification performance, avoidance of channelling etc arising from FPSO motion envelope.</td>
<td>Lower design margins required due to benign motions. Lower duty specifications for columns arising from gas pre-conditioning to pipeline specification.</td>
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</tr>
<tr>
<td>Cooling Medium</td>
<td>Typically Seawater Cooling</td>
<td>Discharge of Seawater at shoreline may breach IFC/World Bank guidelines due to temperature rise. Could require adoption of air-cooling with layout implications</td>
<td>Depending on inshore location, same concern as with at-shore discharge could apply</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Generation on FPSO</td>
<td>Power supply, if reliable, can be arranged from onshore grid</td>
<td>Usually generation from FPSO. However, proximity to shore grid could be arranged as cabled power supply from onshore grid</td>
</tr>
<tr>
<td>Main Control Room, Warehousing and LO</td>
<td>Required on-board FPSO</td>
<td>Could be considered for location onshore in proximity of jetty</td>
<td>On-board FPSO</td>
</tr>
<tr>
<td>LNG and LPG Storage</td>
<td>IHI Prismatic or Twin Row Membrane (case by case review based on prevailing metocean)</td>
<td>Single Row Tanks (standard membrane may be feasible)</td>
<td>Twin Row Membrane or IHI Prismatic</td>
</tr>
<tr>
<td>LNG Offloading</td>
<td>Side to Side Offloading with loading arms or cryogenic hose</td>
<td>Jetty based loading arm</td>
<td>Loading arms for inshore jetty or side-by-side loading (loading arms or cryogenic hose) where no jetty installed</td>
</tr>
</tbody>
</table>
LNG plants whether At-Shore or Onshore have certain common characteristics:

- Feedgas Supply
- Gas Pre-Treatment
- LNG Liquefaction
- Infrastructure
FLNG – Typical Cost Components

Topsides & Hull Make Up over 75% of Total Cost
The original onshore LNG conversions in the USA were based around existing LNG import plants with all of the pipeline infrastructure in place.

This was a considerable benefit to those projects as it gave a schedule and cost advantage over greenfield projects where the new pipelines have to be permitted and installed.

New Onshore and Nearshore projects in the US Gulf Coast will need new pipeline connections for gas. This can be quite extensive involving multiple pipeline connections for guaranteed gas availability.

At-Shore LNG facilities will need new pipeline connections for gas (from existing and new infrastructure) and as such are somewhat comparable to new USGC onshore projects.
LNG Vessels have grown in size over the decades driven by a number of factors including the demand for a clean energy source and the infrastructure and technologies to support this growth.

At-Shore LNG is expected to be able to accommodate all ship sizes (with the exception of Q-Max)
LNG/FLNG EPC Liquefaction costs

At-Shore LNG – Artists Rendering
FID Readiness Cost Estimate

- Trending reductions in cost over the last two years are highly dependent on the state of the shipbuilding/fabrication market in Asia for the At-Shore projects.

- Supply chain softness in cryogenic equipment and materials supports the reducing cost trend.

- The cost profile for Onshore LNG plants in the USGC is more likely to see upward pressure in costs, particularly for labour, subcontractor services and locally supplied materials like concrete, over the next 2-3 years due to the overheated construction market and labour shortages.

- The issue of FID readiness is a major consideration at present and a story of continuing vigilance by all LNG project developers, in order to capture the current weakness in the shipbuilding/fabrication and cryogenic supply chain.
US Gulf Coast LNG World Class Onshore project costs have been heavily influenced by the availability of Brownfield locations with most required permits and existing infrastructure.

Their costs when taking into account the value of sunk cost infrastructure like storage and marine facilities, are in the $600 to $800 per tpa range.

USGC mid-scale Onshore Greenfield Projects are claimed to be in the $500 to $700 per tpa range.

The main risk and uncertainty surrounding mid-scale USGC Onshore project costs are as follows:

- Storage capacity of terminals and their adequacy for delayed shipping.
- Hurricane and storm disruption.
- Shortage of craft labour on the USGC.
- Rapid increase in labour costs on the USGC.
North American mid-scale At-Shore LNG Projects are claimed to be in the $500 to $700 per tpa cost although none have been advanced as far as the mid-scale onshore plants in terms of FEED development, so these figures carry a greater degree of uncertainty.

On that basis North American At-Shore and USCG Onshore would appear to have a comparable costs.

The At-Shore LNG Projects will have an infrastructure and marine component amounting to circa 10% of the project cost. The labour content in this will be in the 20% to 30% range. Labour is really the only major variable in the project cost
Current progress shows a capex cost for facility in the range of $500 - $700 per tonne of LNG production.
The primary constraint on new LNG developments, whether Onshore or At-Shore is the market. Currently there is an overhang of supply globally which is unlikely to diminish before 2022 or thereabouts.

This does not mean that new projects will not take FID, but that this is only likely for vertically integrated projects.

The byword in the industry is FID Ready, as the weakness in the contracting and fabrication market will be mopped up fairly quickly once the supply overhang gets down to a manageable level.
At-Shore LNG approach enables mid-scale modularisation to manage cost and schedule and compete with Onshore.

Pipeline specification Feedgas reduces processing requirements compared to conventional FLNG

Lower Capex projects will be available for the next few years due to the softness in the industry, but will quickly readjust when the trend goes positive.

Current progress shows a capex cost for mid-scale liquefaction facilities in the range of $500 - $700 per tonne of LNG production