LNG Storage Solutions: A Key Consideration and Element in LNG Terminal Operation

Presented by:
Hal Bouknight – Senior Vice President of Business Development
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3. Variation of Storage Tanks for Oil and Gas
4. Tank Material for Low-Temperature Application
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12. Total Solution in LNG Value Chain
IHI Overview
IHI can stand behind your project through its financial strength and support network of 10 major manufacturing centers in Japan plus multiple world wide locations in key industrial segments.
For over 160 years, IHI has helped customers solve their most challenging problems.
We combine process expertise and technology know-how to deliver Full EPC solutions successfully.

- HSE performance is a top priority
- Proven project delivery model
- Full service EPC/CM capabilities
- Direct-hire Construction
- Commissioning and Start-Up services
- Ability to leverage HVEC resources
- Global procurement reach

1080 Eldridge Parkway, Houston, TX
Perspective
Projected U.S. natural gas exports reflect the spread between domestic natural gas prices and world energy prices

The United States transitions from being a net imported of natural gas to a net exported by 2017 in all cases.
Variation of Storage Tanks for Oil and Gas
Variation of Storage Tanks for Oil and Gas

- **Gas Storage**
  Propane, Butane, Nitrogen & Various Industrial Gas

- **Liquid Storage**
  Crude Oil, Heavy Oil, Water

- **Liquefied Gas Storage**
  LNG, LPG, Ethylene, Ammonia, etc.
Tank Material for Low-Temperature Application
Use low temperature steel with suitable fracture strength.

<table>
<thead>
<tr>
<th>Liquid Temperature</th>
<th>°C</th>
<th>°F</th>
<th>Steel Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butane (i)</td>
<td>-12</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>-33</td>
<td>-27</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>-45</td>
<td>-49</td>
<td></td>
</tr>
<tr>
<td>Propylene</td>
<td>-48</td>
<td>-54</td>
<td>High Tensile Steel, Carbon-Manganese Steel</td>
</tr>
<tr>
<td>Ethane</td>
<td>-88</td>
<td>-126</td>
<td>3.5% - 5.5% Ni Steel</td>
</tr>
<tr>
<td>Ethylene</td>
<td>-104</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Methane/ LNG</td>
<td>-163</td>
<td>-261</td>
<td>7% - 9% Ni Steel</td>
</tr>
<tr>
<td>Argon</td>
<td>-186</td>
<td>-303</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-196</td>
<td>-315</td>
<td>9% Ni steel</td>
</tr>
<tr>
<td></td>
<td>-325</td>
<td></td>
<td>API 620 Appendix-Q</td>
</tr>
</tbody>
</table>
Typical Property for Liquefied Gas
Typical Property for Liquefied Gas – LNG

- Main component: Methane (CH4)
- Liquid at -162°C (−260°F).
- Volume of LNG reduced to 1/600 of gaseous state
- Colorless, odorless, clean
  - Liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons
- Density of LNG is roughly 0.42 to 0.48 kg/L
  1. Ocean Transportation
     The reduction in volume makes it much more cost-efficient to transport over long distances where pipelines do not exist.
  2. Large-Volume Storage
     Where large volume natural gas storage is not economical, it can be stored as LNG in specially designed cryogenic tanks.
Storage Concept
### THREE DIFFERENT MAIN CONCEPTS FOR LNG

<table>
<thead>
<tr>
<th>Type</th>
<th>Single Containment</th>
<th>Double Containment</th>
<th>Full Containment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td>Only Inner Container Contain Liquid</td>
<td>Both Inner And Outer Container Contain Liquid</td>
<td>Both Inner And Outer Container Contain Liquid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annular Space Shall Not Be More Than 6 M (20 Ft)</td>
<td>The Secondary Container Is Capable To Contain Both Liquid And Vapor</td>
</tr>
<tr>
<td>Inner Tank</td>
<td>Liquid Tight Container</td>
<td>Liquid And Vapor Tight Container</td>
<td>Liquid Tight Container</td>
</tr>
<tr>
<td>Outer Tank</td>
<td>Vapor Tight Container</td>
<td>Liquid Tight Container</td>
<td>Liquid And Vapor Tight Container</td>
</tr>
<tr>
<td>Dike Wall</td>
<td>Require As Secondary Liquid Container</td>
<td>Not Required</td>
<td>Not Required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Except as may be required by Fire Safety codes or FERC/PHMSA</td>
<td></td>
</tr>
</tbody>
</table>

**Single Containment**

- Inner Tank
- Dike Wall

**Double Containment**

- Annular Space

**Full Containment**

- Outer Tank
Full Containment Type Tank
## Typical Schedule (160,000m³)

<table>
<thead>
<tr>
<th>Work Type</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete work</strong></td>
<td></td>
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<tr>
<td>Slab</td>
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<tr>
<td>PC Wall</td>
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<tr>
<td>RC Roof</td>
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<tr>
<td><strong>Mechanical Work</strong></td>
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</tr>
<tr>
<td>Bottom Liner</td>
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</tr>
<tr>
<td>Steel Roof</td>
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<tr>
<td>Suspended Deck</td>
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<tr>
<td>Bottom Insulation</td>
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<tr>
<td>Roof Air Lifting</td>
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<tr>
<td>Inner Tank</td>
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<tr>
<td>Hydrostatic test</td>
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<tr>
<td>Wall insulation</td>
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<td></td>
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<tr>
<td>Drying, Purge</td>
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</tbody>
</table>
The graph shows the relationship between EPC Cost and Cost per Unit Volume (m$^3$) as a function of Volume (m$^3$). The blue line represents the trend for EPC Cost, which decreases as the volume increases. The red line represents the trend for Cost per Unit Volume, which increases as the volume increases.

Specifically, at a volume of 160,000 m$^3$, the EPC Cost is 100%. The cost per unit volume is not explicitly shown, but the trend indicates an inverse relationship with volume, as the cost per unit volume increases as the volume increases.
Full Containment Type Tank

Conceptual Diagram Of Tank

Inner Tank (Primary Container)
9% Ni Steel

Outer Tank (Secondary Container)
Concrete
Steel Roof (Outer Tank)
Inner Tank Shell (9% Ni Steel)
Hydrostatic Test
Completion of Full Containment Tank
Conversion of Import to Export or Bidirectional Terminal – Considerations
Existing LNG Storage Tanks – Changes in Operation

- Current state of the existing LNG storage tank(s)
- Assuming conversion from import to export (LNG side)
  - LNG loading and unloading rates (reversed)
  - Generally new larger or additional pump(s) required
  - Existing well with changes in pump discharge nozzles or
  - Additional well(s) with new larger nozzles on the tank(s)
  - Use of spare well requiring additional piping, instruments
  - Overall in-tank pumps pumping rate changes will generally leads to
  - Roof-top piping, instruments, structural changes due to the larger pumps or in the worst case scenario additional nozzle(s)/well(s)
  - Safety considerations for the Pressure/Vacuum conditions at the LNG tanks
Finished Concrete Roof
Existing LNG storage tank(s) reconfiguration

• Possible changes to the tank or tank roof top
  – Modification requirement – major/minor
  – Is tank entry required? i.e likely major changes
  – Where structural or other major changes required:
    ✓ Perform structural analysis including FEA analysis for the roof-top
  – Construction methods varies depending on:
    ✓ Existing tank type (single/double/full containment)
    ✓ Changes to the roof top only, internal, or both

• If major reconfiguration – requiring tank-entry
  – Tank warm-ups or re-cooling analysis
  – Decommissioning of the tank(s)
  – Inspections
  – Modifications / testing / commissioning

• Schedule and cost considerations if reconfiguration required
In-ground Storage Tank
Structure of In-Ground LNG Storage Tanks

- Membrane (Stainless Steel)
- Insulation (Polyurethane Foam)
- Roof (low temperature steel)
- Concrete Wall
- Side & Bottom Heaters
- Insulation (Polyurethane Foam)
**Typical Schedule (200,000m³)**

<table>
<thead>
<tr>
<th>Activity</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
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<tbody>
<tr>
<td>Civil Work</td>
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<tr>
<td>Steel Roof</td>
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<tr>
<td>Roof Insulation</td>
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<tr>
<td>Roof Air Lifting</td>
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<tr>
<td>Wall Insulation</td>
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<tr>
<td>Bottom Insulation</td>
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</tr>
<tr>
<td>Wall Membrane</td>
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<td></td>
</tr>
<tr>
<td>Bottom Membrane</td>
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<tr>
<td>Inspection/Test</td>
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<td></td>
</tr>
<tr>
<td>Purge, Drying</td>
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<td></td>
</tr>
</tbody>
</table>
Civil Work – Wall Concrete and Heater
Wall Membrane (SS 304)
Approach for 250,000kl World Largest LNG Storage Tank

Inside view of 250,000kl tank

**Tokyo Gas Ohgishima Works**

<table>
<thead>
<tr>
<th>Capacity</th>
<th>250,000 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner Diameter</td>
<td>72 m (236 ft)</td>
</tr>
<tr>
<td>Liquid Height</td>
<td>61.7 m (202 ft)</td>
</tr>
</tbody>
</table>

**CONCEPT**
1. Same Diameter for the Land District
2. Construction Of Maximum Volume
Variations for Cryogenic Storage Concepts
Variations of Cryogenic Storage Concepts

Onshore       Above ground       Membrane Type - PC Membrane

Small-Mid Scale - Vertical Perlite Insulation Tank

Marine

Floating Storage

SPB Tanks - FSO

Membrane - FPSO

Ground Mounted

Offshore GBS - GBS Tank

Marine

Note: SPB – Self - Supporting Prismatic IMO Type B

GBS – Gravity Base Structure

FPSO – Floating Production, Storage and Offloading Unit

FSRU – Floating Storage and Regasification Unit

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LNG PC Membrane Tank

- RC Roof
- PC Wall
- Suspended Deck
- Membrane (2mm SS304)
- Polyurethane Foam Insulation
- Moisture Barrier
- Thermal Corner Protection (up to 5m height)
Vertical Perlite Insulated Tank for LNG

Outline Drawing

Outer Tank (Carbon Steel)

Insulation (Perlite, Nitrogen Gas)

Content (LNG)

Inner Tank (Stainless Steel)
Outline of SPB Cargo Tank System

Self-supporting, Prismatic-shape IMO type B

Structural concept based on long history and experiences in marine technology

- Robust
- Best fit to hull form
- Restricts motions of cargo liquid inside
Floating Storage/Floating Terminal

LNG-FSO

FLNG

FLPG

IHI-SPB®

LNG Carrier

LNG FSRU

Note: FPSO – Floating Production, Storage and Offloading Unit
FSRU – Floating Storage and Regasification Unit
GBS Membrane Type

GBS Membrane Tank Construction Procedure
Improving Tank Technology
IHI has executed LNG tank seismic test by METI in 1996 to 1999. Large scale model of 8.0m diameter tank has been shaken on the test bench.
Experiment Study of TSUNAMI

IHI Yokohama R&D Center
Focus on Shorter Tank Construction Period

Conventional Roof Air Lift Method: 39 Months

J.C. Method (Jack Climbing Method): Potentially Reduce up to 14 Months
Total Solution in LNG Value Chain
IHI has over the 40 years of experience in developing numerous LNG Import Terminals, Liquefaction Projects, LNG Storage Tanks, and LNG carrier projects. IHI has the proven experience to provide the total LNG Solutions.
IHI
Realize your dreams

Contributing to the development of society through technology