Latest Tank Design for the World’s Largest 270,000m³ Full Containment LNG Tank

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CONTENT

- KOGAS LNG Import
- KOGAS LNG Terminals
- KOGAS LNG Tank Development
- 270,000m³ Full Containment Tank
- Inner Tank Design
- Outer Tank Design
- Roof Frame Design
- EPC Cost Estimates
- Conclusions
KOGAS Overview

KOGAS is solely responsible for nation’s import and supply of natural gas
KOGAS LNG Import in 2010

Total LNG Import
31.8 MT (44 bcm)
Gas Demand Pattern in Korea

Natural Gas Demand in Korea in 2010

- High demand in winter season
- High TDR : 2.5 (TDR : Turn Down Ratio)
  - 3.6 for city gas
  - 1.6 for power generation

Requires Very Large Storage Capacity
LNG Storage Capacity in Korea

Year 2011
8.12 Mm³

Year 2017
15.57 Mm³

(million cubic meters)

PT (Pyeongtaek Terminal), IC (Incheon Terminal), TY (Tongyeong Terminal), SC (Samcheok Terminal), DHGW (Donghai Gas Well)
KOGAS Overview - Natural Gas Supply

◆ LNG Terminals

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Start-up</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyeongtaek</td>
<td>1986</td>
<td>In Service</td>
</tr>
<tr>
<td>Incheon</td>
<td>1996</td>
<td>In Service ★</td>
</tr>
<tr>
<td>Tongyeong</td>
<td>2002</td>
<td>In Service</td>
</tr>
<tr>
<td>Samcheok</td>
<td>2013</td>
<td>Under Construction</td>
</tr>
<tr>
<td>Jeju</td>
<td>2017</td>
<td>Planned</td>
</tr>
</tbody>
</table>

★ The biggest LNG terminal in the world
● LNG Tanks in service : 56
● LNG Tanks under construction : 13

◆ Transmission Pipeline Networks
● Pipeline in service : 2,879 km
● Pipeline under construction : 1,111 km
Incheon LNG Terminal

- Unloading: 2 berths x 11,000 m³/h
- LNG storage capacity: 2.88 million m³
  - 10 above-ground tanks x 100k
  - 10 in-ground tanks (2 x 140k, 8 x 200k)
- 10 BOG compressors x 12,000 m³/h
- 3 HP compressors x 20 ton/h
- 4 Recondensers x 30 ton/h
- Vaporization: 4,230 ton/h
Pyeongtaek LNG Terminal-II

**Terminal-II**
- Jetty: 1 berth, acceptable for Q-max ship, 11,000 m³/h
- LNG storage Capacity: 2.36 Mm³
  - 1.96 Mm³ in operation (4 tanks x 140K, 7 tanks x 200K)
  - 0.40 Mm³ under construction (2 tanks x 200K)
- 6 BOG compressors x 12,000 m³/h
- 2 Recondensers x 30 ton/h
- Vaporization: 2,160 ton/h

**Terminal-I**
- Vaporization: 2,300 ton/h
- 1 Recondensers x 60 ton/h
- 6 BOG compressors x 12,000 m³/h
- LNG storage capacity: 1.00 Mm³ (10 tanks x 100K, membrane type)
- Jetty: 1 berth, conventional ships, 11,000 m³/h
Tongyeong LNG Terminal

- **Unloading**: 1 berth x 11,000 m³/h
- **LNG storage capacity**: 2.62 Mm³
  - 15 tanks (12x140k, 3x200k) in operation
  - 2 tanks (1x140k, 1x200k) under const.
- **4 BOG compressors** x 12,000m³/h
- **2 Recondensers** x 17 ton/h
- **Vaporization**: 1,350 ton/h
Samcheok LNG Terminal

- Unloading: 15,000 m³/h
- LNG storage: 2.61 Mm³
  - 9 tanks x 200,000m³
  - 3 tanks x 270,000m³
- 7 BOG compressors x 12,000m³/h
- 2 Recondensers x 30 ton/h
- Vaporization: 1,320 ton/h
  - 6 ORVs x 180 ton/h
  - 2 SMVs x 120 ton/h
**Jeju LNG Terminal (planned)**

- **Storage**: 2 tanks x 25,000m³
- **2 BOG compressors** x 4,000m³/h
- **Vaporization**: 40 ton/h
  - Air vaporizers
  - Steam vaporizers (back-up)
- LNG tanker lorry station for Seogwipo area
Kogas’ LNG Tank Development Projects

Phase-1 (1997-2002) : Development of LNG Tank Technologies
- Key technologies and materials for LNG tanks
- Construct a 1000m³ pilot LNG storage tank to prove the LNG tank technologies developed at KOGAS
- Membrane containment LNG tank of 140,000m³
- Full containment LNG tank of 140,000m³
  → Applied to 12 tanks at Tongyeong & Pyeongtaek Terminals

Phase-2 (2004-2005) : Development of 200,000m³ LNG Tanks
- Full containment LNG tank of 200,000m³
  → Applied to 22 tanks at Tongyeong, Pyeongtaek and Samcheok Terminals
- Membrane containment LNG tank of 200,000m³
  → Applied to 2 tanks at Incheon Terminal

Phase-3 (2009-2011) : Development of 270,000m³ LNG Tanks
- Full containment LNG tank of 270,000m³
  → will install 3 tanks at Samcheok Terminal
Kogas’ LNG Tank Development

- **270,000m³** Full Containment Above-ground
- **200,000m³** Above-ground 9% Ni Full Containment Membrane Containment
- **1,000m³** Pilot LNG tank
- **140,000m³** above-ground 9% Ni Full Containment Membrane Containment

In-ground 200,000m³ Membrane containment
Pilot LNG Storage Tank

Specifications
- Type: elevated, membrane, suspended deck
- Kogas membrane containment system
  - STS304 corrugated membrane
  - PUF insulation
- Inner diameter 13.76m, height 10.92m
- Outer tank: Pre-stressed concrete (600mmt)
  - Outer diameter 15.38m, height 14.21m
- Net capacity: 1,000m³ (gross 1,300m³)
- Operating level: 1.5~8.81m
- Design pressure: -5~450mbarg
- Operating pressure: 50~350mbarg
- Boil-Off Rate: 0.53vol%/day
- LNG Pump: 50m³/h x 2, 15bar
  - Started operation in 2001

Objectives
- Verify design, construction and operation technologies to develop commercial tanks
- Studies on LNG storage behavior

Features
- Applied Kogas membrane containment system
- Installed a stress measurement system for membrane
- The unique LNG storage tank for R&D purposes
- Connected with the processes of Incheon terminal

Practical Uses
- Evaluation of Kogas containment system
- LNG storage and boil-off behavior studies
- Cyclic fatigue test of warm-up and cool-down
- LNG tank commissioning training
### Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Gross capacity</td>
<td>200,000 m³</td>
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<tr>
<td>Design pressure</td>
<td>29 kPa</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>5-25 kPa</td>
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<tr>
<td>Design BOR</td>
<td>0.05-0.075%/day</td>
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<tr>
<td>Design liquid level</td>
<td>34.61 m</td>
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<tr>
<td>Type of base</td>
<td>Electric heating or Brine heating</td>
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<tr>
<td>Type of roof</td>
<td>Concrete dome</td>
</tr>
<tr>
<td>Inner tank (STS membrane)</td>
<td>Diameter 85.9 m, Height 39.05 m</td>
</tr>
<tr>
<td>Outer tank (PS concrete)</td>
<td>Diameter 86.4 m, Height 52.9 m</td>
</tr>
</tbody>
</table>
200K FC LNG Tank (KFa-200)

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Gross capacity</td>
<td>200,000 m³</td>
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<tr>
<td>Design pressure</td>
<td>29 kPa</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>5-25 kPa</td>
</tr>
<tr>
<td>Design BOR</td>
<td>0.05%wt/day</td>
</tr>
<tr>
<td>Design liquid level</td>
<td>36.22m</td>
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<tr>
<td>Type of base</td>
<td>Electric heating or Brine heating</td>
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<tr>
<td>Type of roof</td>
<td>Concrete dome</td>
</tr>
<tr>
<td>Inner tank (9% nickel steel)</td>
<td>Diameter 84.0m Height 37.6m</td>
</tr>
<tr>
<td>Outer tank (PS concrete)</td>
<td>Diameter 86.4m Height 52.8m</td>
</tr>
</tbody>
</table>

As compared to a net 160K LNG tank,
- Cost-cutting in erection: 9 MUSD per tank
- Saving of construction site: approx. 17%
KOGAS LNG Tank Technologies

KMa : Kogas Membrane type, above-ground Tank
KMi : Kogas Membrane type, in-ground Tank
KFa : Kogas Full containment, above-ground Tank
TY, PT, IC, SC : Tongyeong, Pyeongtaek, Incheon, Samcheok LNG Terminal

Membrane Containment Technology

Pilot LNG Tank (1,000m³)

KMa-140 (140,000m³)

KM-200 (200,000m³)

Full Containment Technology

KMa-200 (200,000m³)

IC #19-20 (in-ground tank)

FL-LNG TK (Australia)

KC-1 LNG Carrier

LNG-LRC (Lined Rock Cavern)

KFa-140 (140,000m³)

KFa-200 (200,000m³)

TY #6-12,17 PT #11-14

TY #13-16 PT #15-23 SC #1-9

POSCO #3-4 PTT LNG #1-2 SLNG #1-2

Implementation for SC#10-12

POSCO : Kwangyang LNG Terminal
SLNG : Singapore LNG Terminal
FL-LNG : Fisherman's Landing LNG Liquefaction Plant
# Kogas’ LNG Tank Design Record

<table>
<thead>
<tr>
<th>Country</th>
<th>LNG Project</th>
<th>No. of Tanks</th>
<th>Tank No.</th>
<th>Type of Tank</th>
<th>Capacity of Tank (m³)</th>
<th>Status</th>
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<tbody>
<tr>
<td><strong>Korea</strong></td>
<td>Pyeongtaek</td>
<td>4</td>
<td>11 - 14</td>
<td>Full Containment</td>
<td>140,000</td>
<td>in operation</td>
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<td>(KOGAS)</td>
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<td>7</td>
<td>15 - 21</td>
<td>Full Containment</td>
<td>200,000</td>
<td>in operation</td>
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<td>22 - 23</td>
<td>Full Containment</td>
<td>200,000</td>
<td>under construction</td>
</tr>
<tr>
<td>Tongyeong</td>
<td>7</td>
<td>6 - 12</td>
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<td>Full Containment</td>
<td>140,000</td>
<td>in operation</td>
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<td>1</td>
<td>17</td>
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<td>Full Containment</td>
<td>140,000</td>
<td>under construction</td>
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<td>3</td>
<td>13 - 15</td>
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<td>Full Containment</td>
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<td>in operation</td>
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<td>Incheon</td>
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<td>19 - 20</td>
<td>Membrane</td>
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<td>200,000</td>
<td>in operation</td>
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<td>(POSCO)</td>
<td>Samcheok</td>
<td>9</td>
<td>1 - 9</td>
<td>Full Containment</td>
<td>200,000</td>
<td>under construction</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10 - 12</td>
<td></td>
<td>Full Containment</td>
<td>270,000</td>
<td>construction in 2012</td>
</tr>
<tr>
<td>Kwangyang</td>
<td>2</td>
<td>3 - 4</td>
<td></td>
<td>Full Containment</td>
<td>165,000</td>
<td>operation/construction</td>
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<tr>
<td>Thailand</td>
<td>PTTLNG</td>
<td>2</td>
<td>1 - 2</td>
<td>Full Containment</td>
<td>160,000</td>
<td>under construction</td>
</tr>
<tr>
<td>Singapore</td>
<td>SLNG</td>
<td>2</td>
<td>1 - 2</td>
<td>Full Containment</td>
<td>150,000</td>
<td>under construction</td>
</tr>
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<td>Australia</td>
<td>LNG Limited</td>
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<td>1</td>
<td>Membrane</td>
<td>180,000</td>
<td>in suspension</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>46</strong></td>
<td></td>
<td></td>
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</tbody>
</table>
Guidelines for the 270,000m³ LNG Tank

- Design in accordance with the requirements of EN 14620:2006
- Above-ground, full containment LNG storage tank
- 9% nickel steel open top inner tank
- Pre-stressed concrete outer tank
- Concrete dome roof with carbon steel vapor barriers
- Suspended ceiling deck
- 9% nickel steel secondary bottom liner
- Thermal protection system up to 5 meters high from the tank bottom
- Bottom heating system in the base slab
- Gross capacity: 270,000 m³
- Design pressure: 29 kPa
- Design boil-off rate: 0.04 wt%/day
- Seismic loads: SSE 0.3g, OBE 0.15g
Inner Tank Design Procedure

- Design Condition
  - Working Volume
  - NPSH
  - Plate Dimension
  - Allowable Stress
  - Filling Height

- Diameter of Inner Tank

- Shell Height

- Shell Courses

- Static Calculation
  - Shell Thickness
  - Annular Plate
  - Stiffener Ring

- Dynamic Calculation
  - Seismic Shell Hoop Tension
  - Shell Thickness
  - Moment on Base
  - Stress & Stability Check
  - Sliding Force

- Shell Thickness

- Annular Plate

- Stiffener Ring

- Bottom Plate

- Design Condition
  - BOR Calculation Results
  - Annular Space
  - Insulation Properties

- Shell Insulation

- Material Selection

- Calculation of Inner Tank Movement

- Calculation of Perlite Pressure

- Blanket Material and Thickness

- Bottom Insulation

- Material Selection

- Arrangement of Insulation

- Calculation of Total Weight on Insulation

- Calculation of Seismic Test Load

- Choose Material
Heat Leak Calculation

- **Design BOR**: 0.04 wt% per day
- **Total Heat Leak**: 259.6 kW
  - 29% from shell
  - 33% from roof
  - 38% from bottom
Considerations for Tank Sizing

- **Tank Capacity**
  - Gross capacity
  - Net capacity

- **Tank Diameter**
  - Inner tank diameter
  - Insulation thickness
  - Outer tank diameter

- **Tank Height**
  - Inner tank height
  - Outer tank height

- **Inner Tank D/H Ratio**
General View of the 270,000m³ Tank
Inner Tank Structure

Bottom Corner Arrangement

Structure of Inner Tank

- Inner Tank
- Perlite Powder
- Cellular Glass
- Resilient Blanket
- Inner Shell
- Top Stiffener
- Intermediate Stiffeners
- Annular Plate (thick plate)
- Bottom Plate (thin plate)
- PCB
- Concrete

Dimensions:
- 92.4m
- 90.0m
- 1200
Buckling Analysis

Critical Buckling Load > 3 x Perlite Pressure
Thermal Analysis for Corner Protection

Normal Operation

Emergency Cases

Minor Leak

Major Leak

NT11

-1.7001e+02

-1.5251e+02

-1.3501e+02

-1.1801e+02

-1.0101e+02

-0.8401e+02

-0.6701e+02

-0.5001e+02

-0.3301e+02

-0.1601e+02

-1.3001e-02

-1.5251e-02

-1.7001e-02
Design of Internal Pipes

![Diagram showing design of internal pipes with labels for Bottom Fil, Pump Wells, and Still Wells.](image-url)
Outer Tank Design Procedure

**Inner Tank Dimensions**

**Outer Tank Dimensions**

**Concrete Outer Tank Design Conditions**

**Roof Cupola Design Conditions**

**Static Analysis**
- 2D Liner Analysis
- Thermal Analysis
- Spillage Case Analysis

**Structural Analysis**
- Before Air Raising
- After Air Raising

**Dynamic Analysis**
- Response Spectrum
- Time History Analysis
- Secondary Response Spectrum

**Stress Check**

**Connection Check**

**Outer Tank Section Design**
- ULS & SLS Check, etc.

**Dynamic Analysis for Inner Tank**
3D Linear Analysis for Earthquake

Vertical - Roof Acceleration

Inplane Force

Horizontal - Overturning

Hoop Force
Thermal Analysis – Stress Contours

Bottom Corner

Summer

Winter

Top Corner
Roof Frame Design

- Model-A: before air raising
- Model-B: after air raising
Comparison of Tank Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>unit</th>
<th>N160</th>
<th>G200</th>
<th>N200</th>
<th>G270</th>
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<tbody>
<tr>
<td>Gross Capacity</td>
<td>m³</td>
<td>171,500</td>
<td>200,000</td>
<td>212,700</td>
<td>270,000</td>
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<td>Net Capacity</td>
<td>m³</td>
<td>160,000</td>
<td>187,300</td>
<td>200,000</td>
<td>255,400</td>
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<td>Design Pressure</td>
<td>kPa</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
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<tr>
<td>Design BOR</td>
<td>wt%/d</td>
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<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
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<td>Design Liquid Level</td>
<td>m</td>
<td>34.25</td>
<td>36.22</td>
<td>38.52</td>
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<td>Inner Tank Diameter</td>
<td>m</td>
<td>80.0</td>
<td>84.0</td>
<td>84.0</td>
<td>90.0</td>
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<tr>
<td>Inner Tank Height</td>
<td>m</td>
<td>35.62</td>
<td>37.6</td>
<td>39.92</td>
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<td>Outer Tank Diameter</td>
<td>m</td>
<td>84.4</td>
<td>86.4</td>
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<tr>
<td>Shell Insulation Thick</td>
<td>mm</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
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<td>1st Course Plate Thick</td>
<td>mm</td>
<td>29.6</td>
<td>32.9</td>
<td>34.9</td>
<td>39.4</td>
</tr>
</tbody>
</table>

The above data are estimated on the basis of the KOGAS design philosophy (‘N’ means net capacity and ‘G’ gross capacity)
The 270,000m$^3$ Tank Construction Project

**Samcheok LNG Terminal**

- **Tanks Nos. 10 to 12**
  - Design: 2011-2012
  - Erection: 2012-2016
  - Operation: 2016

**270,000m$^3$**
## Construction Period

### Typical Construction Period for the Tanks G200 and G270

<table>
<thead>
<tr>
<th>Tank</th>
<th>Description</th>
<th>1st Year</th>
<th>2nd Year</th>
<th>3rd Year</th>
<th>4th Year</th>
<th>Action</th>
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<tbody>
<tr>
<td>G200</td>
<td>Design</td>
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<td>Construction</td>
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<td>EPC Contractor</td>
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<td></td>
<td>Commissioning</td>
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<td>Commissioning</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>KOGAS</td>
</tr>
</tbody>
</table>

G200: LNG storage tank with a gross capacity of 200,000m³  
G270: LNG storage tank with a gross capacity of 270,000m³
EPC Costs at KOGAS

- The EPC cost for one cubic meter storage capacity for the tank G270 is 15% less expensive than that for G200 in Korea.
- Accordingly, it is possible to save the EPC cost of 68 USD/m³ or 23.5 MUSD for a storage of 270,000 m³.
- When three 270,000 m³ tanks are installed at Samcheok Terminal, it is expected to cut the EPC cost of approx. 70.5 MUSD.

<table>
<thead>
<tr>
<th>Tanks</th>
<th>Gross Capacity (V)</th>
<th>EPC Cost (C)</th>
<th>USD/m³ (U=C/V)</th>
<th>For 270,000m³ (U x 270,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G200</td>
<td>200,000 m³</td>
<td>115.8 MUSD</td>
<td>579 USD</td>
<td>156.3 MUSD</td>
</tr>
<tr>
<td>G270</td>
<td>270,000 m³</td>
<td>132.8 MUSD</td>
<td>492 USD</td>
<td>132.8 MUSD</td>
</tr>
<tr>
<td>Difference</td>
<td>70,000 m³</td>
<td>17.0 MUSD</td>
<td>- 87 USD</td>
<td>- 23.5 MUSD</td>
</tr>
</tbody>
</table>

- EPC costs do not include the cost for the tank foundation (ground preparation, piling)
- MUSD : million US dollar
Conclusions

- KOGAS developed the world’s largest full containment LNG storage tank with a gross capacity of 270,000m$^3$.
- The typical design of the 270,000m$^3$ tank was completed in 2011 and the detailed design for the tanks Nos. 10 to 12 at the KOGAS Samcheok LNG Terminal will be finished till early 2012.
- Compared to the 200,000m$^3$ tank, the 270,000m$^3$ tank can provide a cost-saving of 15% and an additional storage capacity of 35% (in Korea).
- KOGAS expects a cost-cutting of approx. 70 million US dollars and an additional storage capacity of 210,000m$^3$ from the 2nd Samcheok Terminal expansion project (tanks Nos.10 to 12).