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International Gas Union Research Conference

Latest Tank Design for the World's Largest 270,000m^3 Full Containment LNG Tank

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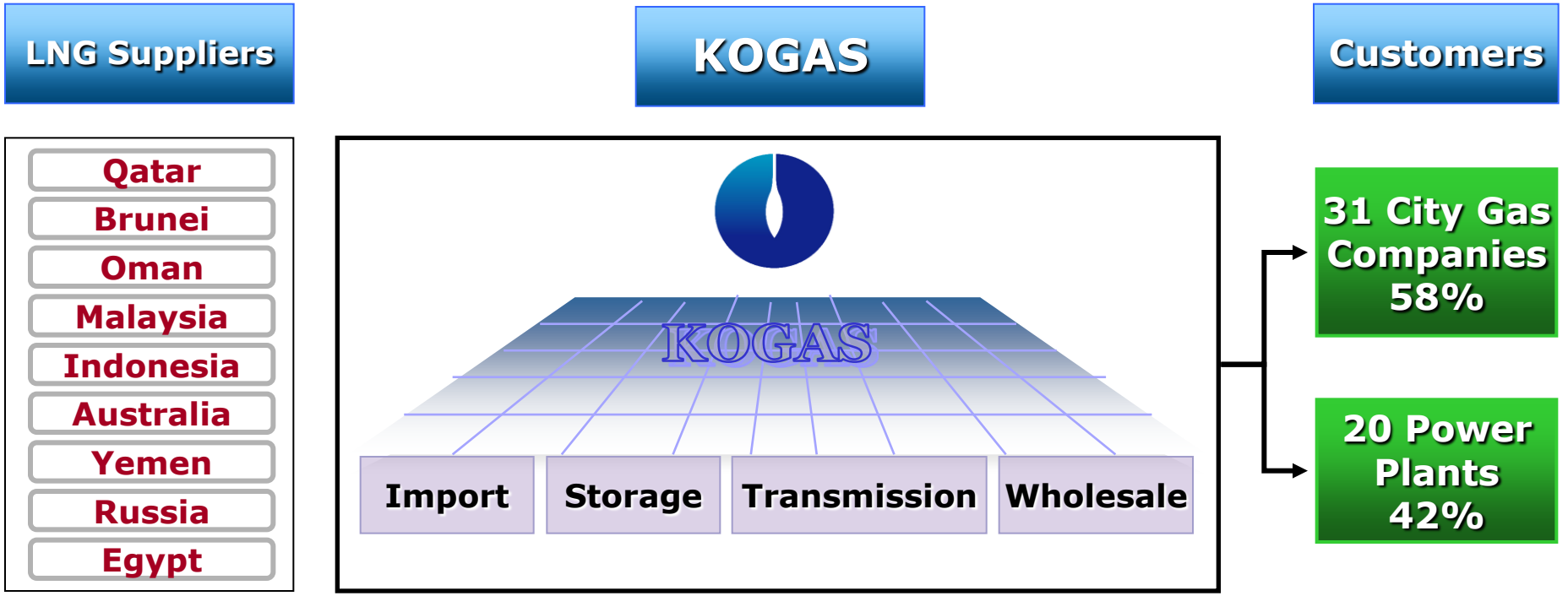
- KOGAS LNG Import
- KOGAS LNG Terminals
- KOGAS LNG Tank Development
- 270,000m^3 Full Containment Tank
- Inner Tank Design
- Outer Tank Design
- Roof Frame Design
- EPC Cost Estimates
- Conclusions

KOGAS Overview

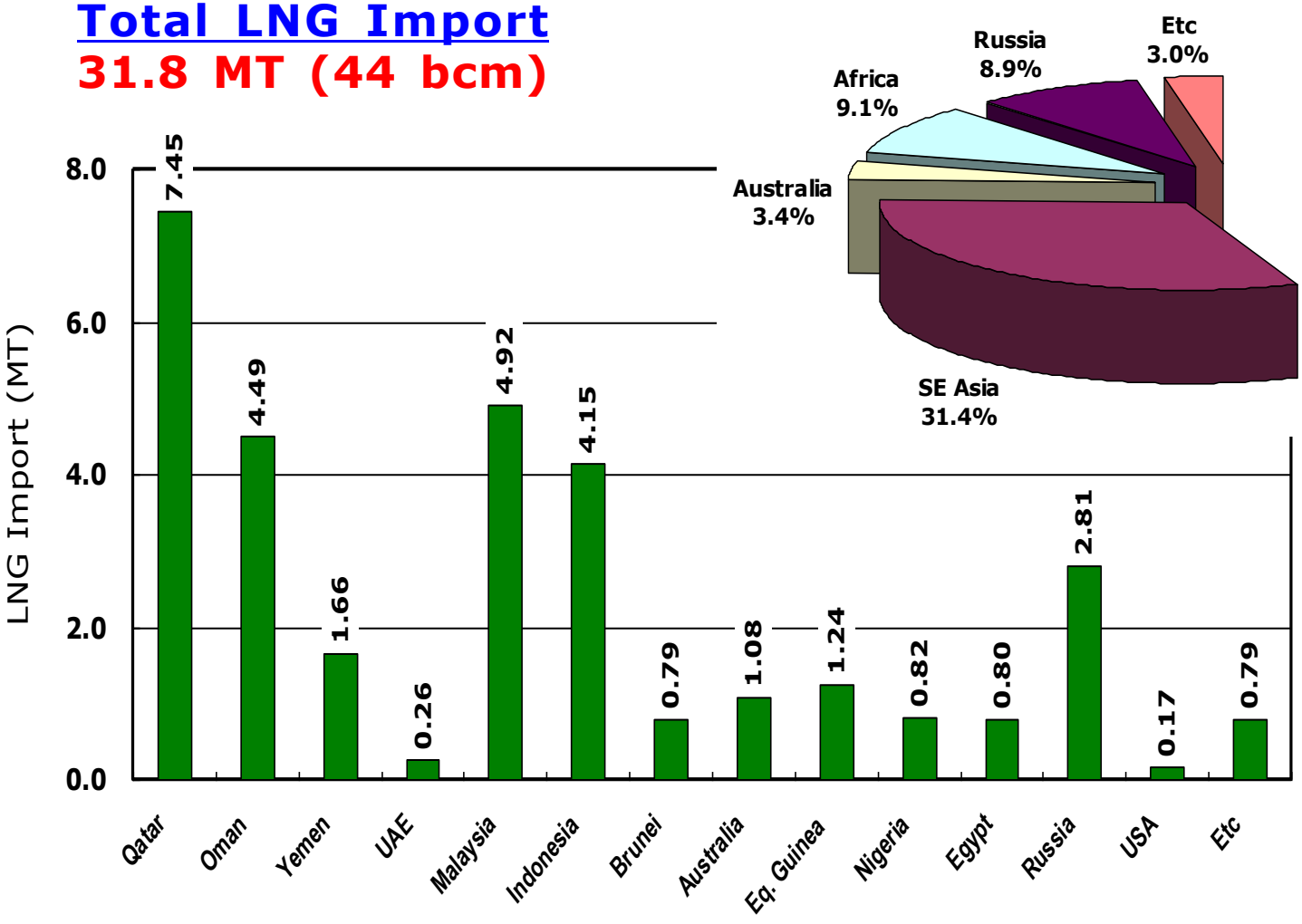


KOGAS is solely responsible for nation's import and supply of natural gas

KOGAS LNG Import in 2010

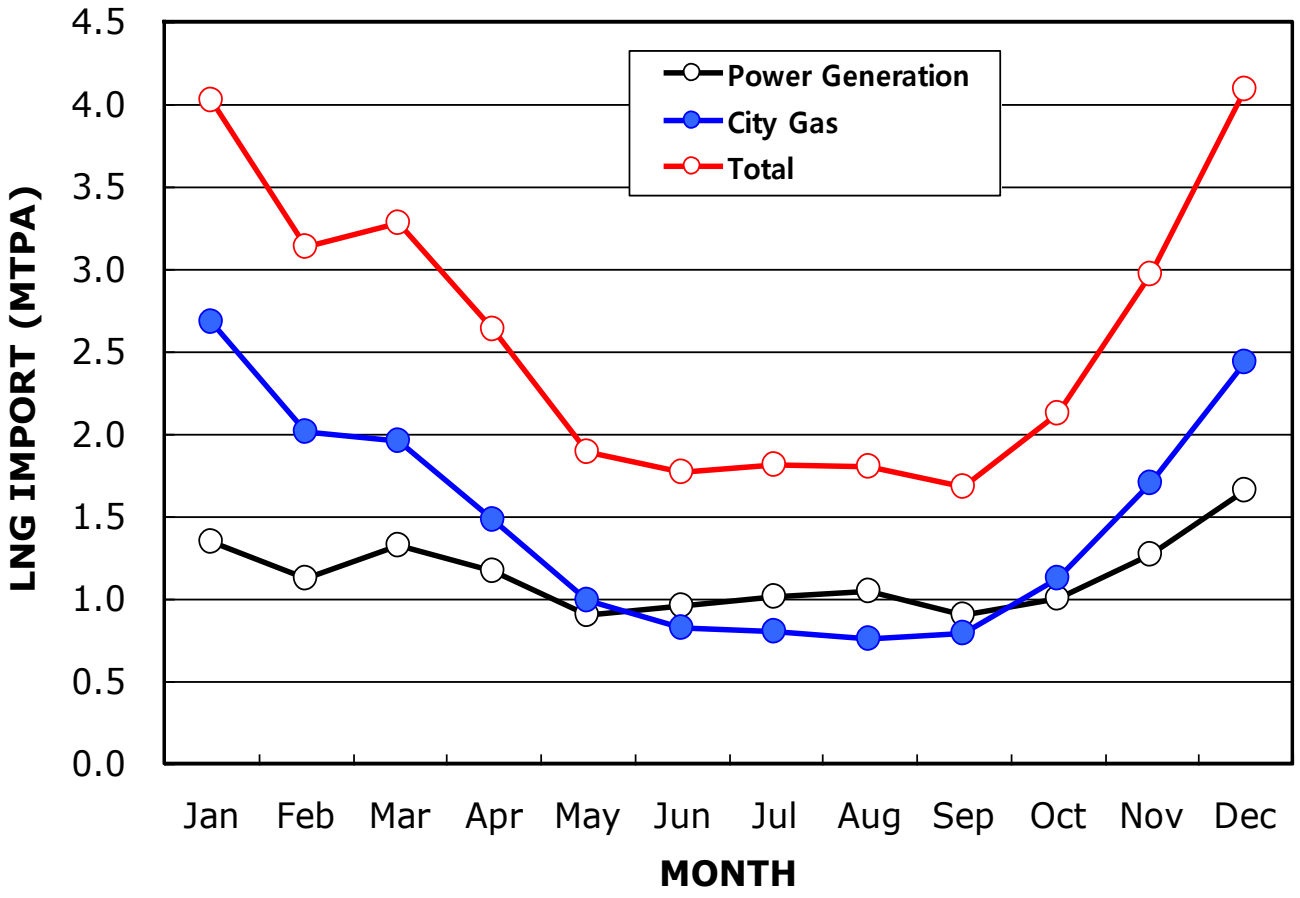
Total LNG Import

31.8 MT (44 bcm)



Gas Demand Pattern in Korea

Natural Gas Demand in Korea in 2010



Requires Very Large Storage Capacity

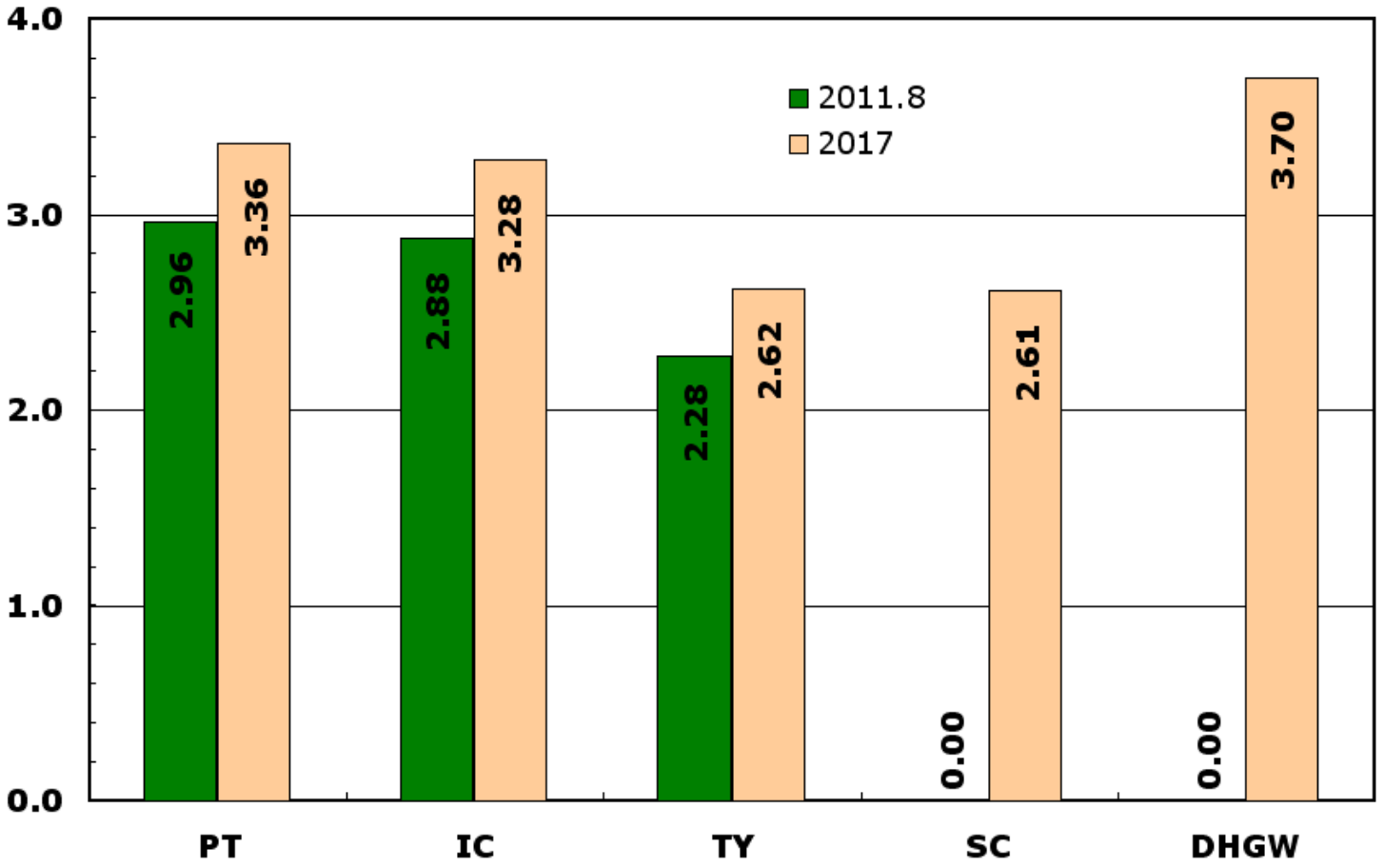
- **High demand in winter season**
- **High TDR : 2.5**

(TDR : Turn Down Ratio)

- **3.6 for city gas**
- **1.6 for power generation**

LNG Storage Capacity in Korea

(million cubic meters)

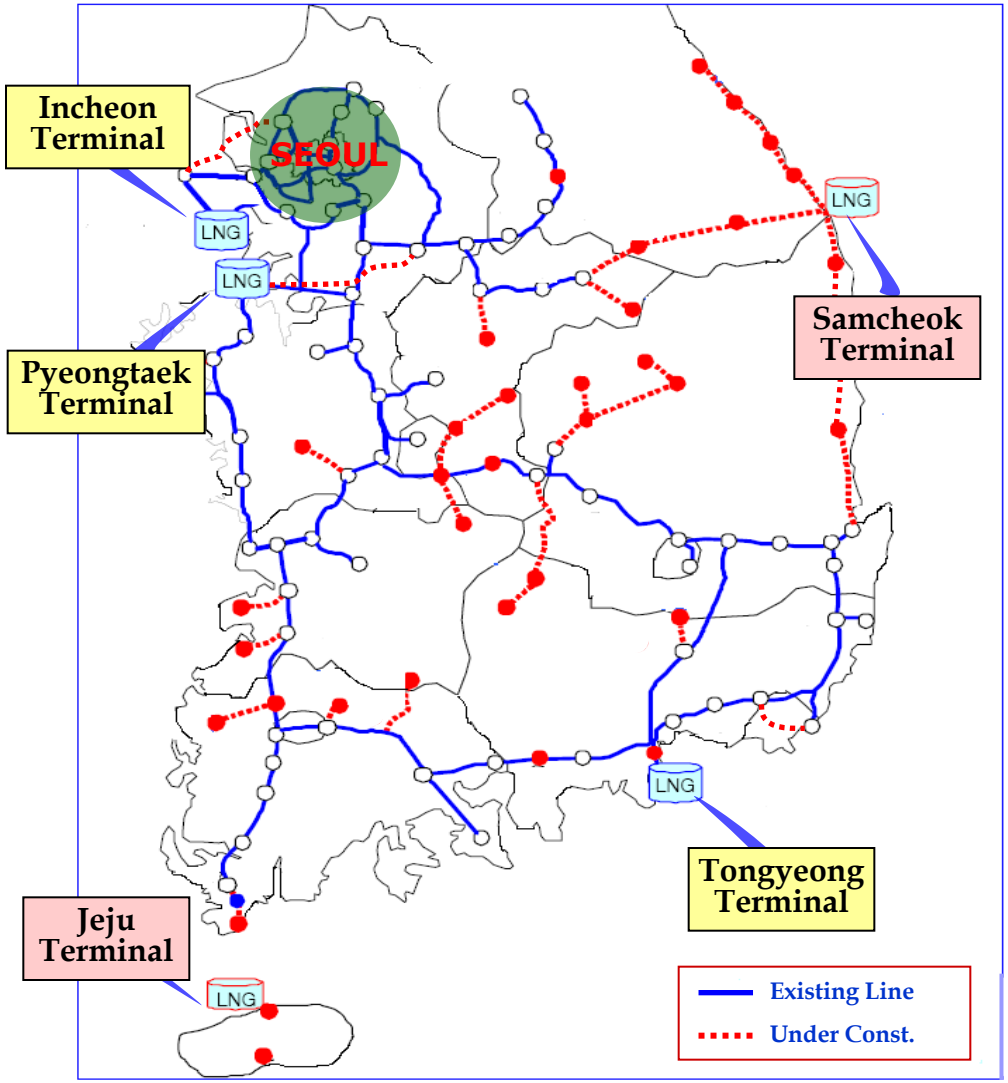


Year 2017
15.57 Mm^3

Year 2011
8.12 Mm^3

PT (Pyeongtaek Teminal), IC (Incheon Terminal), TY (Tongyeong Terminal), SC (Samcheok Terminal), DHGW (Donghai Gas Well)

KOGAS Overview - Natural Gas Supply



◆ LNG Terminals

Terminal	Start-up	Remarks
Pyeongtaek	1986	In Service
Incheon	1996	In Service ★
Tongyeong	2002	In Service
Samcheok	2013	Under Construction
Jeju	2017	Planned

★ 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 m^3/h
- LNG storage capacity : 2.88 million m^3
  - 10 above-ground tanks x 100k
  - 10 in-ground tanks (2 x 140k, 8 x 200k)
- 10 BOG compressors x 12,000 m^3/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**

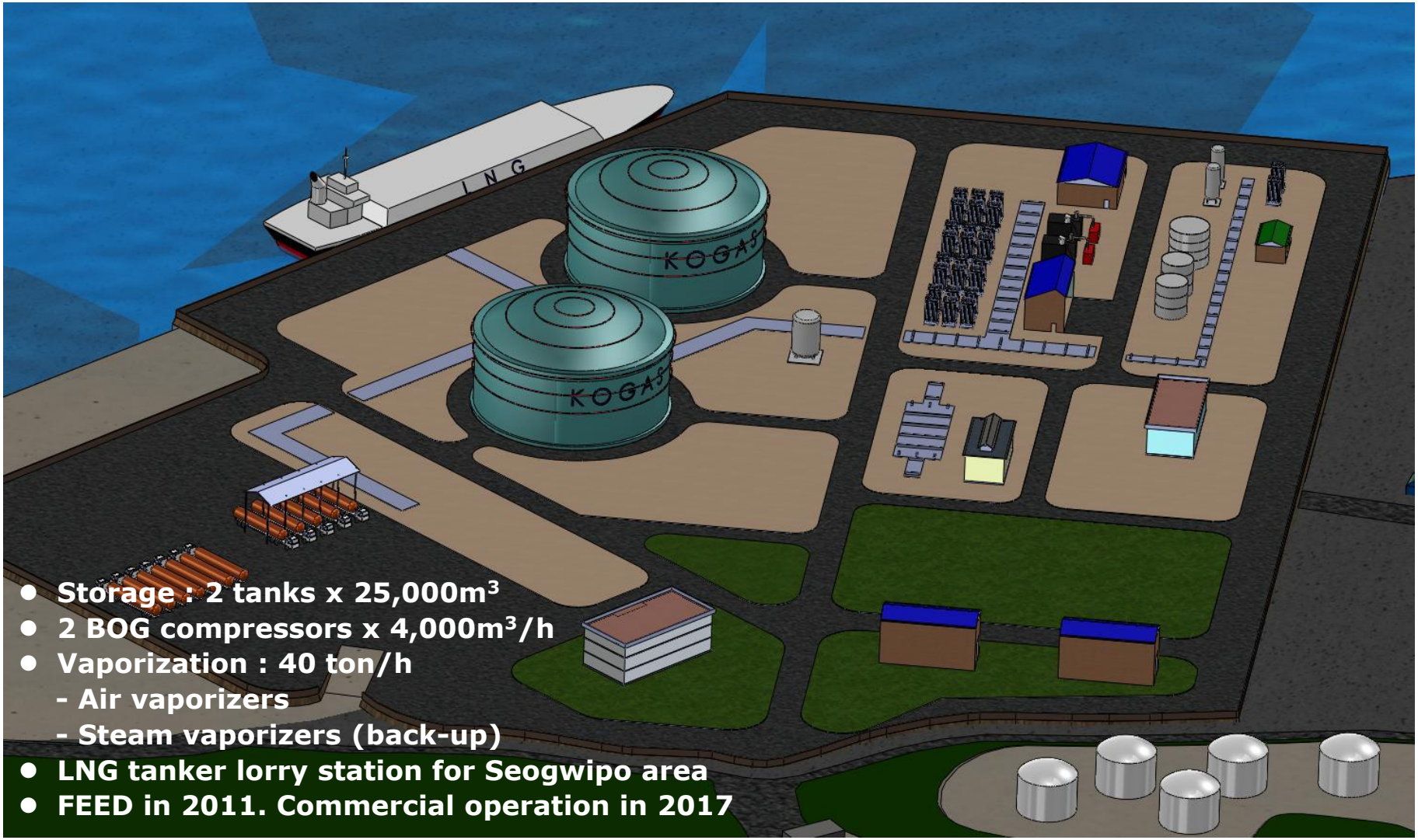
Tongyeong LNG Terminal

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

Samcheok LNG Terminal

- Unloading : 15,000 m^3/h
- LNG storage : 2.61 Mm^3
  - 9 tanks x 200,000m^3
  - 3 tanks x 270,000m^3
- 7 BOG compressors x 12,000m^3/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
- FEED in 2011. Commercial operation in 2017

Kogas' LNG Tank Development Projects

- **Phase-1 (1997-2002) : Development of LNG Tank Technologies**
  - Key technologies and materials for LNG tanks
  - Construct a 1000m^3 pilot LNG storage tank to prove the LNG tank technologies developed at KOGAS
  - Membrane containment LNG tank of 140,000m^3
  - Full containment LNG tank of 140,000m^3

    → **Applied to 12 tanks at Tongyeong & Pyeongtaek Terminals**

- **Phase-2 (2004-2005) : Development of 200,000m^3 LNG Tanks**
  - Full containment LNG tank of 200,000m^3

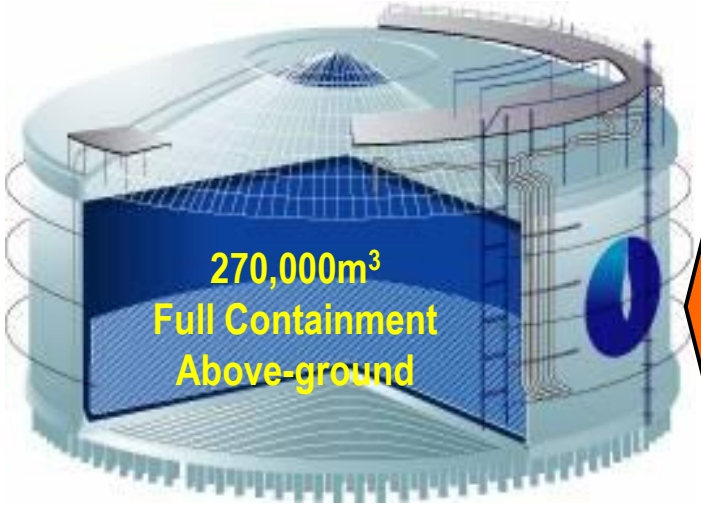
    → **Applied to 22 tanks at Tongyeong, Pyeongtaek and Samcheok Terminals**
  - Membrane containment LNG tank of 200,000m^3

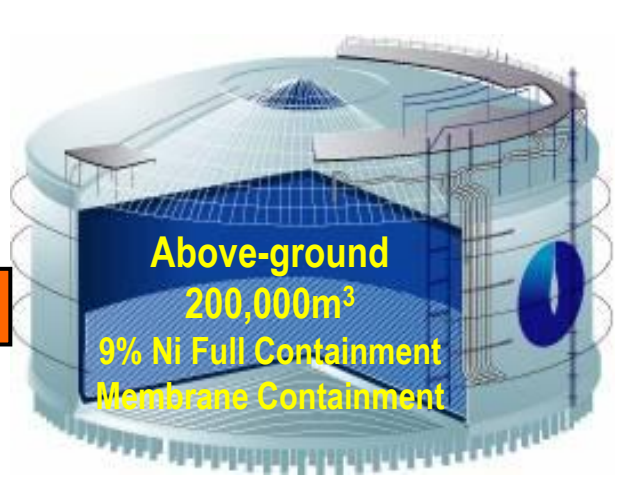
    → **Applied to 2 tanks at Incheon Terminal**

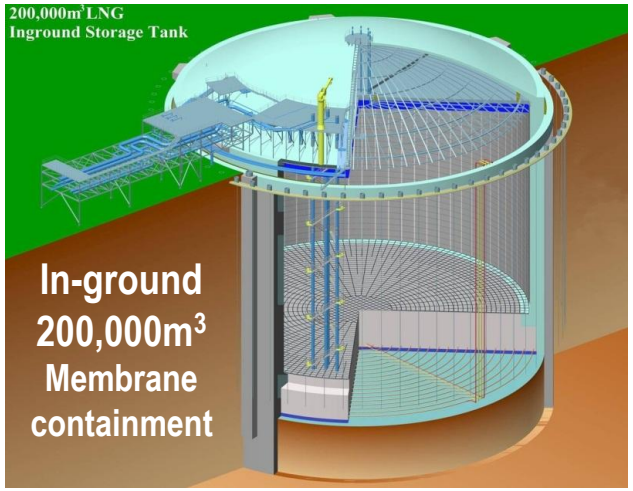
- **Phase-3 (2009-2011) : Development of 270,000m^3 LNG Tanks**
  - Full containment LNG tank of 270,000m^3

    → **will install 3 tanks at Samcheok Terminal**

Kogas' LNG Tank Development







Pilot LNG Storage Tank

❒ 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

❒ 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 : 1,000m^3 (gross 1,300m^3)
- Operating level : 1.5~8.81m
- Design pressure : -5~450mbarg
- Operating pressure : 50~350mbarg
- Boil-Off Rate : 0.53vol%/day
- LNG Pump : 50m^3/h x 2, 15bar
- ❖ Started operation in 2001

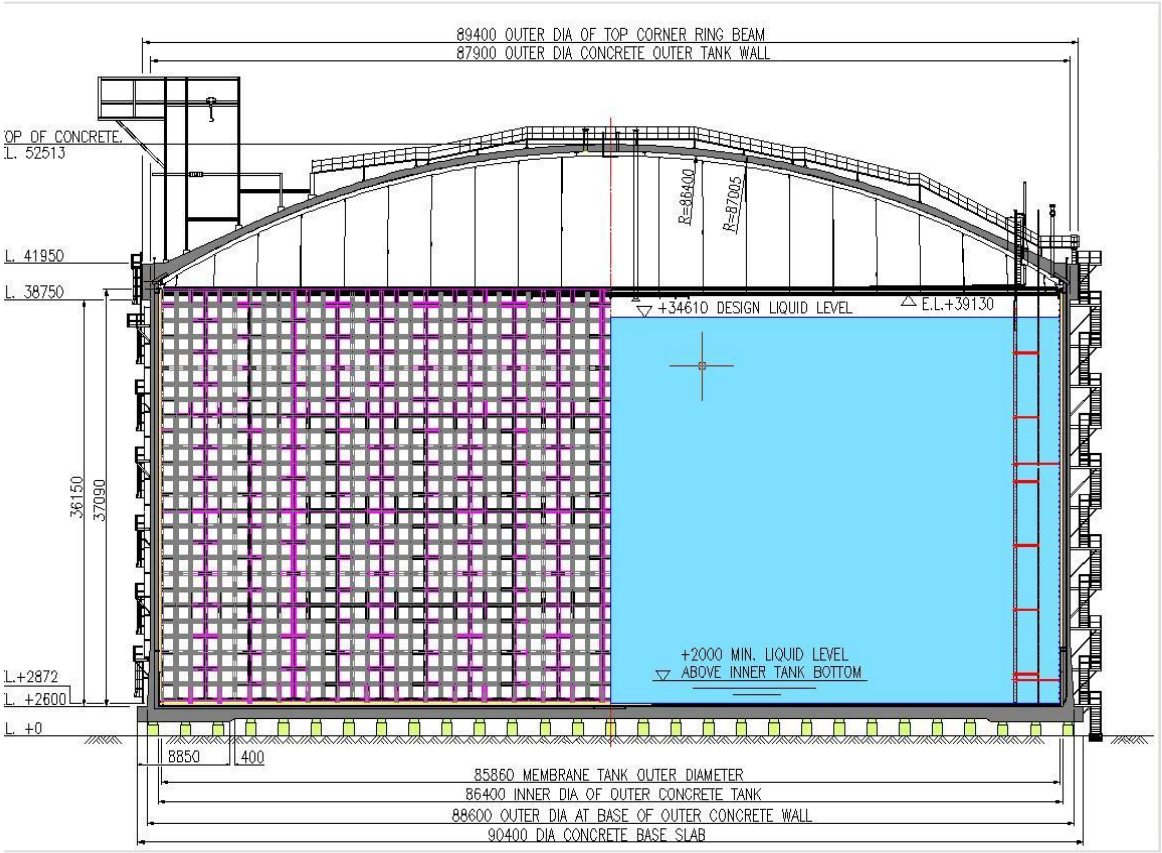
❒ Practical Uses

- 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**

200K MC LNG Tank (KMa-200)

Specifications

Gross capacity	200,000 m^3
Design pressure	29 kPa
Operating pressure	5-25 kPa
Design BOR	0.05-0.075%/day
Design liquid level	34.61m
Type of base	Electric heating or Brine heating
Type of roof	Concrete dome
Inner tank (STS membrane)	Diameter 85.9m Height 39.05m
Outer tank (PS concrete)	Diameter 86.4m Height 52.9m



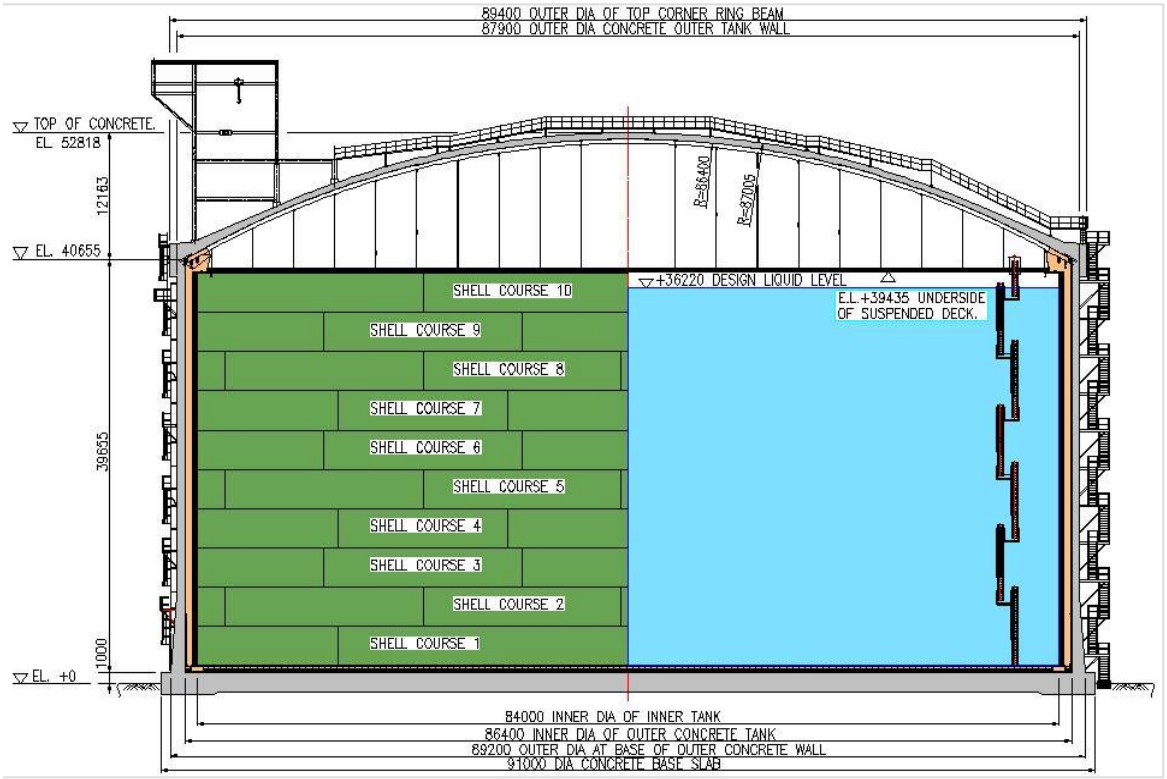
200K FC LNG Tank (KFa-200)

Specifications

Gross capacity	200,000 m^3
Design pressure	29 kPa
Operating pressure	5-25 kPa
Design BOR	0.05%wt/day
Design liquid level	36.22m
Type of base	Electric heating or Brine heating
Type of roof	Concrete dome
Inner tank (9% nickel steel)	Diameter 84.0m Height 37.6m
Outer tank (PS concrete)	Diameter 86.4m Height 52.8m

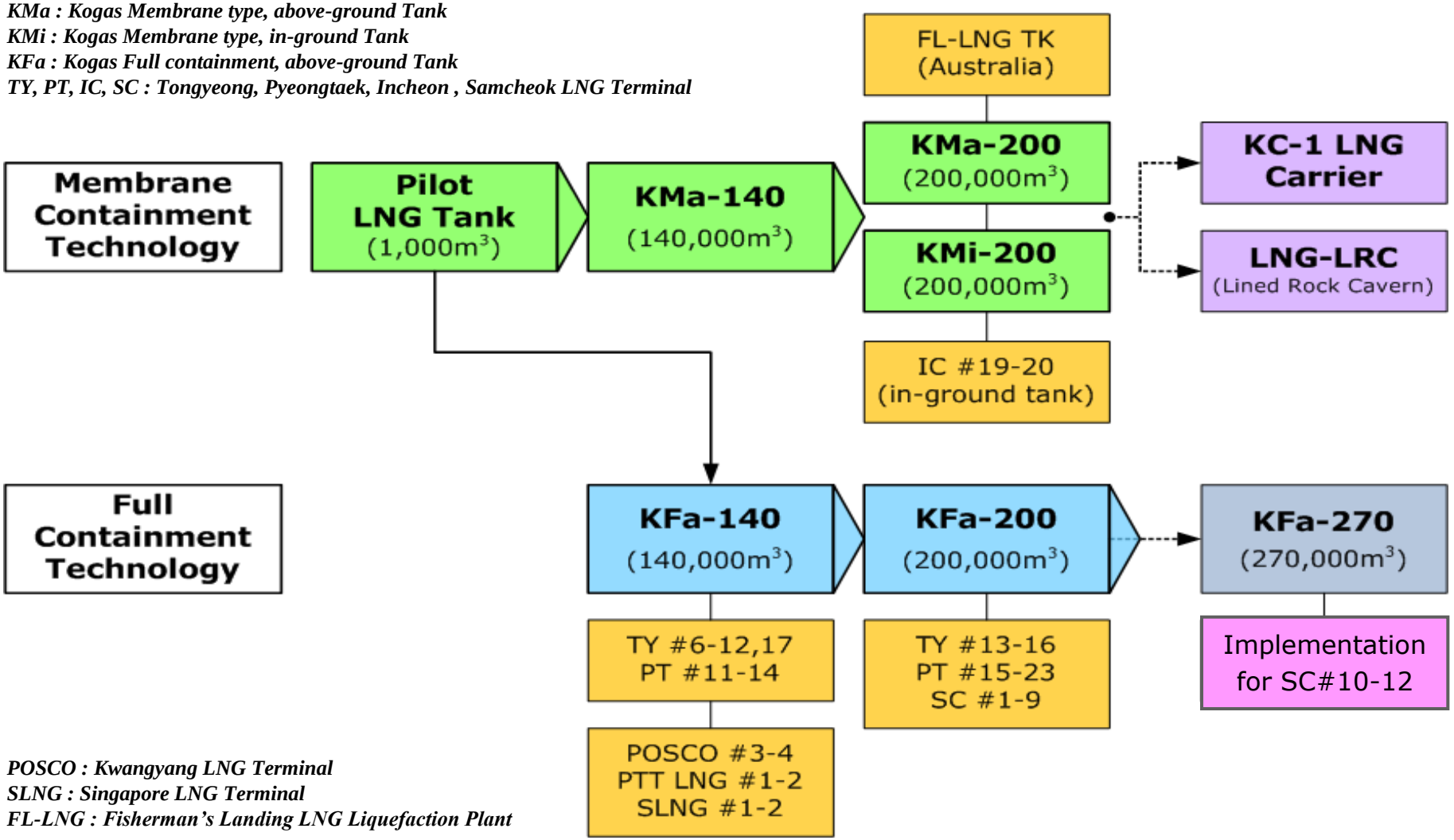
As compared to a net 160K LNG tank,

- **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



POSCO : Kwangyang LNG Terminal
SLNG : Singapore LNG Terminal
FL-LNG : Fisherman's Landing LNG Liquefaction Plant

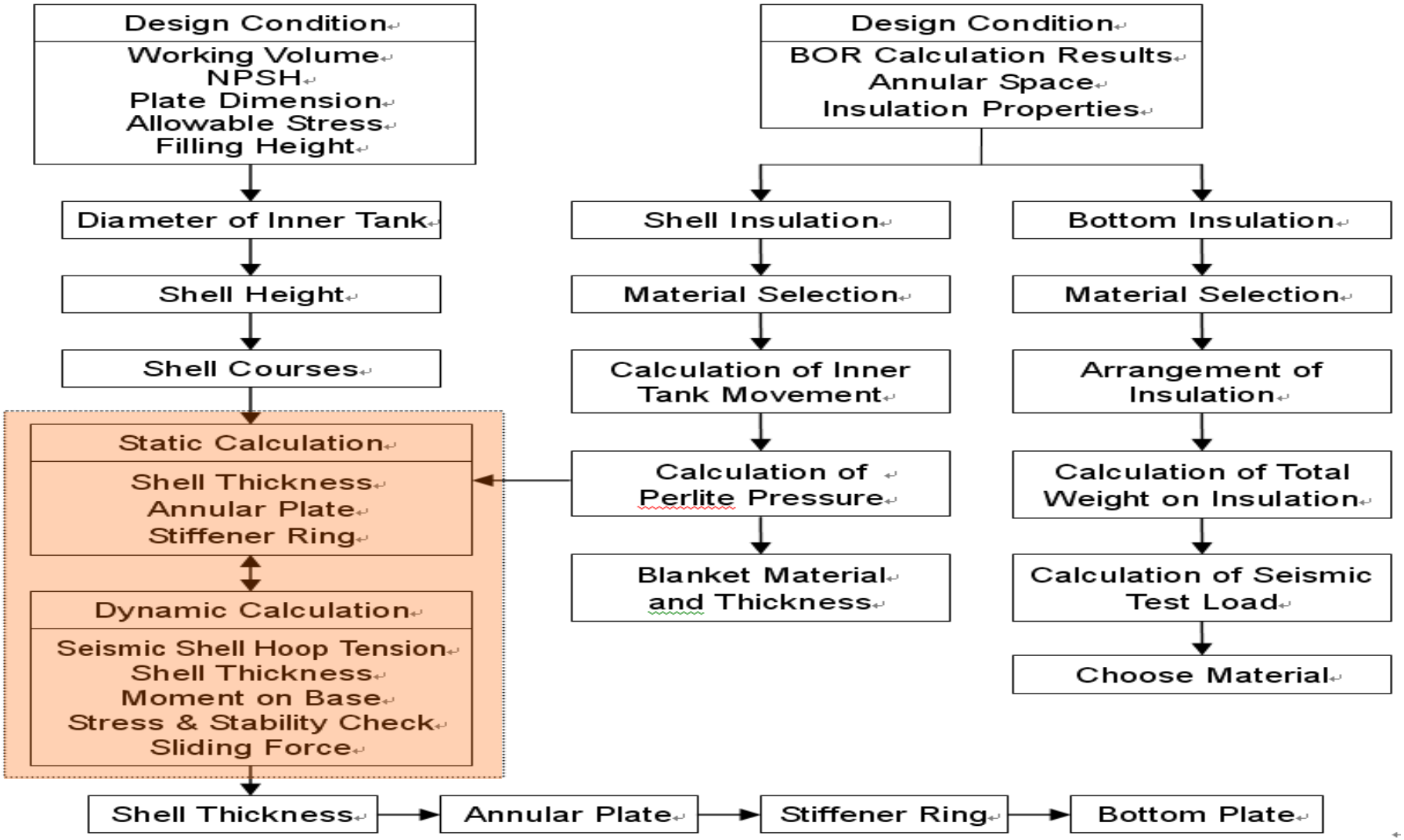
Kogas' LNG Tank Design Record

Country	LNG Project	No. of Tanks	Tank No.	Type of Tank	Capacity of Tank (m^3)	Status
Korea (KOGAS)	Pyeongtaek	4	11 - 14	Full Containment	140,000	in operation
		7	15 - 21	Full Containment	200,000	in operation
		2	22 - 23	Full Containment	200,000	under construction
	Tongyeong	7	6 - 12	Full Containment	140,000	in operation
		1	17	Full Containment	140,000	under construction
		3	13 - 15	Full Containment	200,000	in operation
		1	16	Full Containment	200,000	under construction
	Incheon	2	19 - 20	Membrane	200,000	in operation
	Samcheok	9	1 - 9	Full Containment	200,000	under construction
		3	10 - 12	Full Containment	270,000	construction in 2012
(POSCO)	Kwangyang	2	3 - 4	Full Containment	165,000	operation/construction
Thailand	PTTLNG	2	1 - 2	Full Containment	160,000	under construction
Singapore	SLNG	2	1 - 2	Full Containment	150,000	under construction
Australia	LNG Limited	1	1	Membrane	180,000	in suspension
Total		**46**				

Guidelines for the 270,000m^3 LNG Tank

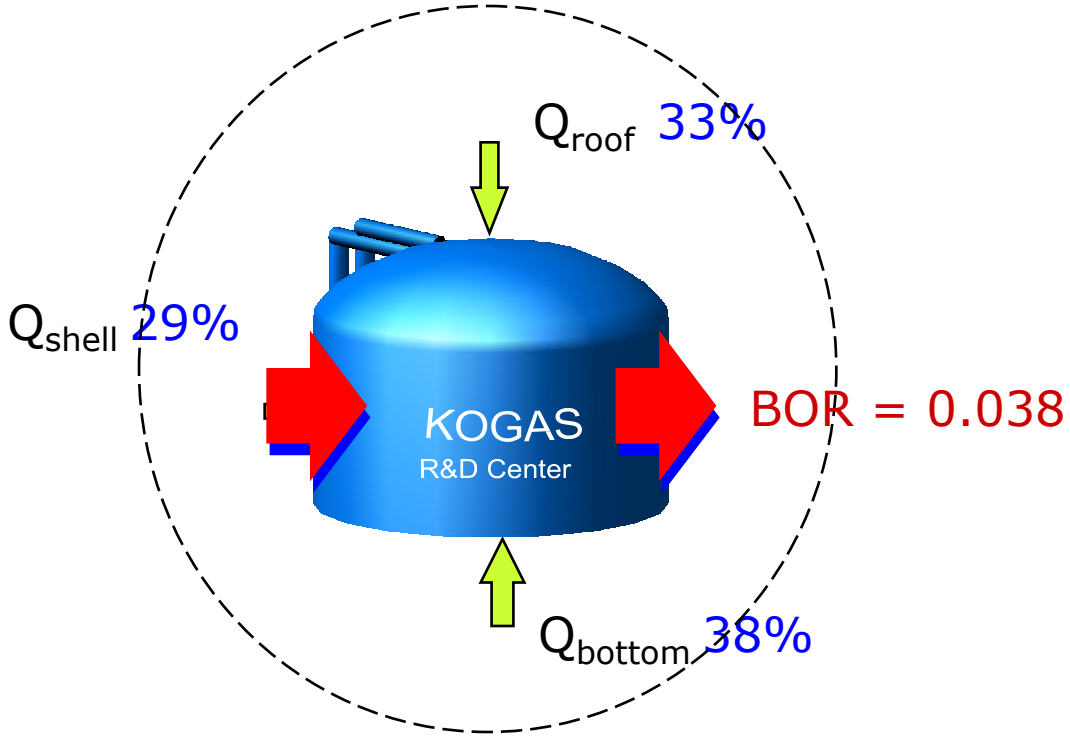
- Design in accordance with the requirements of EN 14620:2006
- Above-ground, full containment LNG storage tank
- 9% nickel steel open top inner tank
- Pre-stressed concrete outer tank
- Concrete dome roof with carbon steel vapor barriers
- Suspended ceiling deck
- 9% nickel steel secondary bottom liner
- Thermal protection system up to 5 meters high from the tank bottom
- Bottom heating system in the base slab
- Gross capacity : 270,000 m^3
- Design pressure : 29 kPa
- Design boil-off rate : 0.04 wt%/day
- Seismic loads : SSE 0.3g, OBE 0.15g

Inner Tank Design Procedure



Heat Leak Calculation

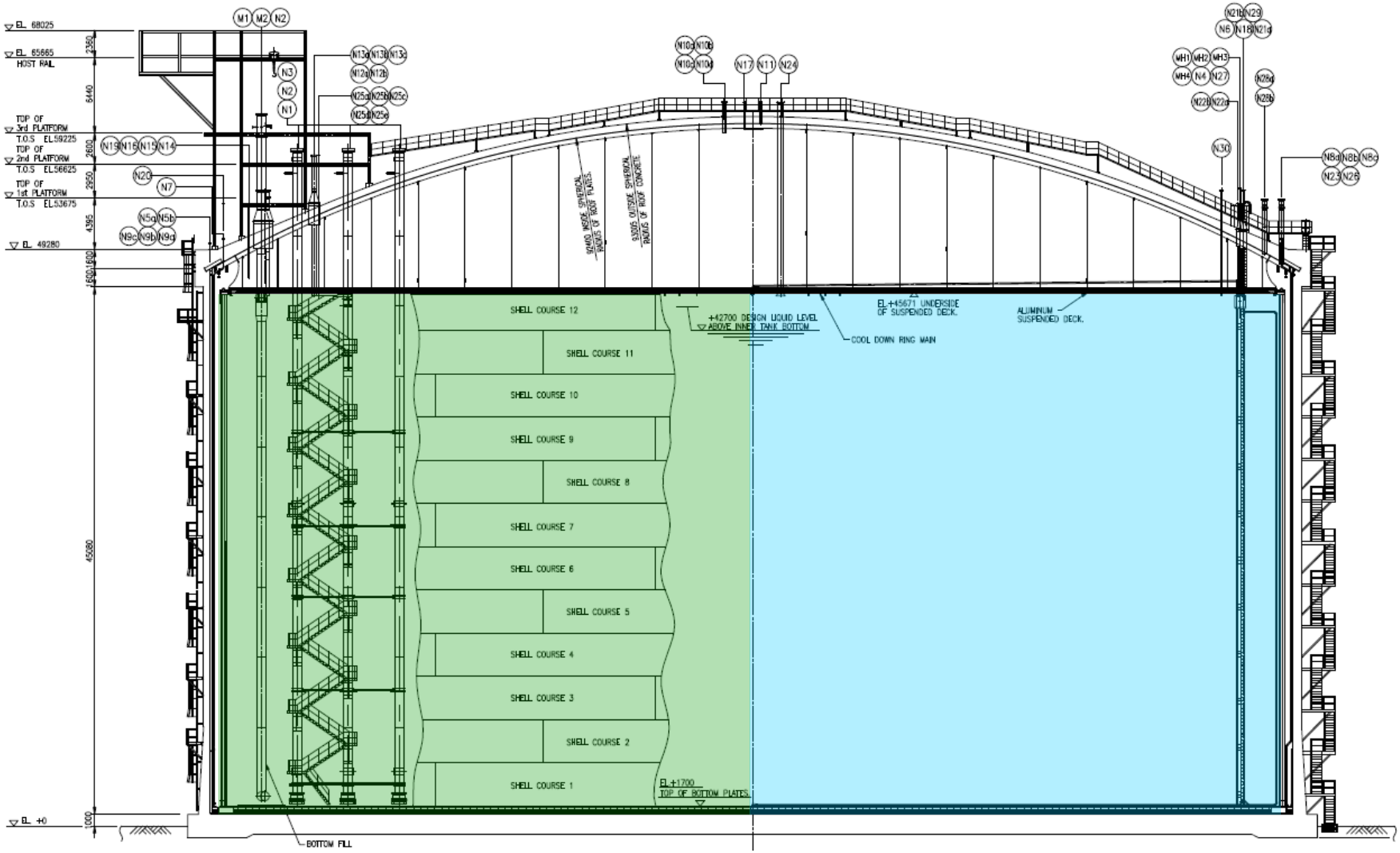
- **Design BOR : 0.04wt% per day**
- **Total Heat Leak : 259.6 kW**
  - ✓ 29% from shell
  - ✓ 33% from roof
  - ✓ 38% from bottom



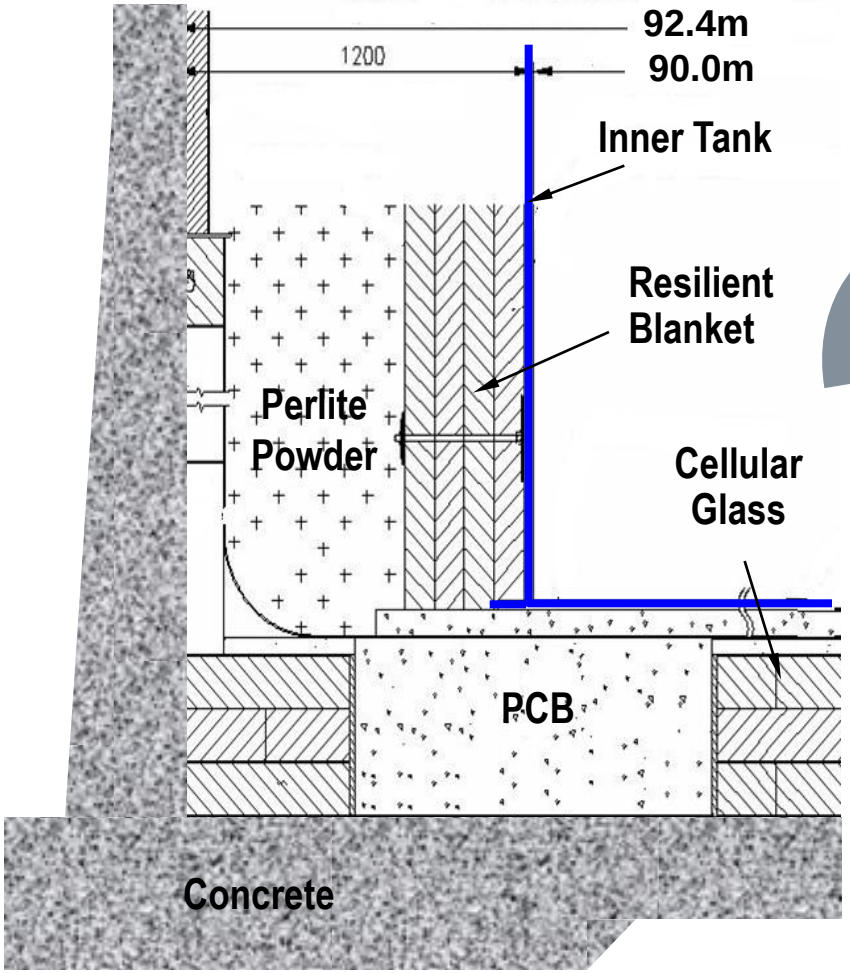
Considerations for Tank Sizing

- **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**

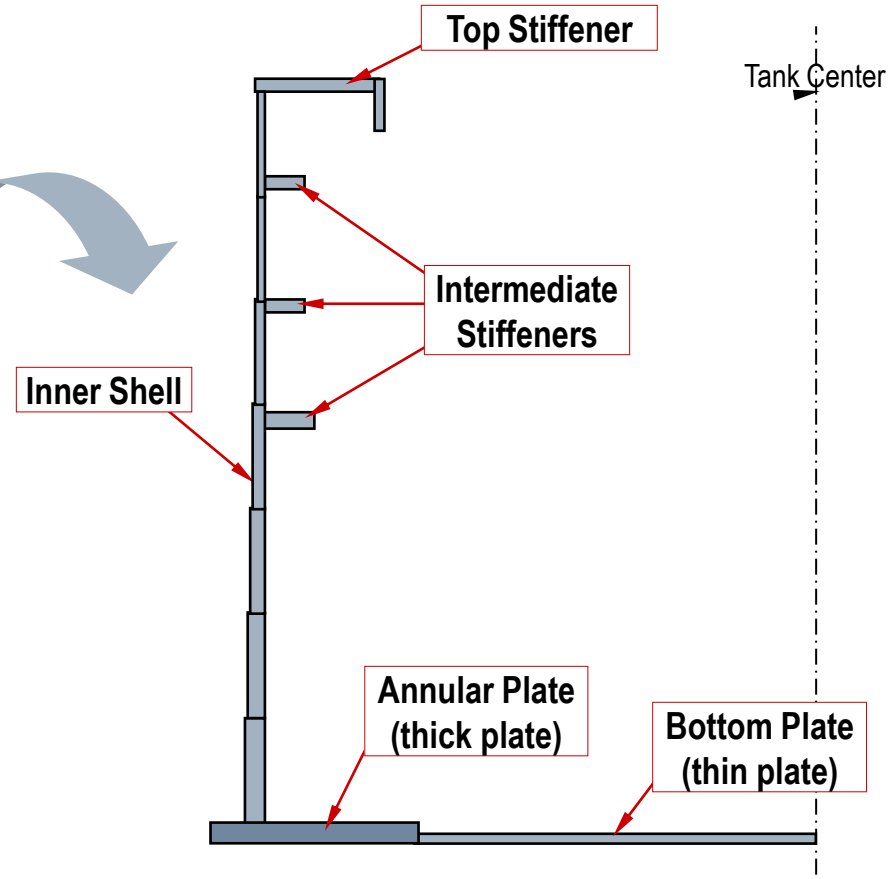
General View of the 270,000m³ Tank



Inner Tank Structure

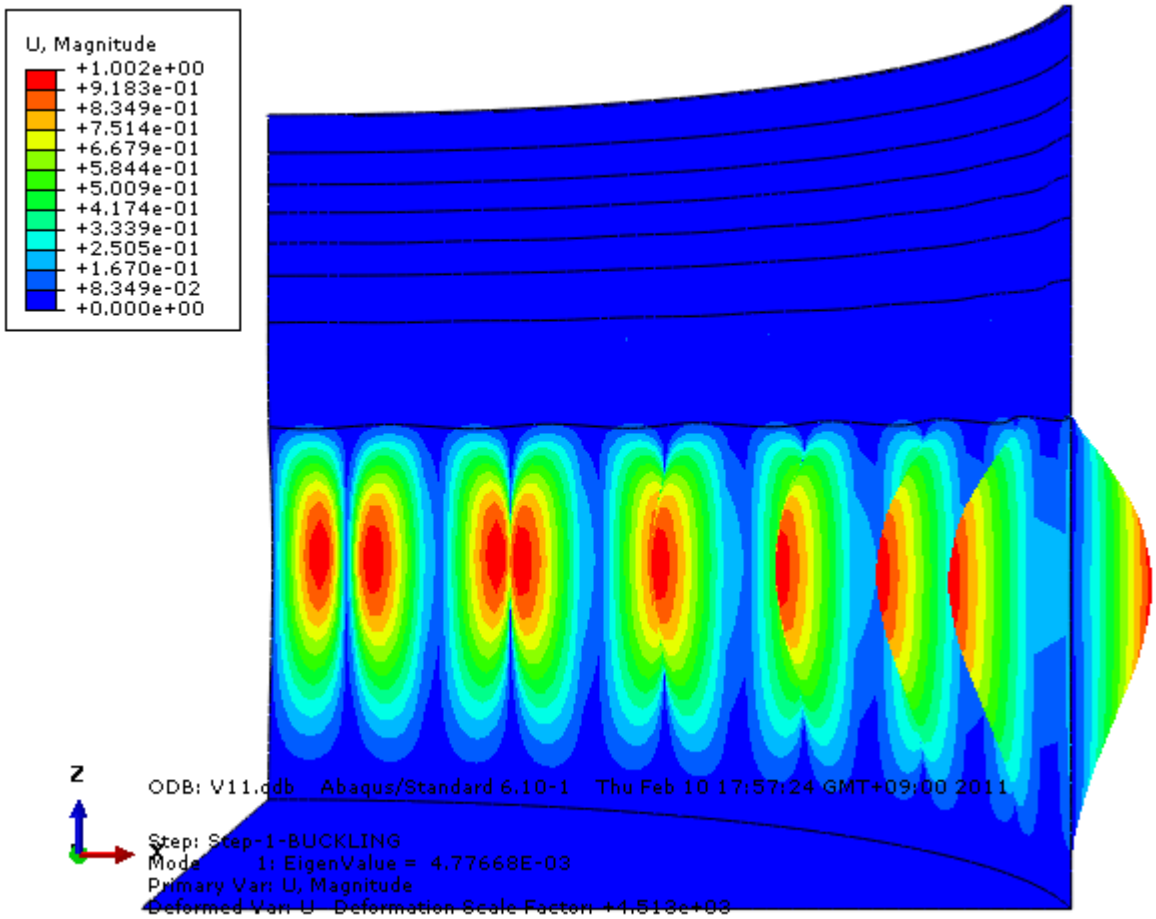


Bottom Corner Arrangement



Structure of Inner Tank

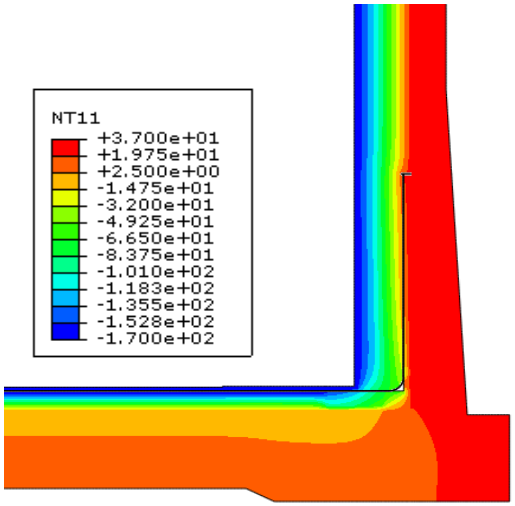
Buckling Analysis



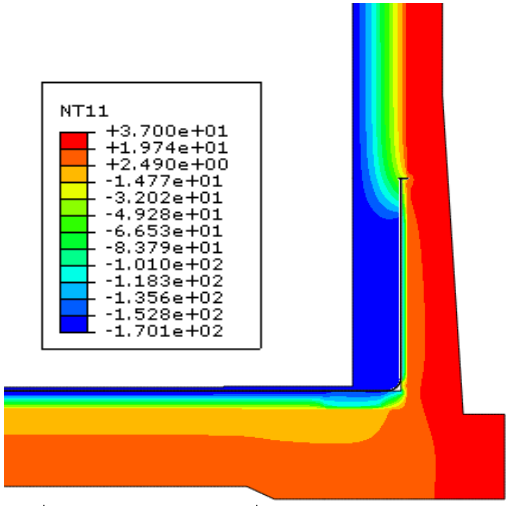
Critical Buckling Load > 3 x Perlite Pressure

Thermal Analysis for Corner Protection

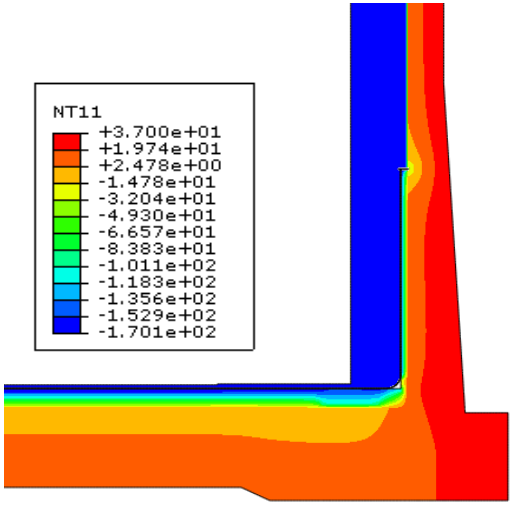
Normal Operation



Emergency Cases

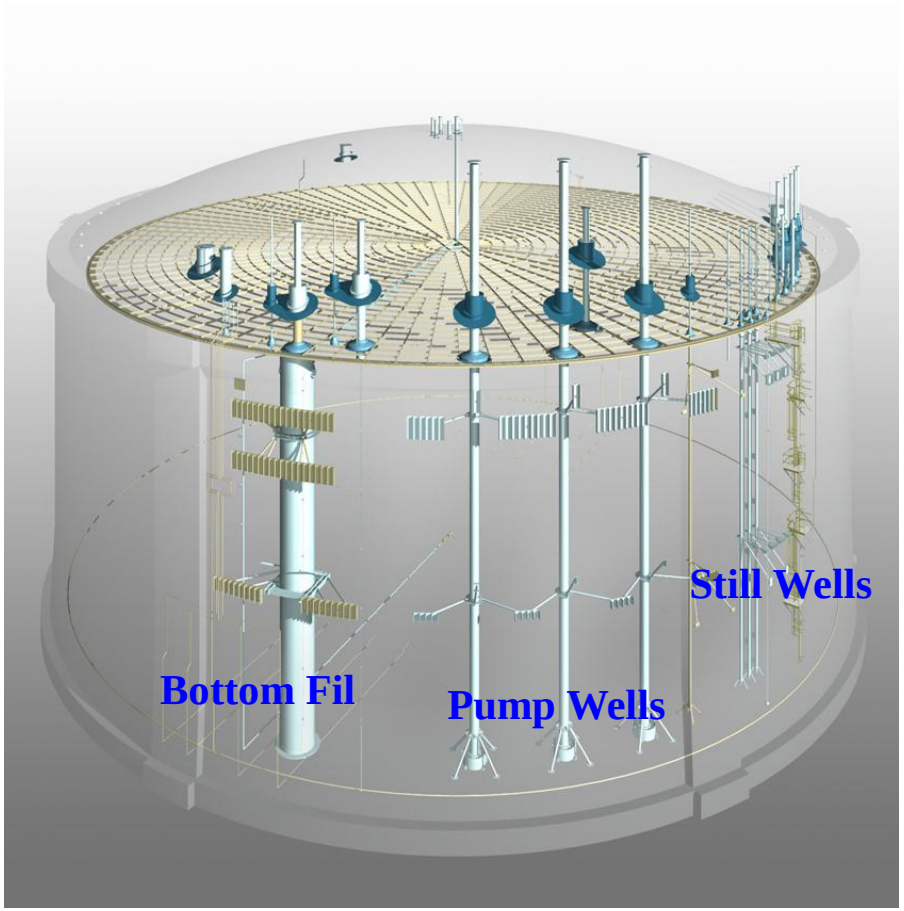


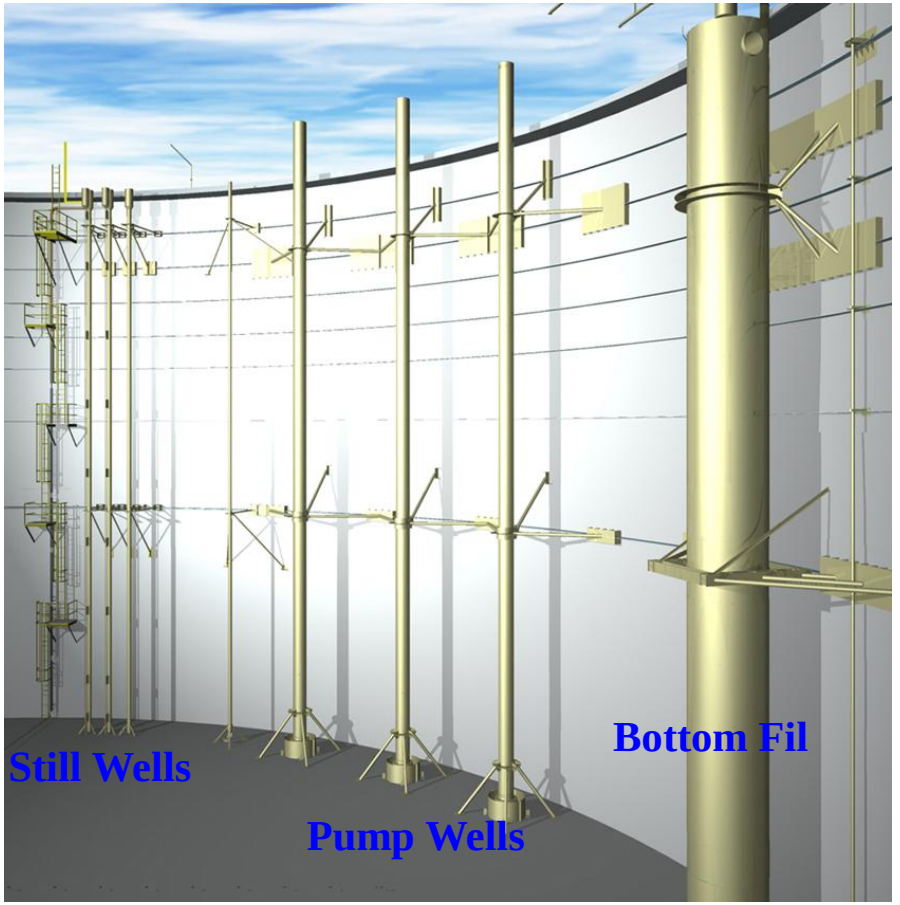
Minor Leak



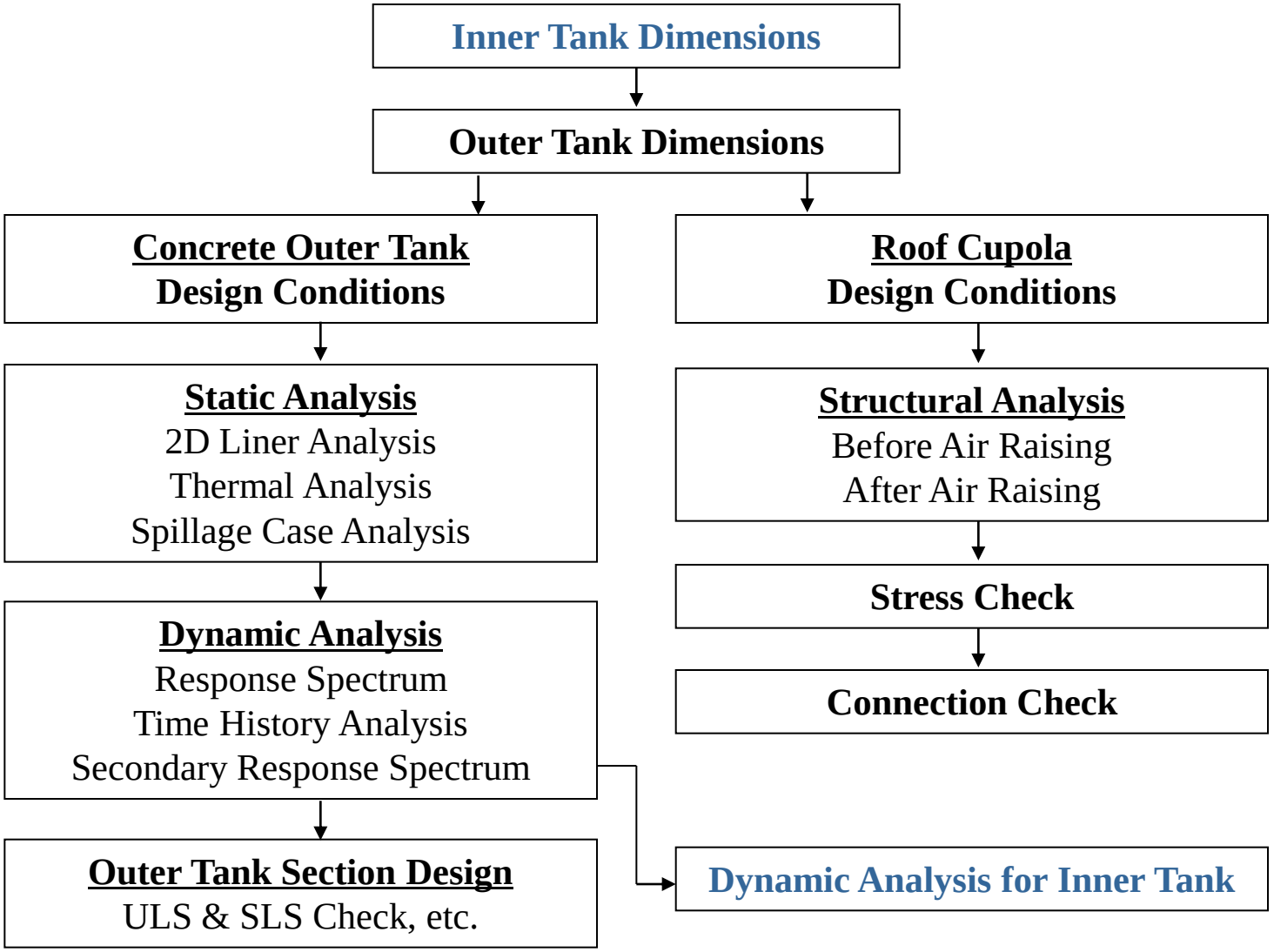
Major Leak

Design of Internal Pipes

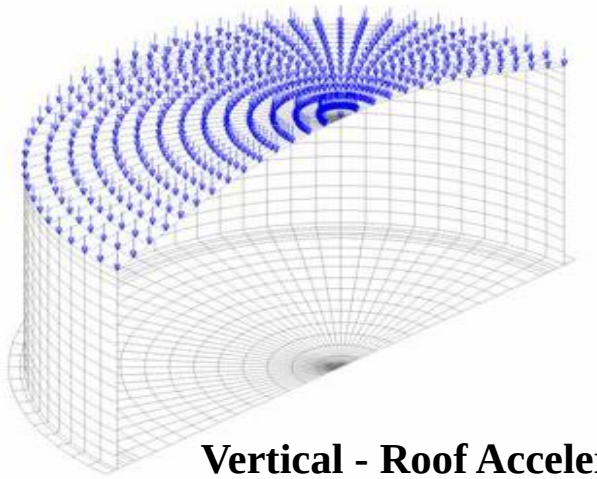




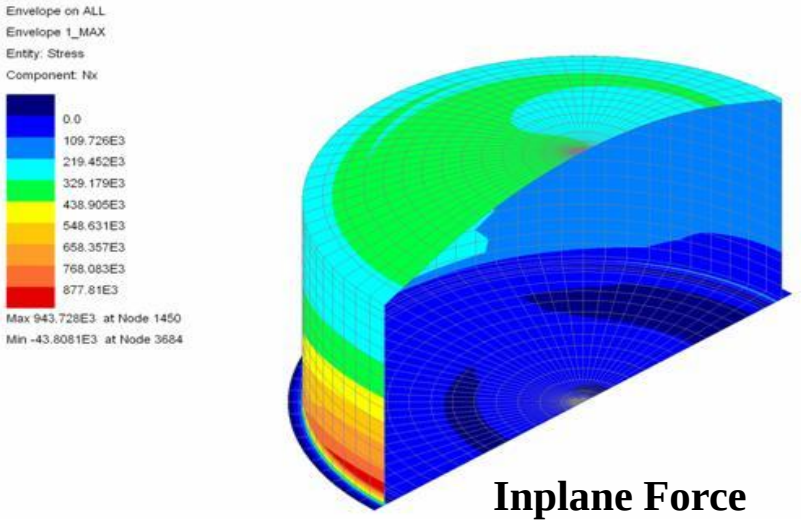
Outer Tank Design Procedure



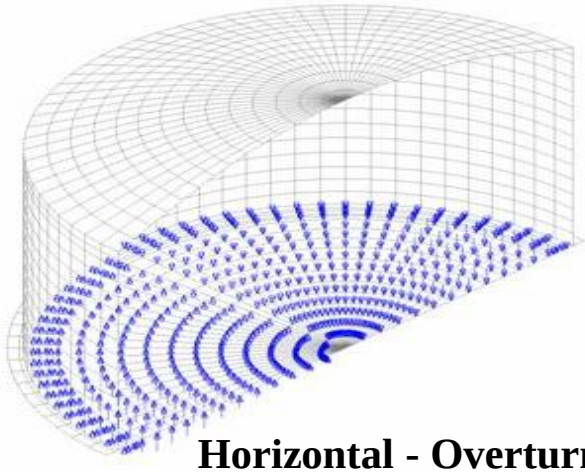
3D Linear Analysis for Earthquake



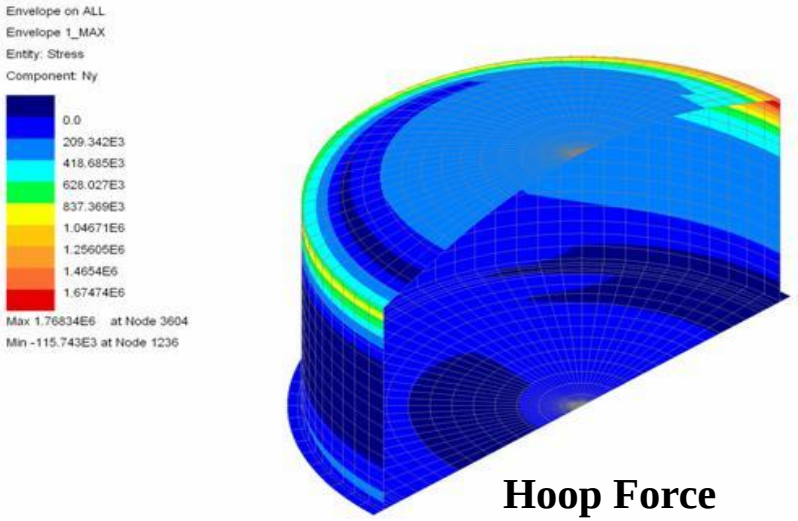
Vertical - Roof Acceleration



Inplane Force



Horizontal - Overturning



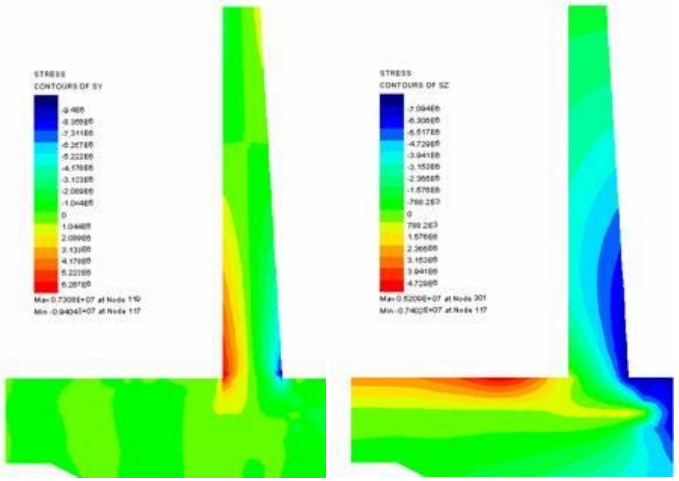
Hoop Force

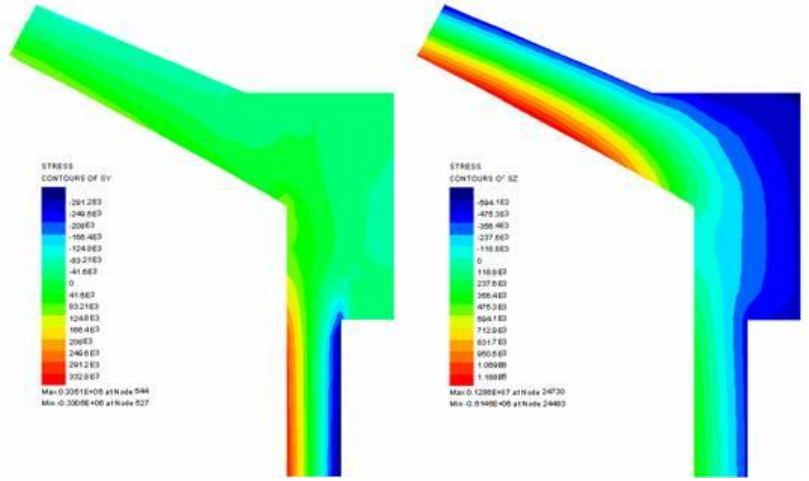
Thermal Analysis – Stress Contours

Bottom Corner

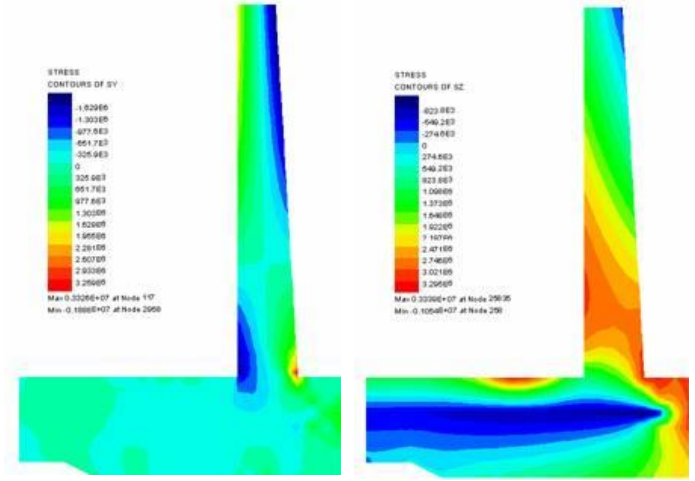
Top Corner

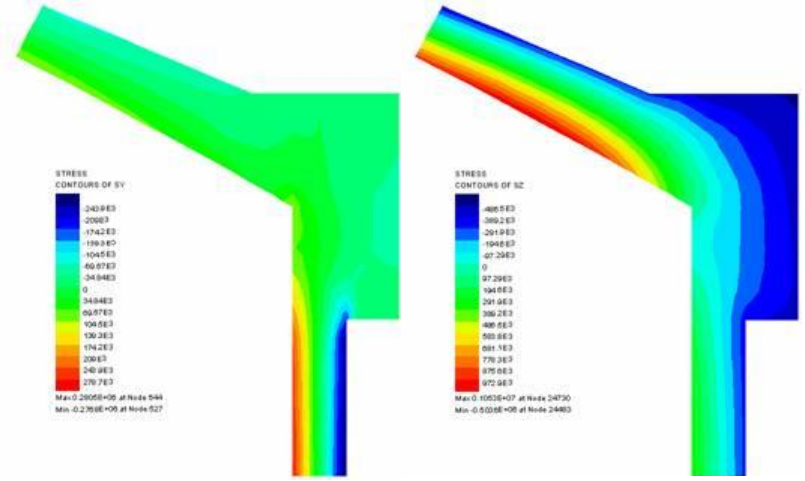
Summer





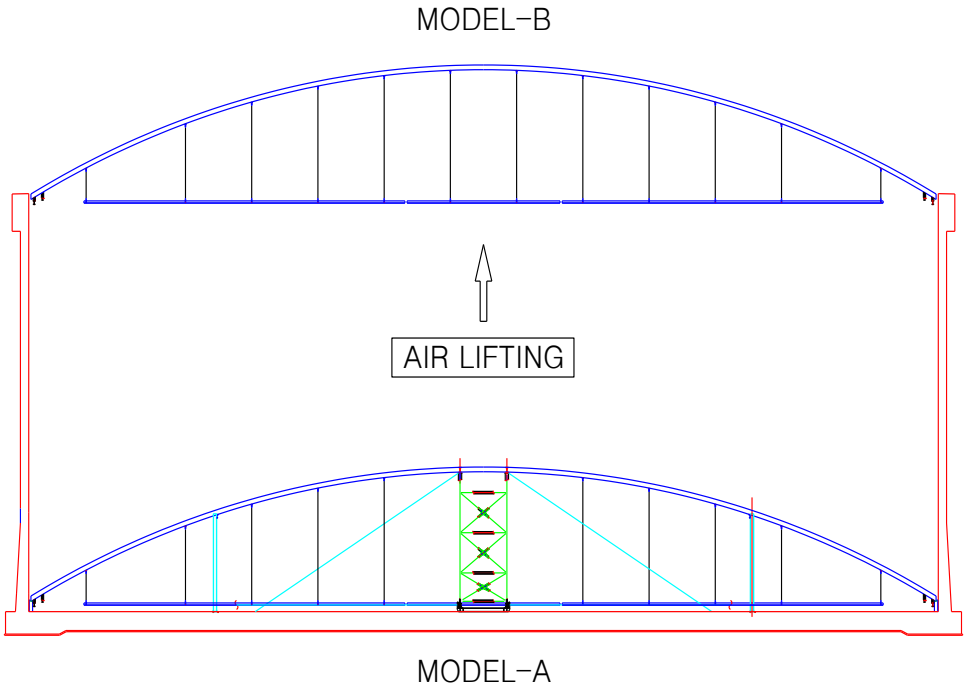
Winter

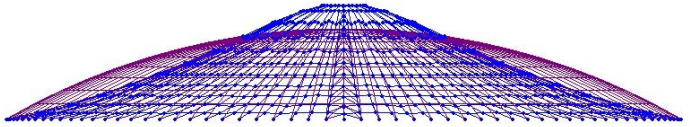


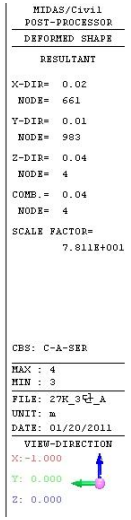


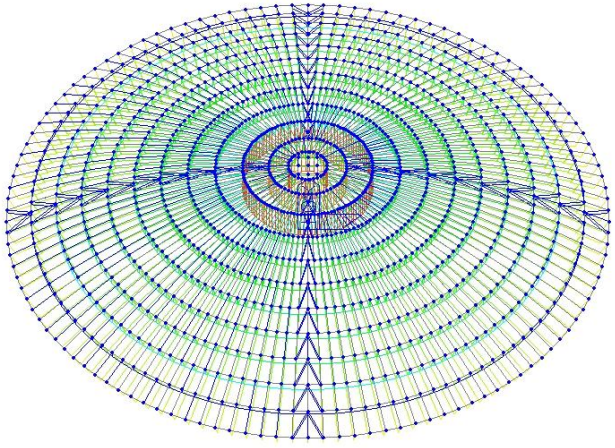
Roof Frame Design

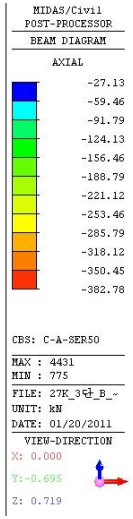
- **Model-A : before air raising**
- **Model-B : after air raising**











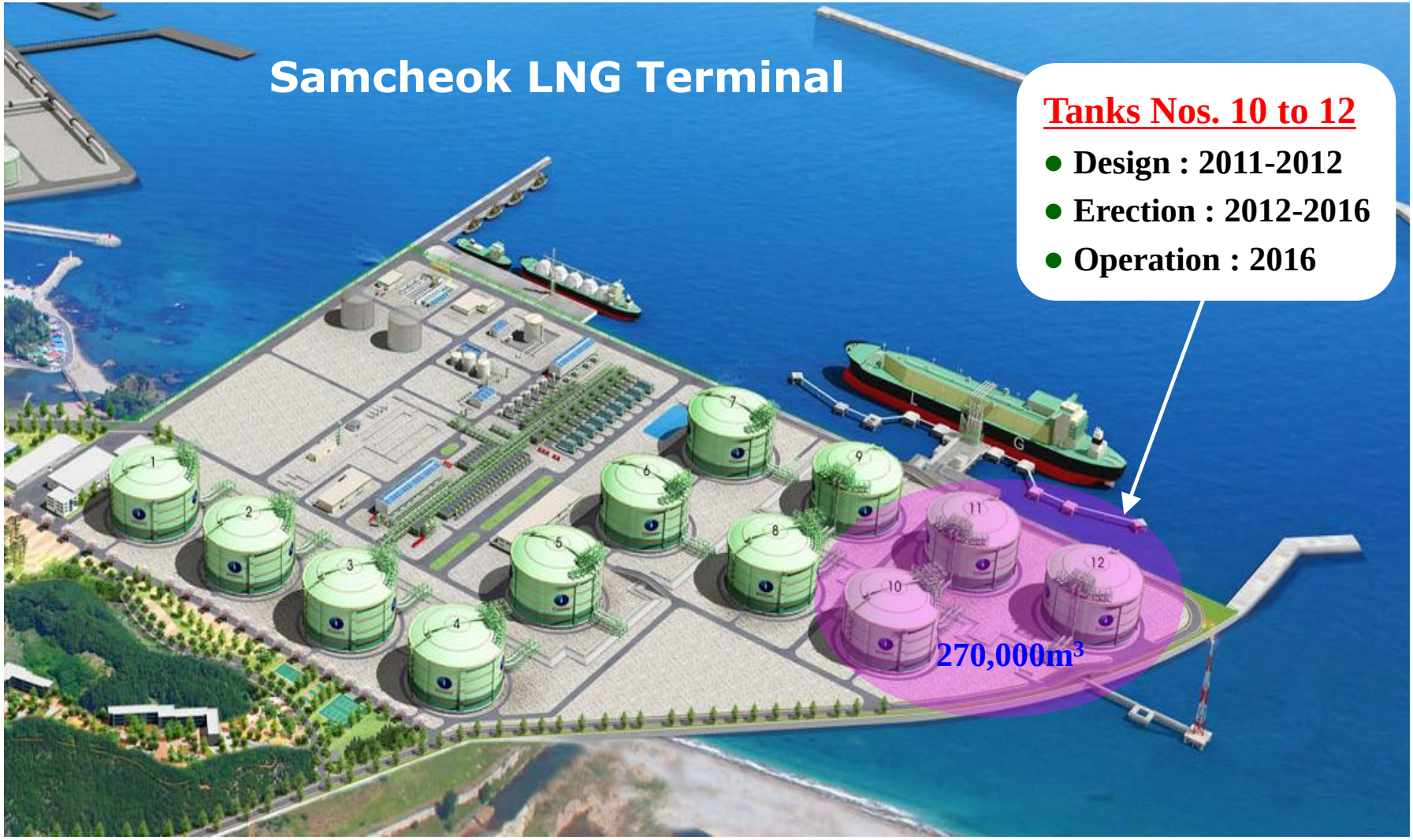
Comparison of Tank Specifications

❍ Comparison of Tank Specifications

Description	unit	N160	**G200**	N200	**G270**
Gross Capacity	m^3	171,500	**200,000**	212,700	**270,000**
Net Capacity	m^3	**160,000**	187,300	**200,000**	255,400
Design Pressure	kPa	29	29	29	29
Design BOR	wt%/d	0.05	0.05	0.05	0.04
Design Liquid Level	m	34.25	36.22	38.52	42.7
Inner Tank Diameter	m	80.0	84.0	84.0	90.0
Inner Tank Height	m	35.62	37.6	39.92	43.44
Outer Tank Diameter	m	84.4	86.4	86.4	92.4
Shell Insulation Thick	mm	1,200	1,200	1,200	1,200
1^{st} Course Plate Thick	mm	29.6	32.9	34.9	39.4

❖ *The above data are estimated on the basis of the KOGAS design philosophy ('N' means net capacity and 'G' gross capacity)*

The 270,000m³ Tank Construction Project



Construction Period

❍ Typical Construction Period for the Tanks G200 and G270

Tank	Description	1st Year	2nd Year	3rd Year	4th Year	Action
G200	**Design**					***Provided by KOGAS***
	Construction	**39**				***EPC Contractor***
	Commissioning				**2**	***KOGAS***
G270	**Design**					***Provided by KOGAS***
	Construction	**42**				***EPC Contractor***
	Commissioning				**2**	***KOGAS***

G200 : LNG storage tank with a gross capacity of 200,000m^3
G270 : LNG storage tank with a gross capacity of 270,000m^3

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/m^3 or 23.5 MUSD for a storage of 270,000m^3.**
- **When three 270,000m^3 tanks are installed at Samcheok Terminal, it is expected to cut the EPC cost of approx. 70.5 MUSD.**

Tanks	Gross Capacity (V)	EPC Cost (C)	USD/m^3 (U=C/V)	For 270,000m^3 (U x 270,000)
G200	**200,000 m^3**	**115.8 MUSD**	**579 USD**	**156.3 MUSD**
G270	**270,000 m^3**	**132.8 MUSD**	**492 USD**	**132.8 MUSD**
Difference	70,000 m^3	17.0 MUSD	**- 87 USD**	**- 23.5 MUSD**

❖ 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).