LNG Transportation

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Overview

- Onshore tank boil-off gas
- LNG roll-over
- LNG history, market & trade
- The LNG challenge
- LNG tanker containment systems:
  - 1. Moss type 2. Prismatic tanks
  - 3. GTT NO96 (Ni 36-steel) 4. GTT Mark III (18% Cr/8% Ni-S/S)
- Onboard BOG re-liquefaction, propulsion systems
- LNG sloshing, shipboard roll-over, FLNG handling

World's LNG plants (2018)

IGU World LNG Report — 2019 Ed.

Handling boil-off gas

- Cost of eliminating "boil-off" gas (BOG) may be prohibitive
- How does one tackle this problem?
- Selection of a storage design system should consider:
  - a) Capital costs of storage tanks
  - b) Cost of rejecting the boil-off gas from storage tank
  - c) Capital & running costs of boil-off treatment
- Large tanks of 250,000m^3 generate more BOG
- Type of storage facility matters:
  - If a peak shaving facility replenished by LNG truck BOG could be fed into network
  - If LNG tanks are part of a NG-LNG plant, BOG can be re-liquefied
- BOG generated during cargo export operations is re-liquefied
- BOG generated during NG liquefaction is *recirculated* in LNG process

LNG roll-over

- LNG composition

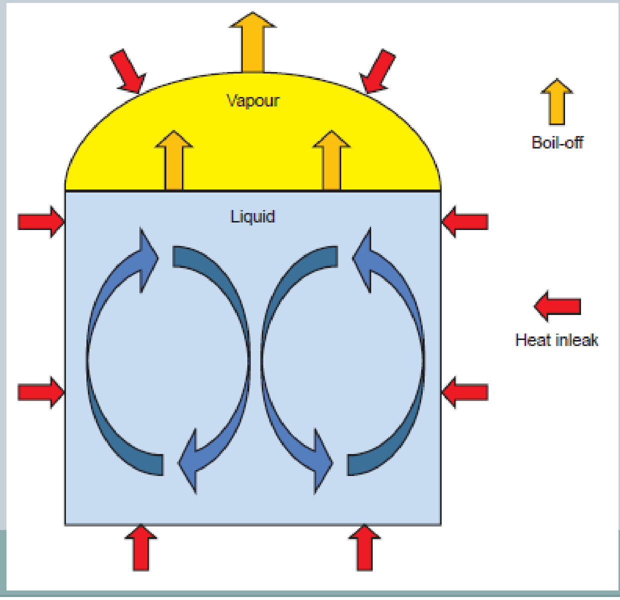
Component	Composition Range (mol%)
Nitrogen	0.00 – 1.00
Methane	84.55 – 96.38
Ethane	2.00 – 11.41
Propane	0.35 – 3.21
Isobutane	0.00 – 0.70
n-Butane	0.00 – 1.30
Isopentane	0.00 – 0.02
n-Pentane	0.00 – 0.04
HHV gas	1021 – 1157
Btu/scf (kJ/Sm^3)	(38,000 – 43,090)
Wobbe number	1353 – 1432
GPM, on C_2+ basis	0.71 – 4.08
(m^3/1,000m^3)	(0.094 – 0.543)

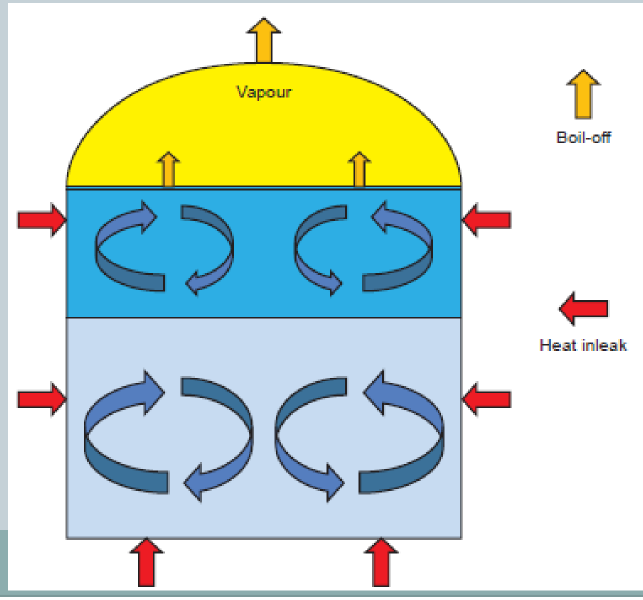
Source: McCartney (2003).

Constituents	Molecular weight	Relative Density (Air = 1)	Gross Cal. Val. MJm^{-3}(st)	Spontaneous Ignition Temperature °C
1	2	3	4	5
Methane	16	0.55	37.71	540
Ethane	30	1.04	66.35	515
Ethylene	28	0.97	59.72	425
Propane	44	1.53	93.94	450
Propylene	42	1.45	87.09	460
Butanes	58	2.00	n-121.80 iso-121.44	365-460
Butylene 1	56	1.94	114.98	385
Hydrogen	2	0.07	12.10	400
Petrol	80	3 to 4	174.5	280

LNG roll-over (2)

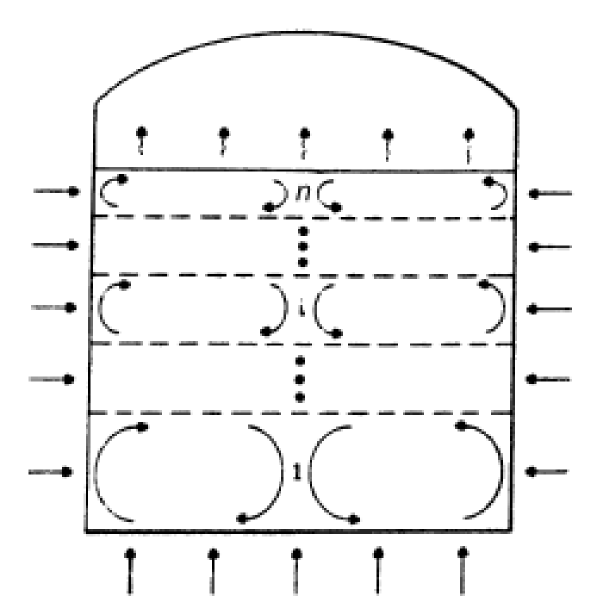
- LNG cargoes have different compositions
- Therefore, different LNG densities & vapour pressure
- Heat influx in the tank evaporates LNG
- Variations in ρ_{LNG} fractions result in *stratification* ($\Delta\rho_{LNG}$=1 kg·m^{-3})
- 'Lighter' LNG components boil-off faster ('aging')
- → Slight increase in 'heavier' LNG

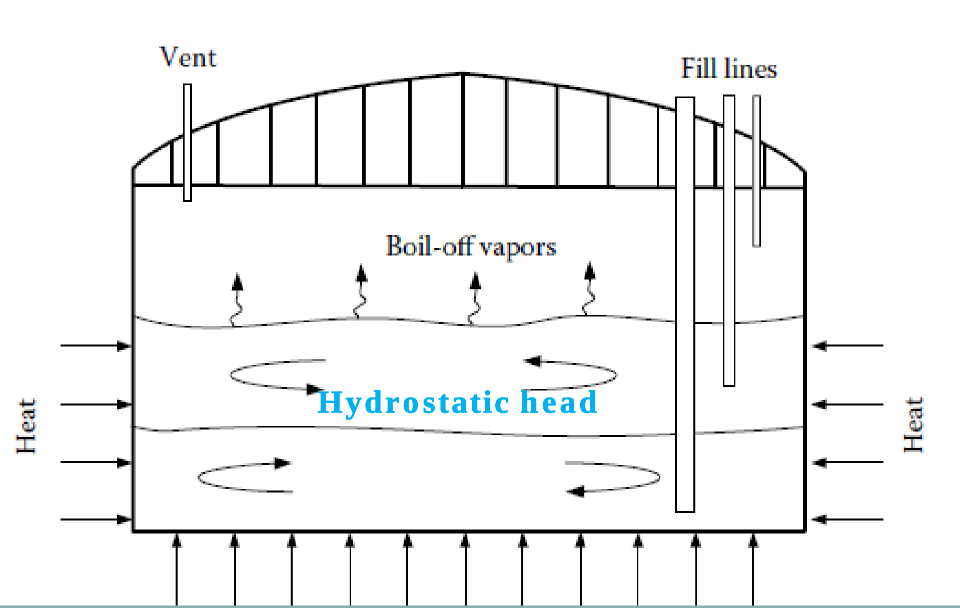




LNG roll-over (3)

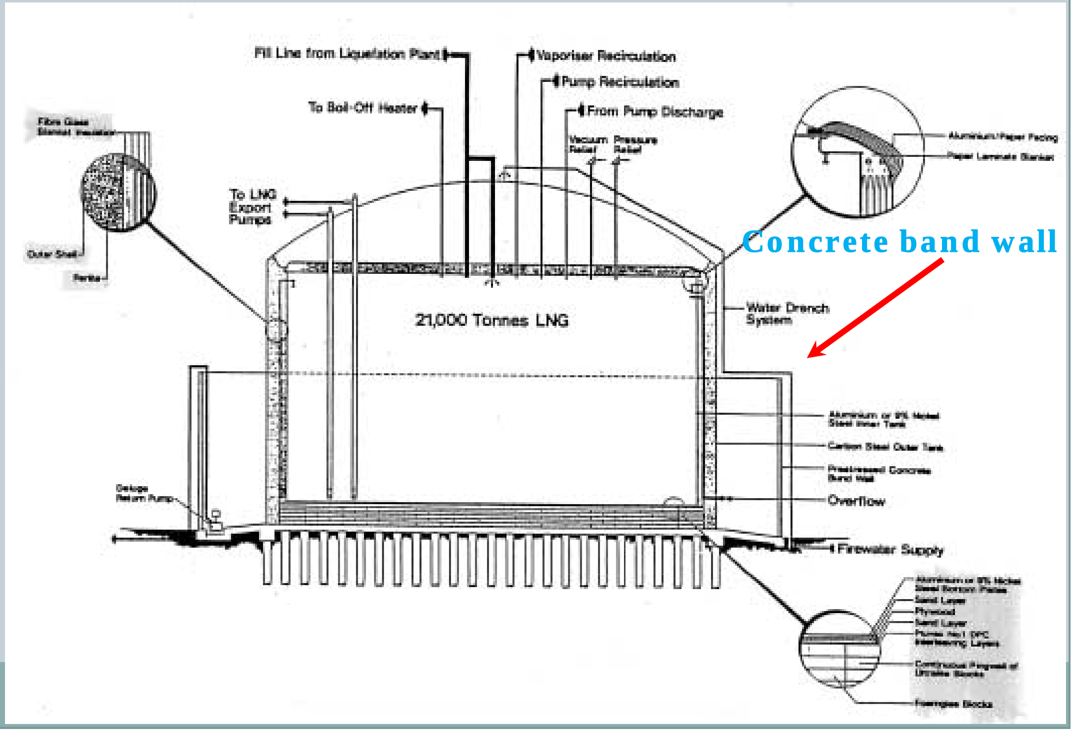
- Incomplete mixing gives rise to different of LNG cells
- Little heat or mass transfer btw cells
- Discrete LNG layers *suppress* or *delay* LNG vaporisation
- *Rollover* is the rapid LNG vaporisation and rise of bottom layer to top
- Increased pressure imperils integrity of the tank lid





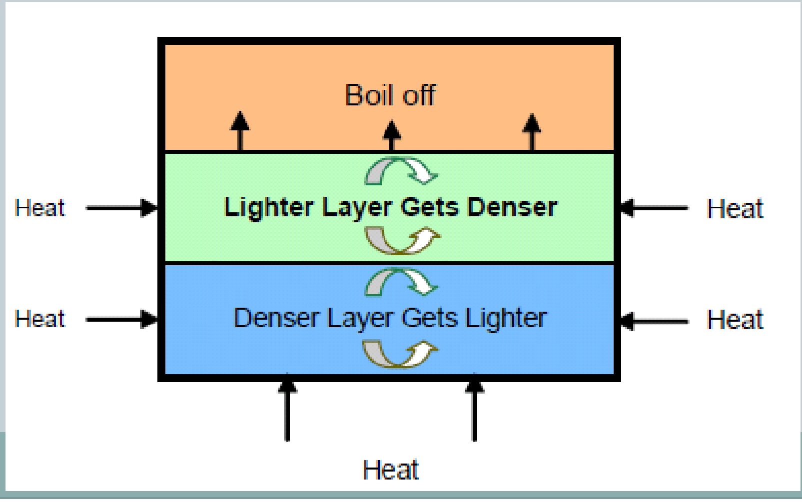
LNG roll-over (4)

- If ‘density inversion’ exceeds hydrostatic head phases ‘flip’ or ‘rollover’
- 1971: First venting incident in La Spezia, Italy
- 1970-1982: 41 roll-over incidents in 22 plants
- Provisions to accommodate flux of ‘boil-off’:
  - Vent
  - Flare
  - Recompress or
  - Re-liquefy
- Important variables:
  - Mixing of different LNG cargoes
  - LNG density discrepancies



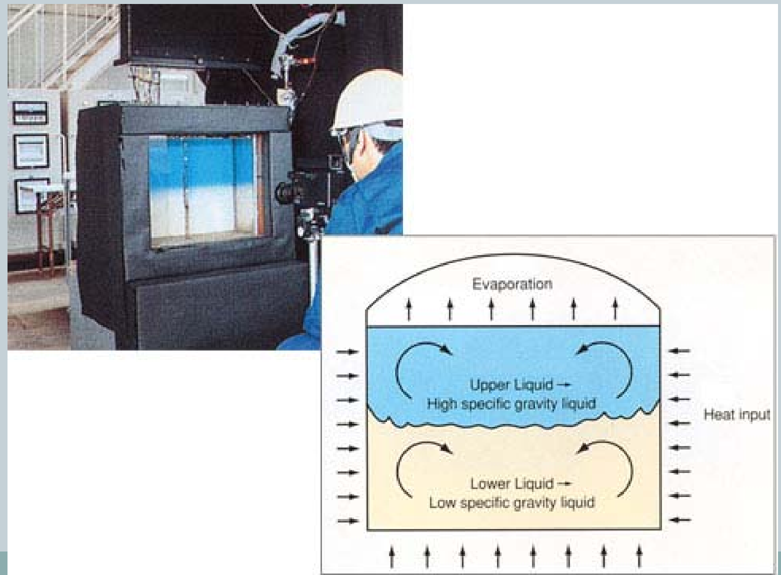
Roll-over counter-measures

- Tank features:
  - Monitor temperature to avoid excess heat influx in liquid layers
  - Use tank fill methods to augment mixing:
    - Jet mixing
    - Bottom loading via standpipe, or
    - Top loading via splash plate
- Limit variability in LNG composition
- Mix tank contents by combining top & bottom tank filling points
- Use N_2>1 mol% (lowers ρ with vaporisation)



More roll-over countermeasures

- Promote LNG mixing by pump recirculation
- Pressure control of the tank
- Monitoring parameters (boil-off rate) related to stratification
- Connect high capacity vent to the tank
- Tank construction able to sustain reasonable internal pressure
- Store different cargoes in different tanks, where possible



LNG stratification inside tank

LNG Transportation

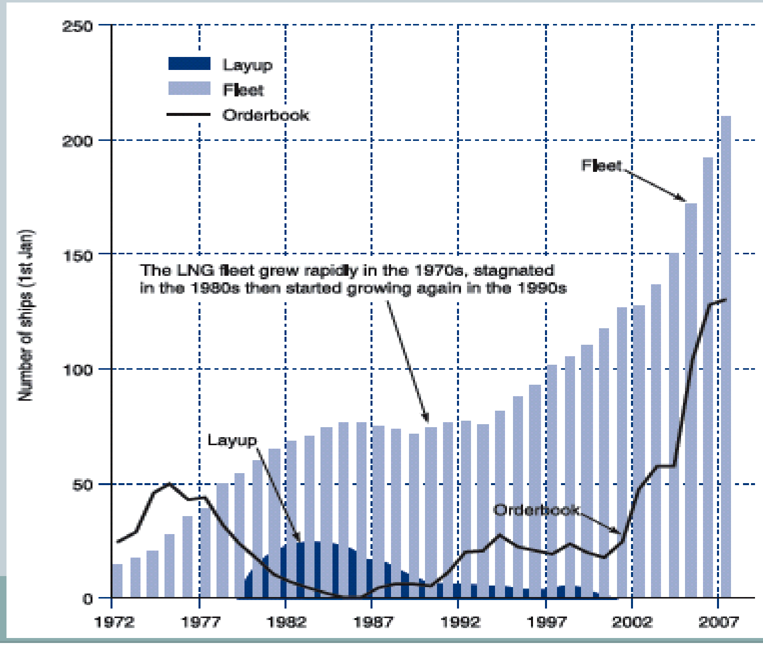
Liquefied Natural Gas (LNG) history

- 1934: first attempt to export LNG dates in Hungary
- 1959: Louisiana to Chicago via Mississippi River
- 1964: *Methane Princess* 1st *large* scale LNG exports: Libya-UK
- Early 1980s: NG given impetus
- LNG vessels operate on 20 or so year long shuttle contracts
- LNG fleet capacity. 5MMm^3 (2008) → 35MMm^3 ('07) → 55MMm^3 ('10)
- LNG will meet 14 to 16% of global gas demand by 2015 (NGR, '07)
- Typical LNG shipload cost $20–35 m, charter rate of LNG ship ~$70,000/d

Size: 27,400 m^3

The LNG market

- 1973: several LNG projects were deferred or cancelled altogether
- 3rd largest seaborne energy trade after oil & coal. World energy use:
  - 2005. Oil: 3.8 bn tons | Coal: 3 bn tons | NG: 2.5 bn tons
- 1983: 1/3 of the LNG fleet were laid-up
- 1980-'05. Oil: ME-Europe cost $7–10/tonne; LNG: $25–100/tonne,
- LNG ships move NG to power plants & some LNG to chemical plants

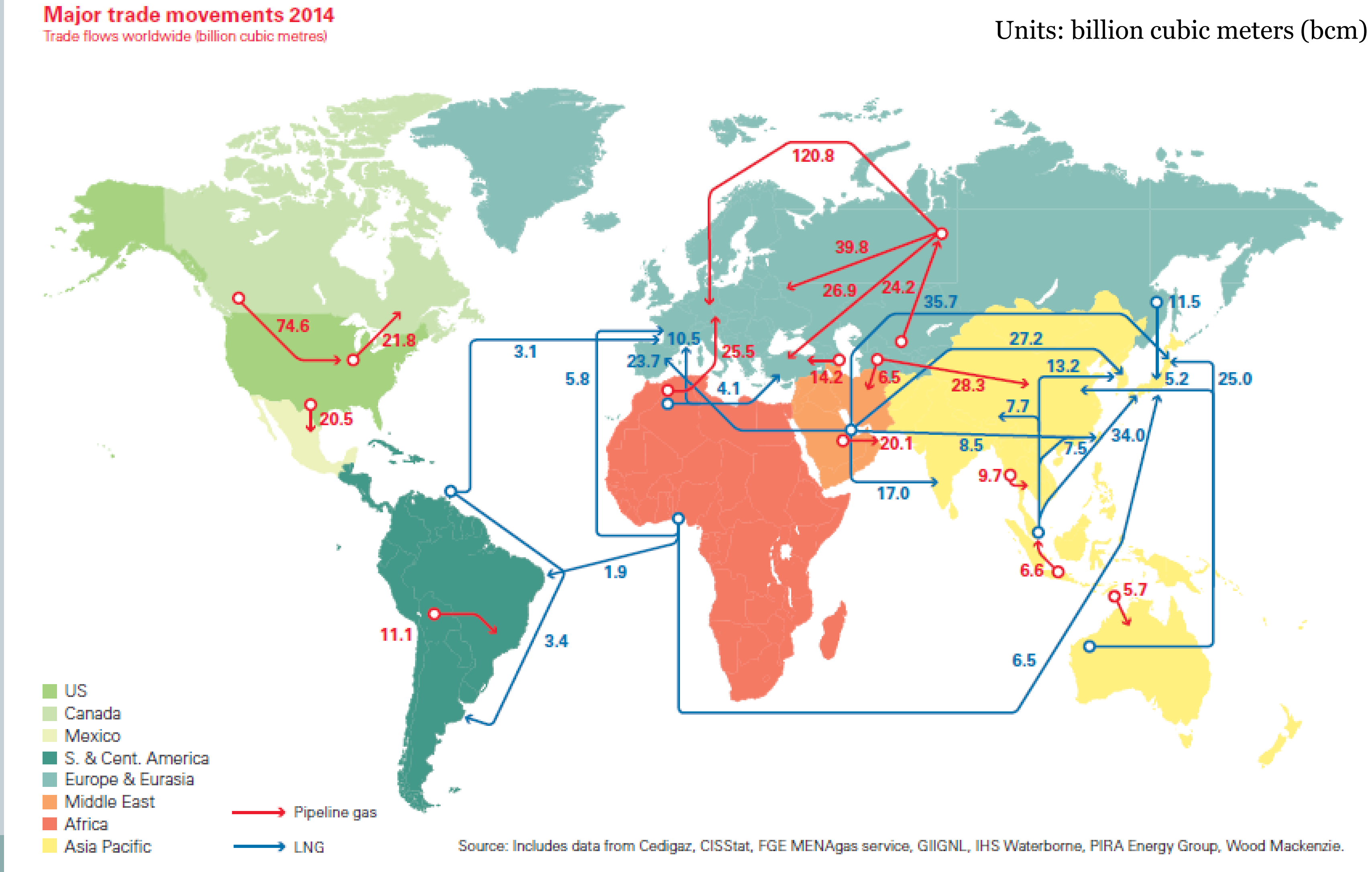


LNG market (2)

- As of 2011: 18 LNG exporting countries; 25 LNG importing countries
- Trade movement of NG (2012):
  - Total NG exports: 1,033 bcm
  - By pipelines: 705 bcm (imports, 68%)
  - LNG: 327 bcm (exports, 32%)
- 3 biggest LNG exporters (2011):
  - Qatar: 75.5 MT
  - Malaysia: 25 MT
  - Indonesia: 21.4 MT
- 3 largest LNG importers (2011):
  - Japan: 78.8 MT
  - South Korea: 35 MT
  - UK: 18.6 MT

Major NG trade routes (2014)

Units: billion cubic meters (bcm)



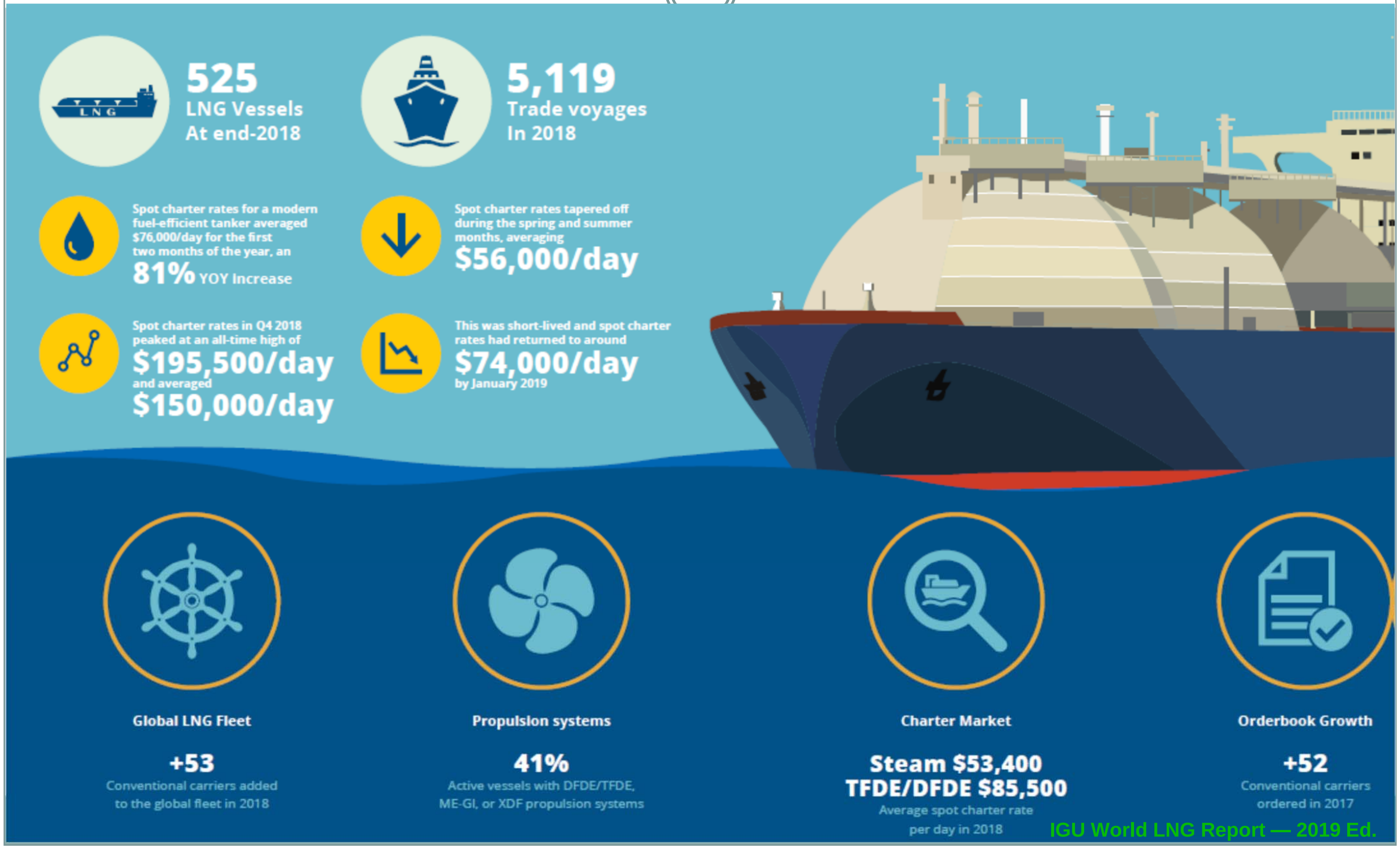
LNG shipping

LNG seaborne transport

- Ships committed to 15-20 year contracts
- Modern vessels feature on-board boil-off gas re-liquefaction
- LNG stored at atmospheric pressure at –163˚C
- Need for dedicated loading & unloading facilities
- 50% of their time empty: laden voyage (full) & ballast leg (empty)
- Operational costs = *f*(laden trip days, sea state, ambient temp.,…)

LNG carriers

Dual-Fuel Diesel Electric/Tri-Fuel Diesel Electric (DFDE/TFDE)



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World LNG vessel fleet

- Projected world LNG fleet for *2013*:
- Vessel sizes:
  - Small: <120,000m^3
  - Standard: 120,000-175,000m^3
  - Q-flex: 216,000m^3
  - Q-max: 260,000m^3
- Major LNG shipyards S. Korea:
  - Daewoo, Samsung HI, Hyundai
- Japan:
  - Kawasaki
- Cost of LNG ships: $130M (138,000m^3)
- In 1995, same size ship cost: $280M
- End of 2018: 525 LNG carriers (incl. FSRUs)

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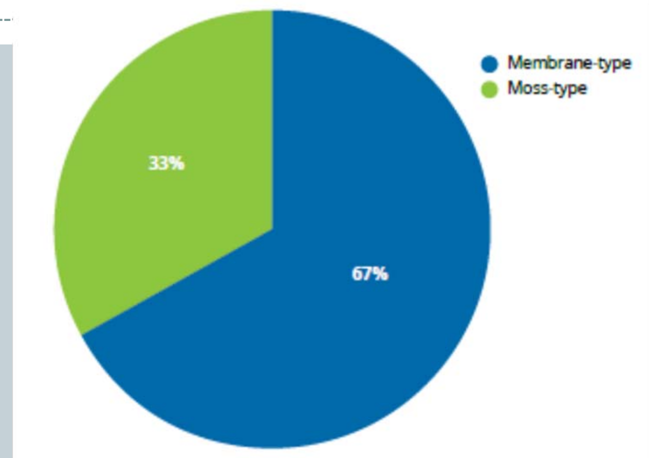

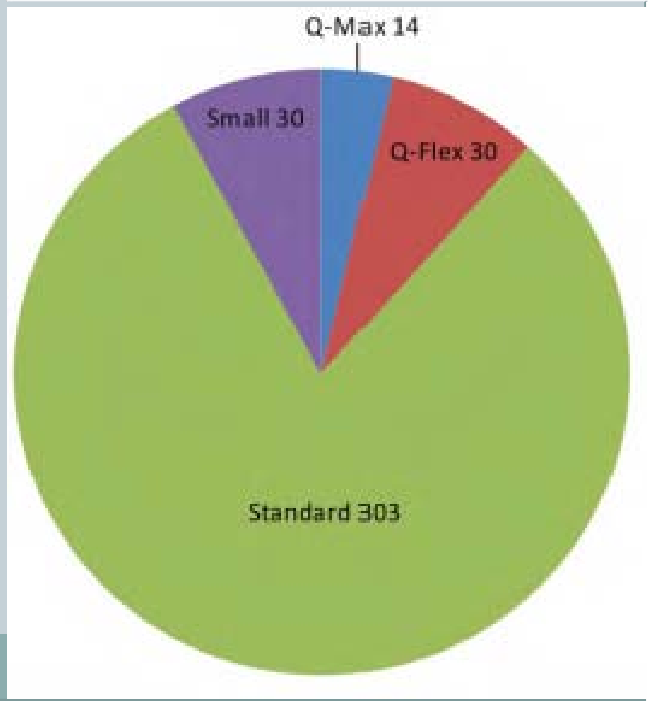

World LNG carrier fleet stats

- End of 2018

Propulsion Type	LNG Fuel Consumption (tonnes/day)	Average Vessel Capacity	Typical Age
Steam	175	<150,000	>10
DFDE/TFDE	130	150,000-180,000	<15
ME-GI	110	150,000-180,000	<5
XDF	108	150,000-180,000	<1
Steam Re-heat	140	150,000-180,000	Not Active

DFDE/TFDE: Dual-Fuel Diesel Electric/Tri-Fuel Diesel Electric

XDF: Two-Stroke Engine

ME-GI: M-type, Electronically Controlled, Gas Injection

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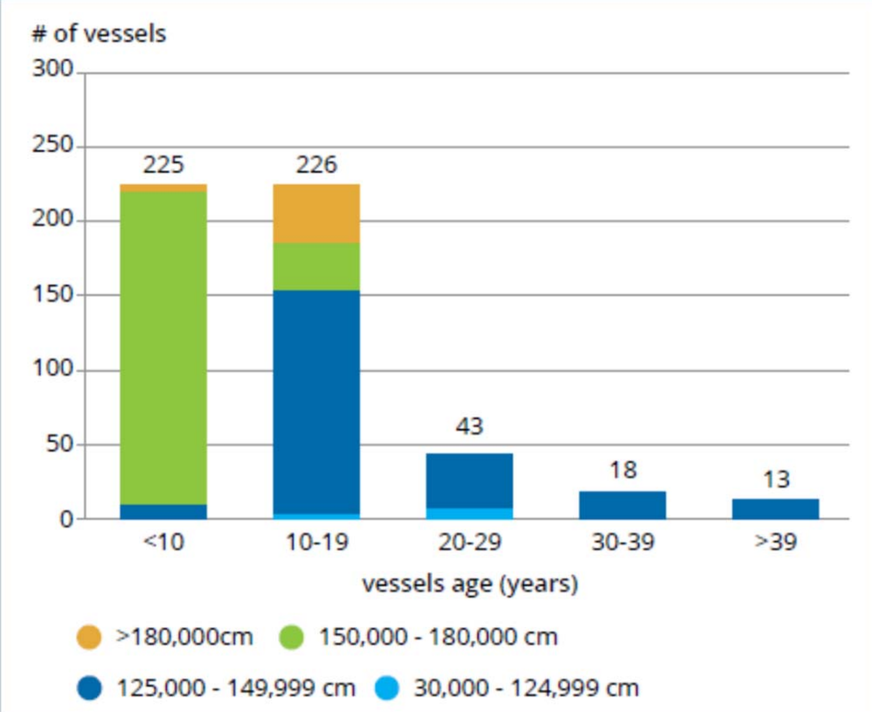
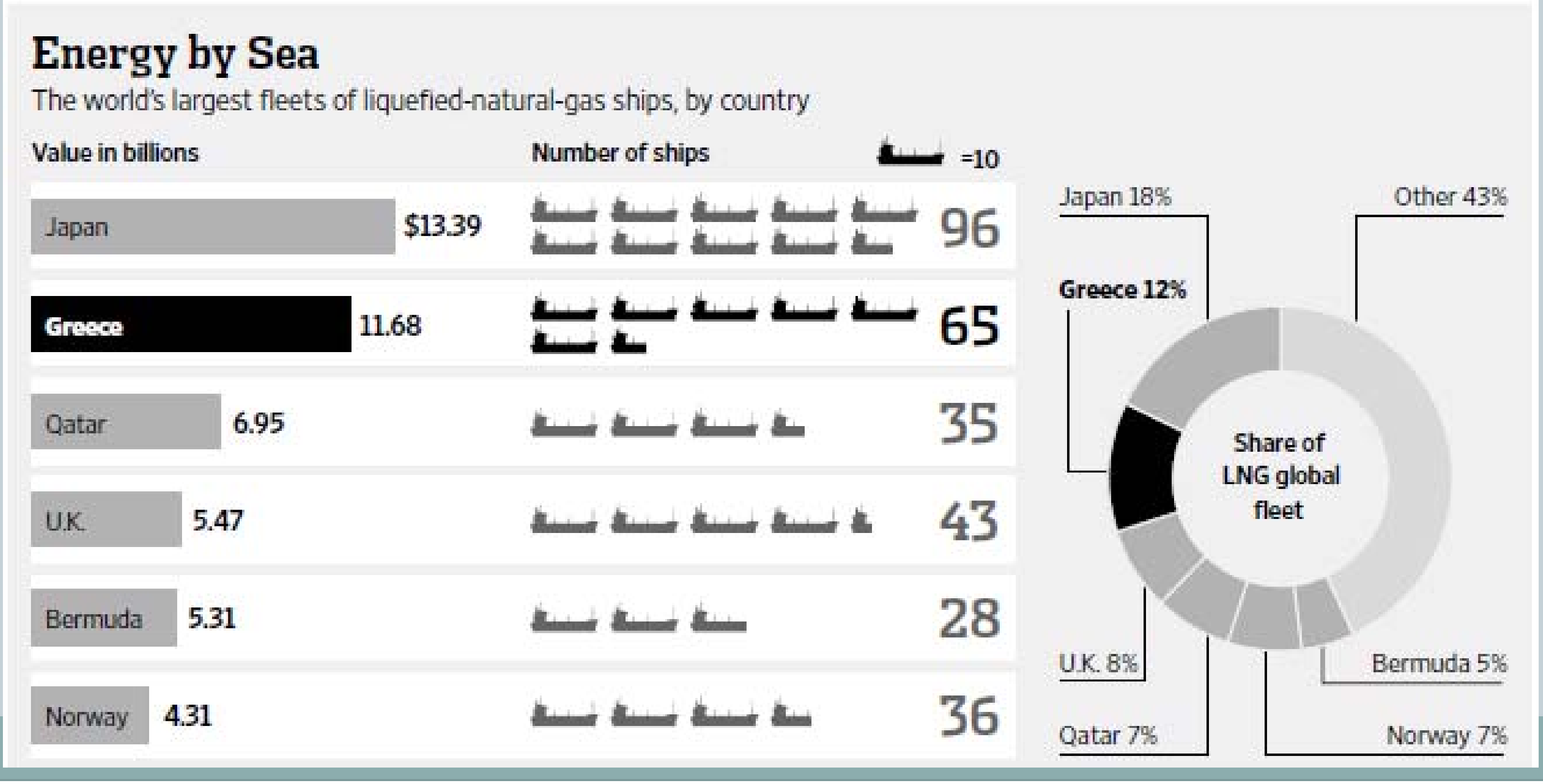


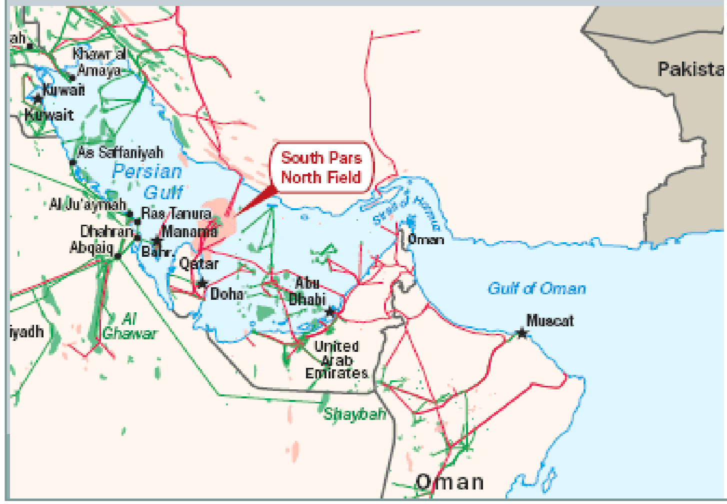
Who owns the world's LNG fleet?

- Greek shipowners invested $1.8bn on 11 LNG newbuildings in 2014
- Average cost/vessel ≈ $165m
- Betting on LNG spot market & EU energy diversity



Trade-routes & transit bottlenecks

- Principal LNG trade routes:
  - Persian Gulf to Far East
  - Persian Gulf to Europe
  - South Asia to North Asia
- LNG bottlenecks:
  - Straits of Hormuz (20% of LNG)
  - Malacca Straits
  - Suez Canal (1.5tcf, 13% of LN
  - Bab el-Mandab



LNG ships

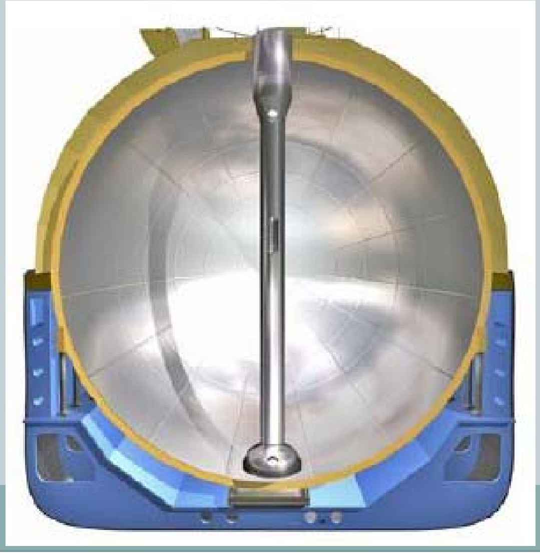
- Technological achievement
- High tech vessels operated by qualified crew
- 360 LNG carriers operating in deep-sea trade (end of 2011)
- Traditionally, prime mover was a steam turbine
- Nowadays, focus is on slow-speed diesel engines (<300rpm)
- High speed vessels: 18-20.5 knots (91% of ships)
- Expensive vessels with good safety record
- Dedicated ships tied to specific routes

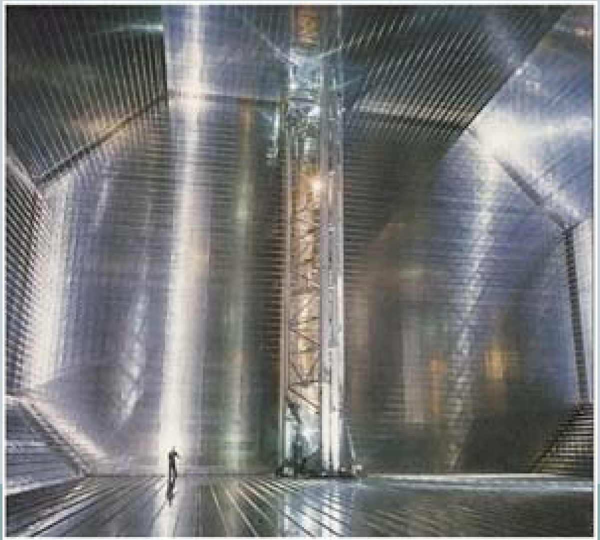
Particulars of LNG ships

	length overall Lc	length between perpen-diculars Lpp [m]	beam B [m]	draft T [m]	gross tonnage GT tys [t]	tank capacity Vol thousands [m^3]	type of tanks	vessel's name
1	151	140	28	7.6	20.5	19	spherical	Surya Aki
2	216	–	33	9.5	40	36	membrane	LNG Lerici
3	239	226	40	11	66	87	membrane	Polar Alaska
4	272	259	47	10.5	80	125	spherical	Northwest Seaeagle
5	270 ÷275	260 ÷265	42	11÷12	90 ÷ 111	132 ÷ 135	membrane	Inigo Tapias Golar
6	285	274	43.5	12.5	97.5	145	membrane	Maran Gas Asclepius
7	289	–	49	11.9	118	145	spherical	Muscat LNG
9	315	–	50	12,0	136	216	membrane	Q-flex
10	340	–	54	12,0	–	270	membrane	Q-max

LNG carriers

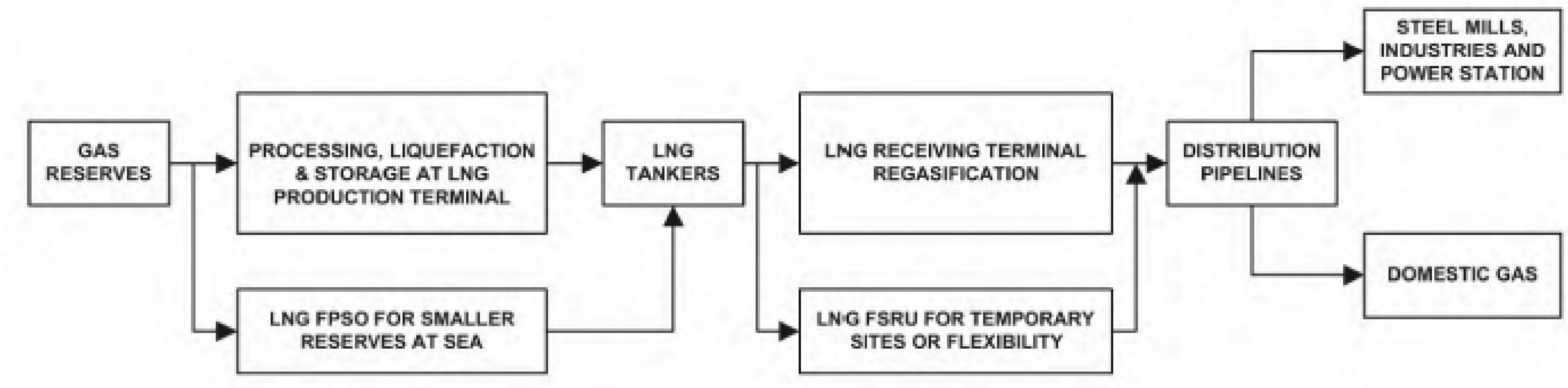
- LNG vessels are *fully refrigerated* ships
- Two major containment systems:
  - Self-supporting tanks
  - Integral/Membrane design
- Materials: aluminium, balsa wood, stain. steel, polyurethane
- Sophisticated and expensive vessels
- Subtle operational details





Special characteristics of LNG

- Cryogenic cargo at −163°C
- Low mass density, ρ_{LNG}=0.41-0.5t·m^{-3} (ρ_{H2O} =1t·m^{-3}@25°C)
- Low dynamic viscosity, μ_{LNG}=188μkg/m-s (μ_{LNG}= ~0.9$m$kg/m-s)
- Flammable cargo (within range of 5-15% in air)
- Colourless & odourless cargo
- Generates boil-off gas; BOG rises on top of tank: ρ_{BOG} (@−100°C) <ρ_{Air}
- Cold burns may arise from contact with LNG *or* cryogenic surfaces
- Brittle fracture of metals due to low cargo temperature



The LNG carrier design challenge

- Cryogenic ships need to:
  - Endure the ultra-low temperature of the cargo
  - Minimize or avoid free-surface effects
  - Posses loading-unloading provisions
  - Tolerate forces from super-cooled gas (“sloshing”)
  - Handle Boil-Off Gas (BOG)
  - Manage risks from flammable cargo
  - LNG loaded in liquefied form @ −163˚C; BOG unavoidable
  - Considerable segregated ballast tanks
  - Isolate hull from thermal stresses
- LNG tanks:
  - Withstand contraction & expansion (thermal stresses)
  - Minimize heat influx
  - Isolate hull from cold temperatures. T<−50˚C steel becomes brittle & breaks
  - Monitor LNG parameters (eg, BOG)
  - `Stratification & roll-over hazards

LNG ship design considerations

- Older ship data may not inform solutions of modern problems eg structural & containment behavior
- Computational methods are widely used in industry
- Design challenges:
  - Vibrations (larger engines)
  - Propulsion systems
  - Hull fatigue
  - Sloshing in LNG membrane tanks
  - New routes (eg Artic's Northern sea route)

LNG tanker designs

- Four types of LNG containment systems:
  - 1. Moss type
  - 2. Prismatic tanks
  - 3. GTT NO96 (Ni 36-steel)
  - 4. GTT Mark III (18% Cr/8% Ni-S/S)

(1 and 2) → **1.** Free-standing or independent (Self-supporting)

(3 and 4) → **2.** Membrane (non-free standing)

Thermal insulation systems

- Insulation materials aim to:
  - Minimize heat influx into tanks & conserve cargo
  - Protect hull from cryogenic cargo temperatures
  - Minimize heat flow from hull into tanks
  - Protect personnel from cold burns
- No insulation is 100% efficient more so if ΔT is ~200°C
- Insulation qualities:
  - Non-flammable
  - Non hygroscopic
  - Long life
  - Efficient over a wide range of temperatures (–170°C to 60°C)
  - Low material & installation costs
  - Lightweight
  - Compact
  - Easily applied and deformable

Some insulating materials

- 1. Balsa wood
- 2. Perlite
- 3. Polyurethane foam

1. Balsa wood

- Native tree to Brazil, Bolivia & Mexico. 30m tall
- Uses: model bridges, surfboards, wind turbine blades, GRP, composites
- High strength:weight ratio, high rigidity, compressive & tensile strength
- Tested extensively in temperatures down to –160°C
- Balsa wood tank insulation consists of wood strips, ρ=40-340kg/m^3
- Insulation bonded together with *resorcinol glue*
- Applied in varying grain orientations in prefabricated flat panels
- Panels measure 1×3m by 0.25m thick

2. Perlite

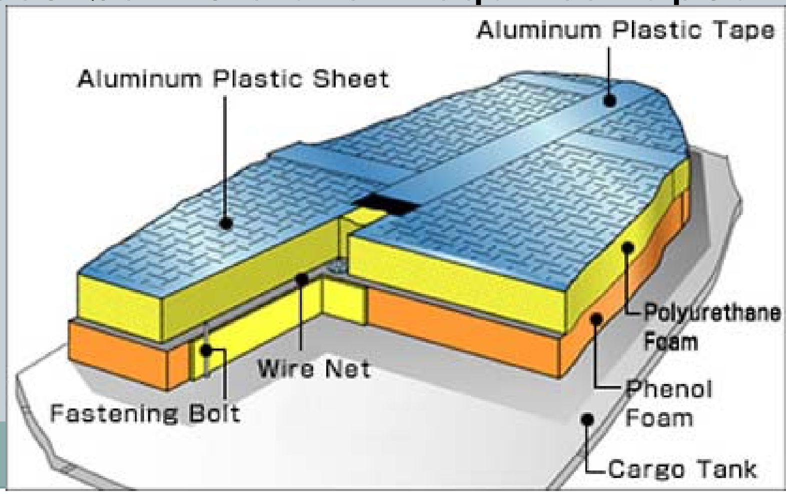
- Perlite is a type of *volcanic glass* rock. Cost $50/tonne
- Expanded perlite is commonly used as insulation
- Advantages:
  - Possesses low thermal conductivity (λ)
  - Easy handling
  - Inexpensive
  - Non-flammable
  - Low moisture retention.

- Drawbacks:
  - Characterized by lack of mechanical strength
  - Cannot offer a liquid or gas tight barrier
  - Non-renewable
  - Applications limited to a min. cargo temperature of −55°C
  - Water ingress can lead to loss of insulation strength & may be difficult to remove
  - Silicon treatment prior to application lessens water content

2. Perlite (2)

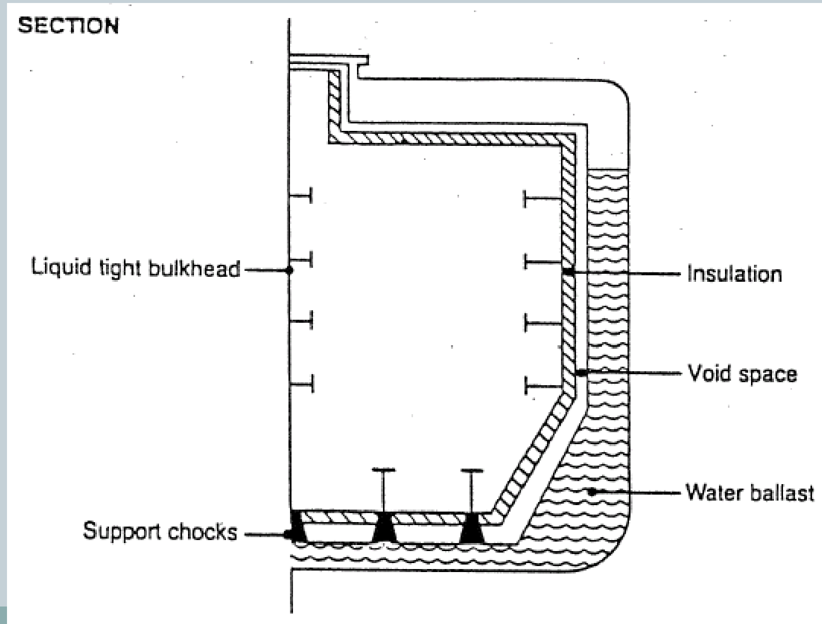
3. Polyurethane foam

- Polyurethane Foam (PUF) is a cellular plastic
- PUFs exhibit a wide range of stiffness, hardness, densities
- Characterized by high strength to weight ratio
- Uses: foam seating, engine gaskets, home insulation panels, RIBs, ...
- Possessed low λ; Relatively low cost insulation
- PUF strength governed by ρ
- Membrane tanks require high ρ_{PUF}: 90-100kg/m^3
- Con: PUF readily absorbs moisture. Requires vapour barrier.



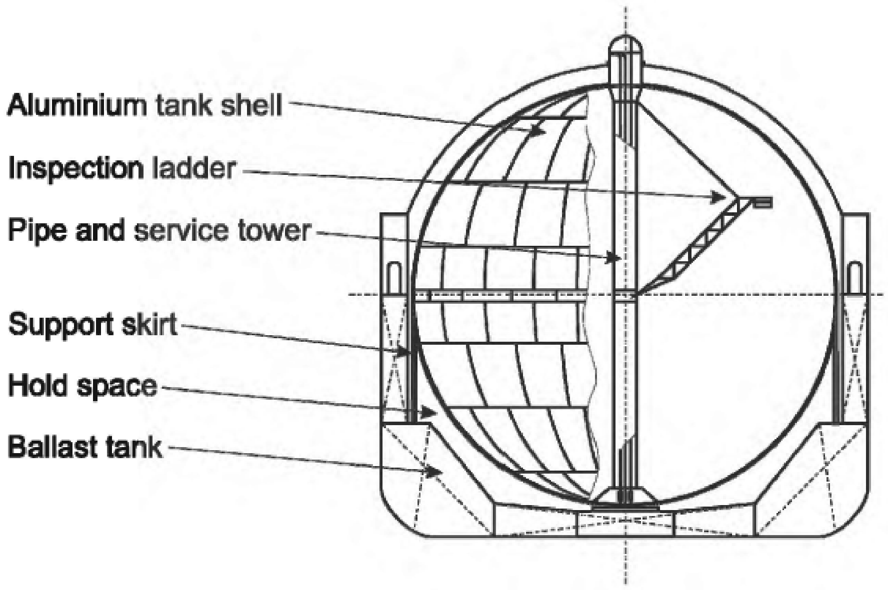
1(a). Self-supporting tanks

- Tanks expand & contract independently of vessel's hull
- Inner material: 9% nickel steel or aluminium (more costly)
- If the first layer is breached, LNG is contained by outer membrane
- Reliable & safe design
- Cons: a) Do not fully utilize ship's cargo capacity, b) costly construction



1(b). Moss system

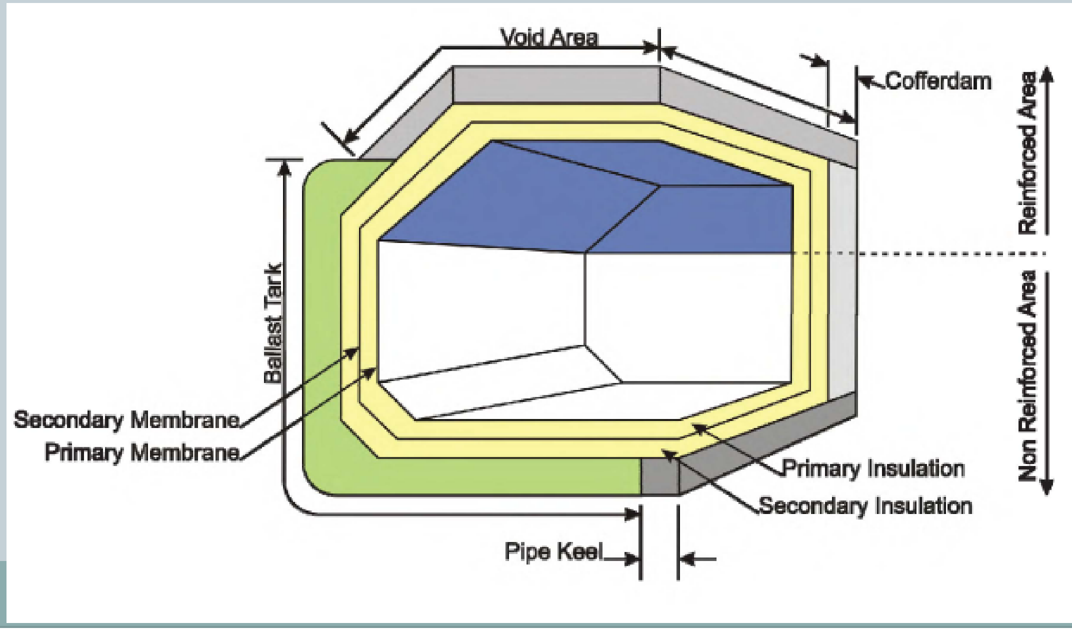
- Features spherical Al (or Al alloy) or 9% Ni steel tanks
- Exhibit single layer of *styrofoam* 150-250mm thick
- Tanks independent of ship hull; mounted on hull
- Al or Al alloy: i) Resistance to brittle fracture, ii) Lower weight that steel, iii) cost more than steel
- No secondary containment; spherical shape's highly resistant to leaks



2. Membrane (or integral) tanks

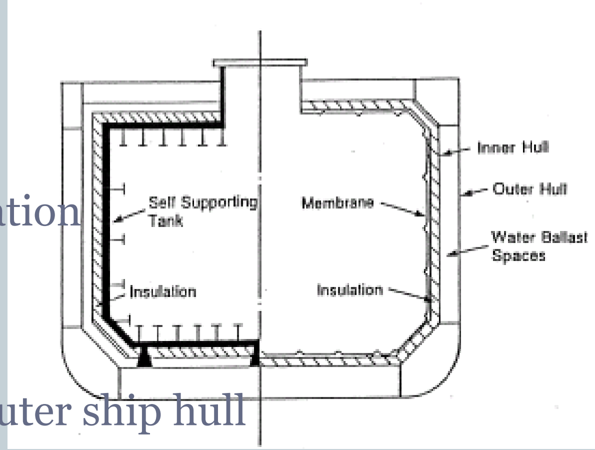
- Non self-supporting. Most popular containment stms
- Possess primary & secondary membrane barriers
- Thermal insulation separates LNG tank from hull
- Membranes made up of Invar (36% Ni Fe) or SS
- Insulation: plywood boxes filled with Perlite
- Technigaz system exhibits SS membrane

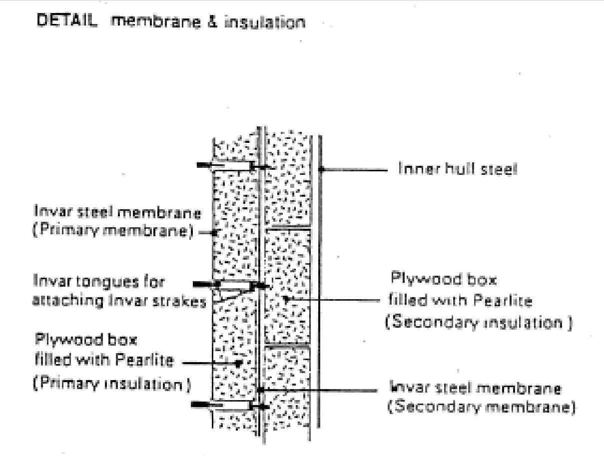
"Leak-before-failure"

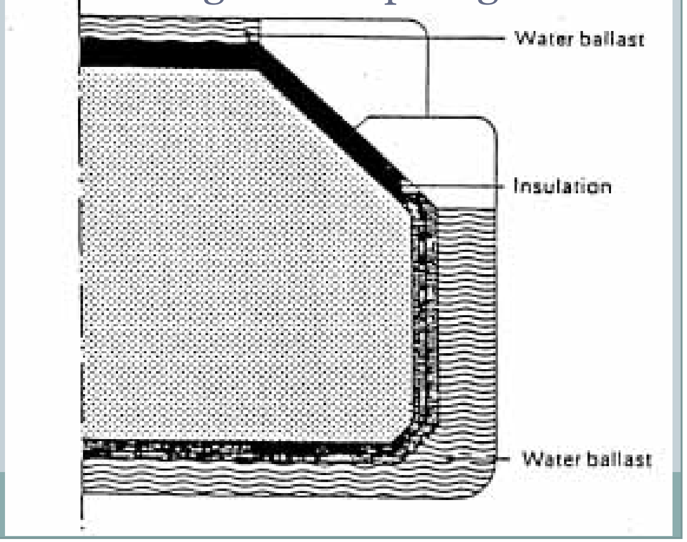


2. Membrane tanks (2)

- Pros:
  - Better space utilization than self-supporting
  - Less dead space for monitoring against leaks
  - Potential savings in tank material; no load carrying insulation
  - Identical construction methods for all tanker dimensions
- Drawbacks:
  - In the event of leak LNG may traverse inner & probably outer ship hull
  - Hard to weld large membrane areas
  - Considerable thermal stresses developed by LNG tanks extending over ship length Therefore, divide hold into subdivisions.



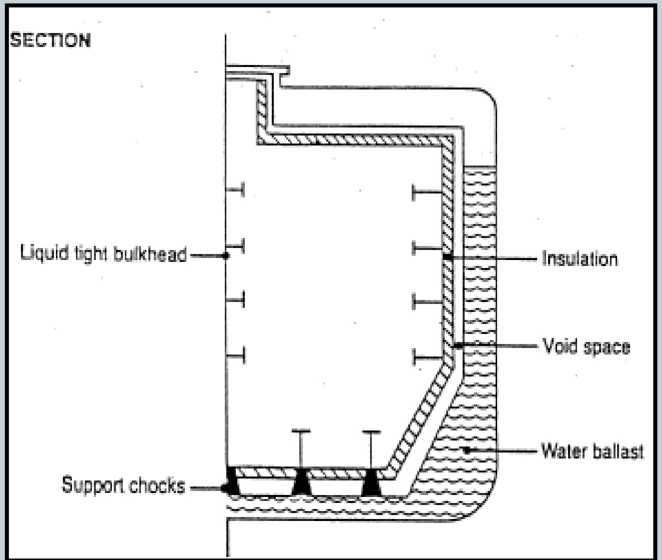


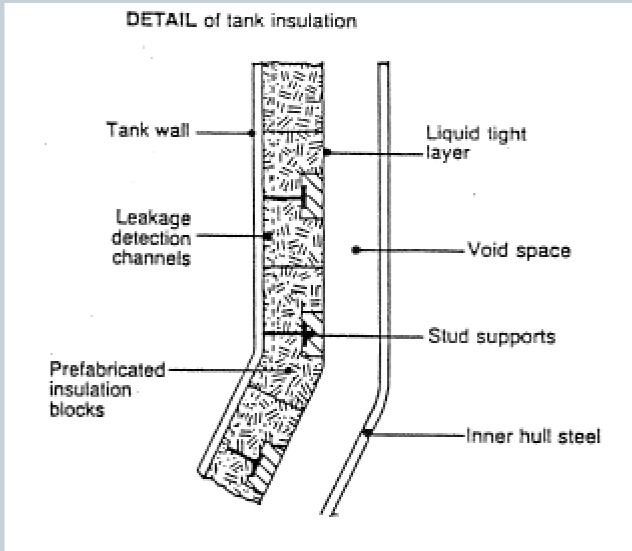


Gaz Transport design

3. Prismatic tank system

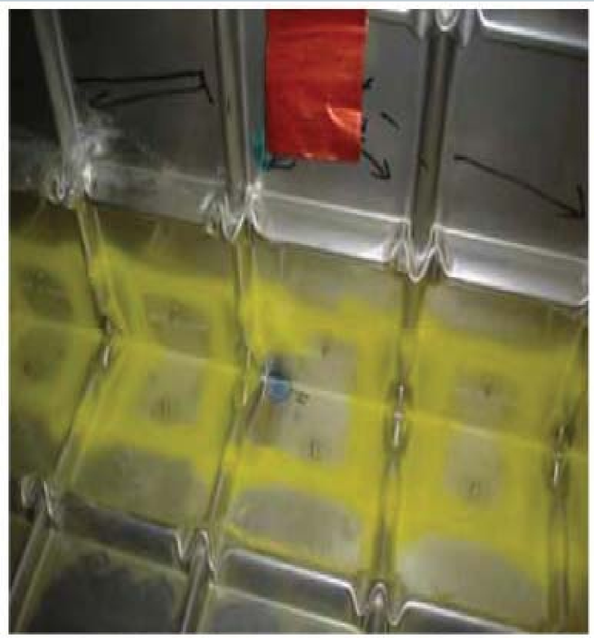
- Inner tank shell made-up of SS or invar (36% Ni iron)
- Require secondary barrier
- Stresses in prismatic tanks transmitted to frames, girders & stiffeners
- A breach in cargo containment might escape undetected
- GTT 96 Membrane; TG Mark III; CS1





3. Prismatic tank system (2)

- Need to insulate heat influx from hull into tank
- More slosh resistant (vs membrane type)
- Hull requires protection from cryogenic gas
- Second containment system offer 2nd line of defence against leak
- In case of leak there is sufficient time to discharge cargo in terminal



TG Mark III

LNG design considerations

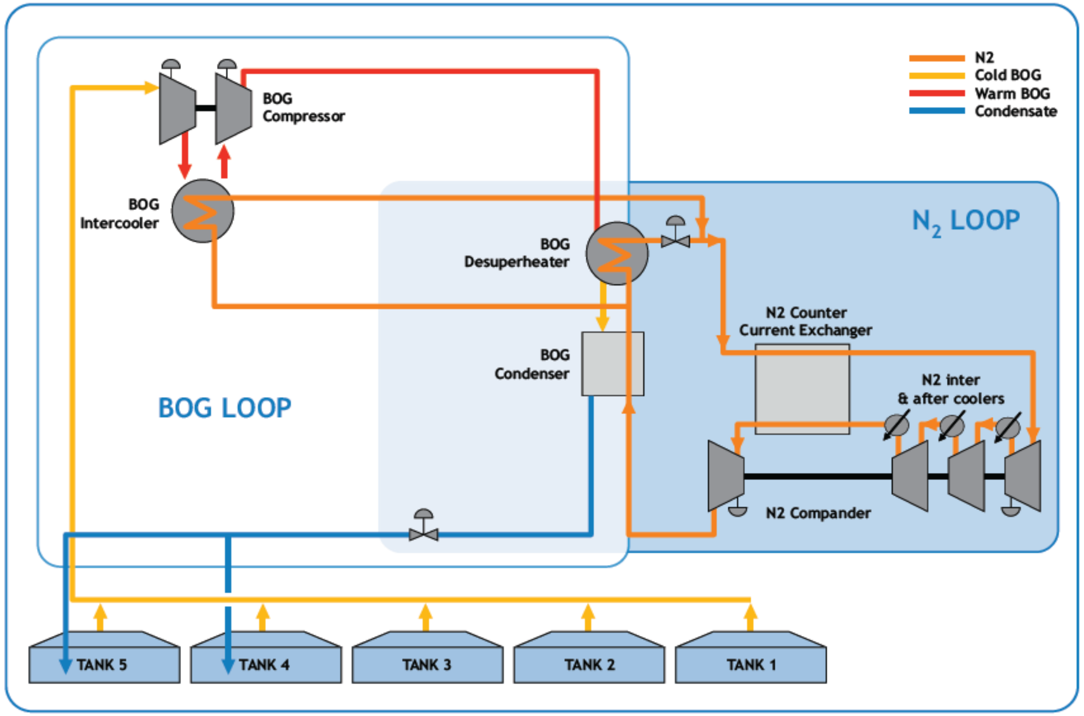
- Prismatic tanks better utilize hull volume (than self-supporting)
- Spherical tanks are leak resistant
- Self-supporting tanks withstand greater sloshing forces
- Typical insulation thickness: 270mm
- Prismatic & membrane containment stms are liable to cracks
- Careful loading & unloading procedures have to adhered to
- Membrane materials:
  - Al
  - Invar (36% Ni iron)
  - 9% Ni steel
  - SS

On-board BOG re-liquefaction

- Typically, 0.1%-0.25%/d of LNG cargo boils-off
- For a 25 day journey it amounts to ~4.4% of the cargo! $425,000/trip!
- Options:
  - Feed ship engine(s) or auxiliary machinery
  - Re-liquefy & inject in LNG tanks
  - Vent or flare
- Prior 2006, LNG ships did not carry re-liquefaction systems
- Onboard liquefaction considerations:
  - Energy intensive process
  - Spatial constraints
  - Weight limitations
  - Operational limitations
  - Diurnal fluctuations
  - BOG rate is affected by route
  - BOG rate = *f*(laden trip, ballast leg, sea state, tank spraying, tank sizes, insulation, ...)
  - No operation during return voyage or unloading

On-board BOG re-liquefaction (2)

- Capacity of BOG re-liquefaction plants (228,000m³) = ~6,500 kg/h
- Systems designed to: a) Handle peak BOG release, b) Operational within short notice
- Intermittency & short notice major considerations
- Power demand: 5.2MW (@−100˚C gas inlet T)

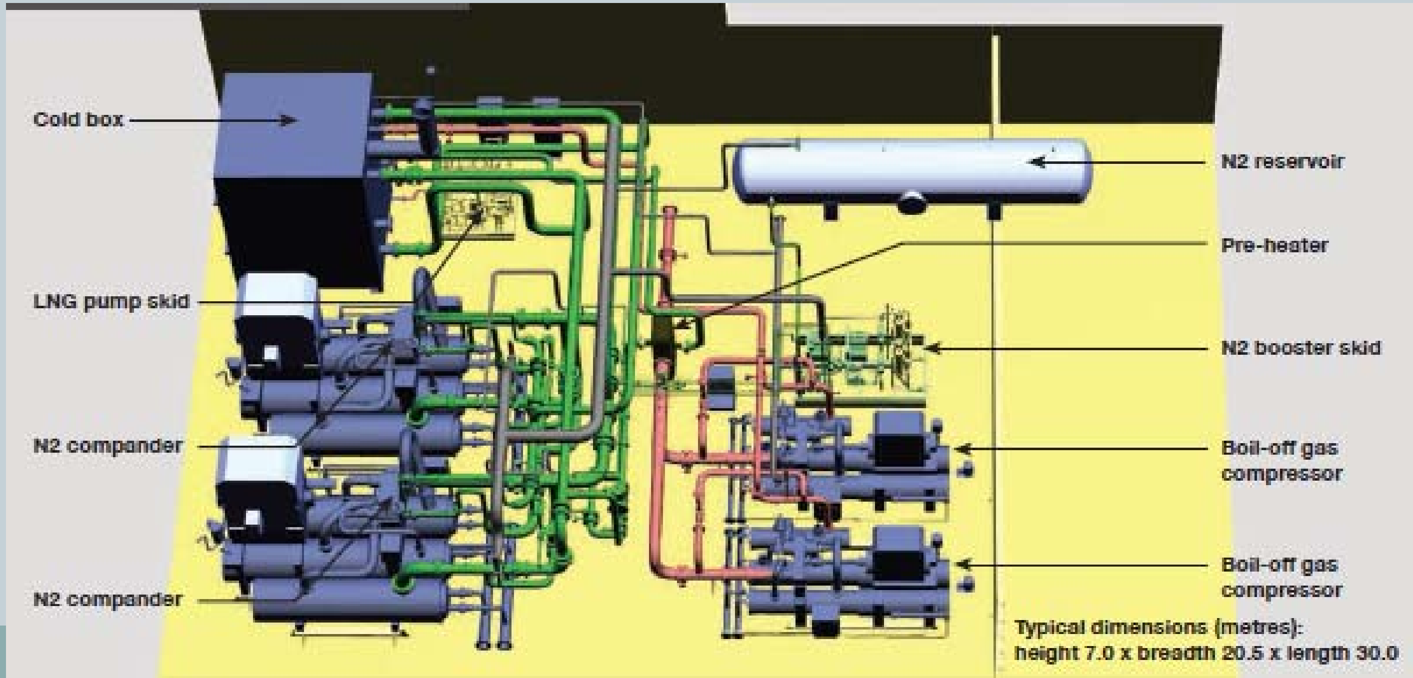


Reverse Brayton (nitrogen) cycle

EcoRel, Cryostar

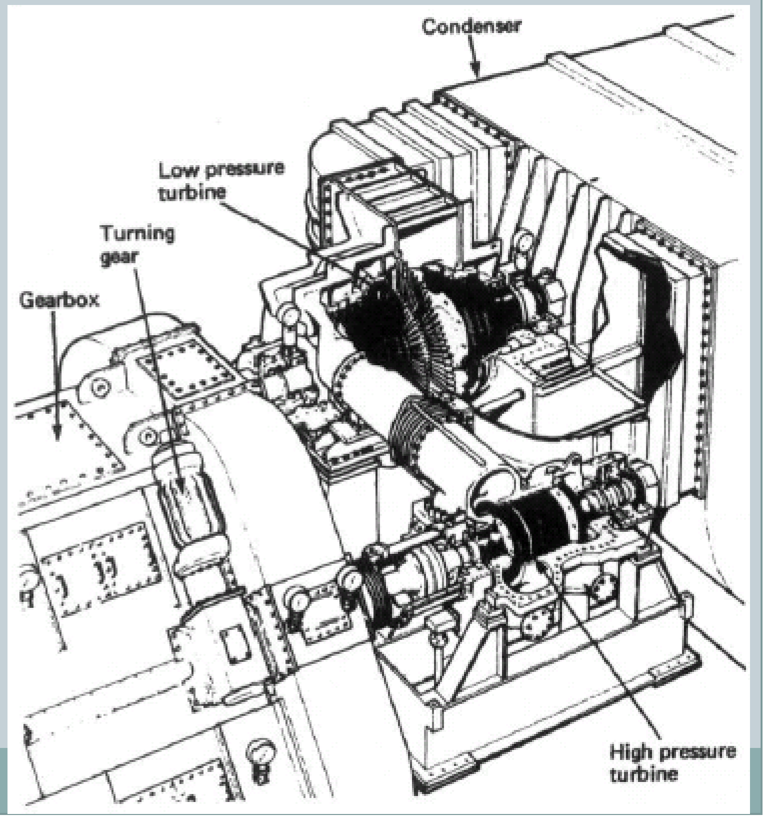
On-board BOG re-liquefaction (3)

- Larger size LNG ships financially justify on-board liquefaction
- Slow speed diesel engines more efficient than steam turbines
- Manufacturers:
  - Wärtsilä
  - Tractebel Gas Engineering
  - Cryostar



LNG propulsion systems

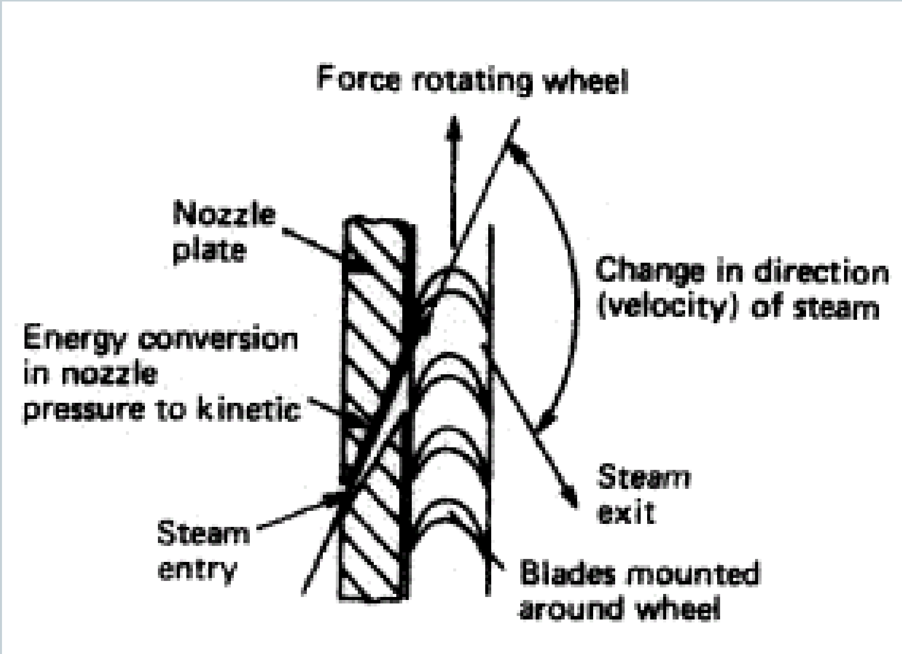
- Until 2006, LNG ships were powered by stream turbines
- 2006: first medium speed diesel engine LNG
- 2007: on-board liquefaction & slow-speed diesel engine(s) (<125rpm)
- Services speeds: 15-21knots
- Depending on vessel size *dual* engines & *twin* propellers are needed
- Highly skewed propellers lower prop. induced vibrations & *cavitation*
- Twin rudders improve vessel *manoeuvrability*
- Recently, slow-speed marine diesel ICE (on HFO) were introduced



LNG propulsion systems (2)

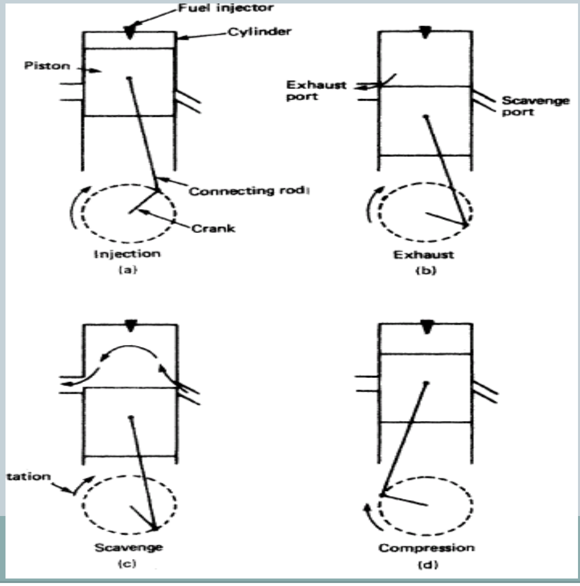
Steam turbines

- Pros:
  - Little or no vibrations
  - Relatively lightweight
  - Minimal space requirements
  - Comparatively low maintenance costs
  - Can accommodate virtually any power rating
  - Dual fuel prime mover
- Cons:
  - Higher specific fuel consumption (vs diesel engines)
  - Marine boilers
  - Low efficiency of 28% (vs. 38-40%)



LNG propulsion systems (3)

- Q-Max LNG vessels powered by slow speed diesel engines
- Other vessels feature electric propulsion
- No dual fuel (NG & HFO) currently exist *commercially*
- Wärtsilä: "It has been demonstrated successfully for the *first time* that low-speed engine performance can fully comply with IMO… while the low pressure 2-stroke dual-fuel engine is operating on gas. Low pressure 2 stroke gas engine will be available commercially in 2014."



Two-stroke dual fuel (LNG) engines

- 9 Sept., 2014: Wärtsilä awarded milestone order to supply 2-stroke dual-fuel engines for large LNG carriers

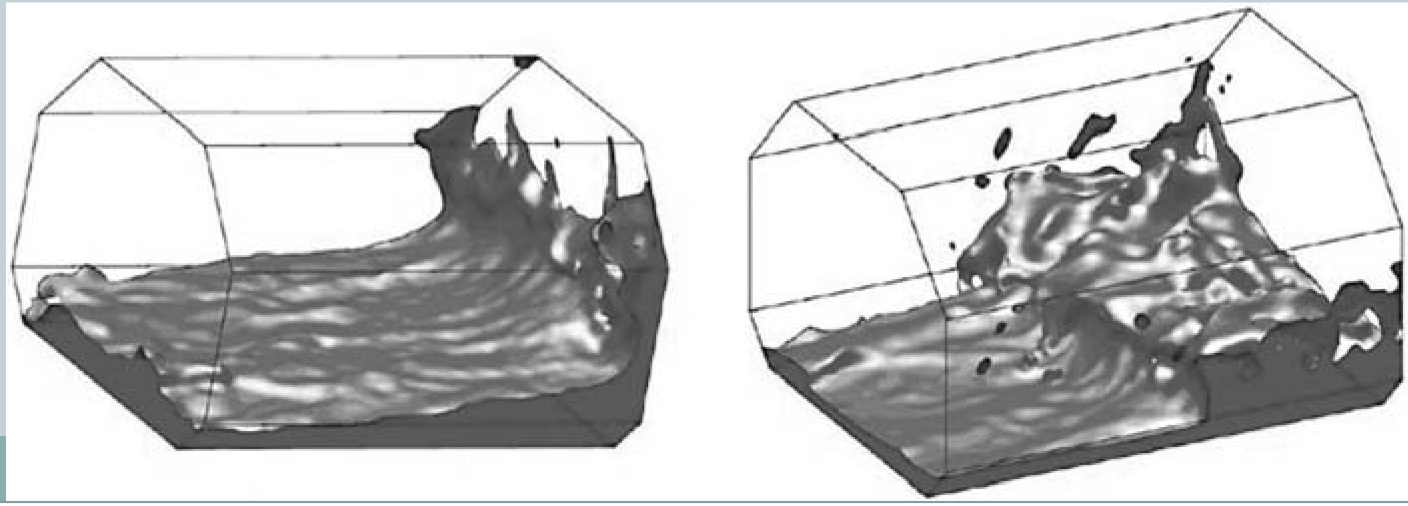
Wärtsilä Corporation, Press release:

Two new large, 180,000 m^3 LNG carriers being built by the Samsung Heavy Industries (SHI) in Korea on behalf of a collaboration between SK Shipping and Marubeni, are to be powered by 6-cylinder Wärtsilä X62DF 2-stroke dual-fuel engines. This is a milestone order for the marine sector as these will be the first large LNG carriers featuring Wärtsilä's 2-stroke dual-fuel technology. The order was placed in September and will be entered in Wärtsilä's September order book.

This development is set to revolutionize LNG transportation!

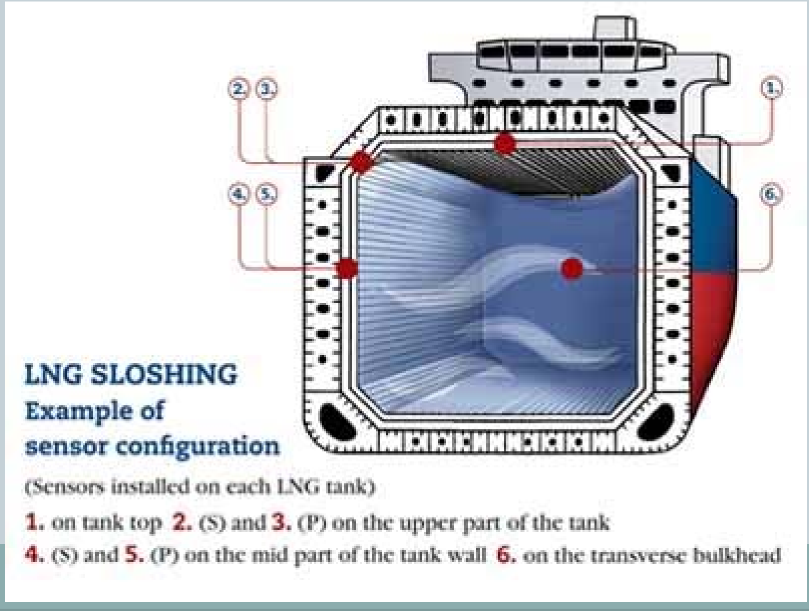
Sloshing

- 1970: First sloshing incident onboard Polar Alaska; detached pump
- Sloshing encountered in membrane & prismatic tanks types
- *Sloshing* refers to cargo fluid forces arising from rough sea conditions which can damage equipment or prismatic tank surfaces (eg, corners)
- Part load is a defining factor
- LNG carriers abide to loading restrictions:
  - Either **<10% full** or **>70%** full. Lower risk: 0-10% or 70-100%
  - Ship speed



Sloshing (2)

- Sloshing experiments of air & water offer insight in *sloshing dynamics*
- Numerical simulations (CFD) help *benchmark* experimental rigs & *estimate* fluid loads
- BOG bubbles in tanks compound understanding of sloshing
- DNV class notation offers guidance for sloshing effects
- *Membrane response*, *fatigue life* & *pump tower* require evaluation



LNG carrier roll-over

- Circumstances reported in literature
- Individual LNG ship tanks may store 50,000m^3
- Mixing different composition cargoes increases changes of stratification
- Avoid venting:
  - Expensive cargo
  - Greenhouse gas (GWP: 72)
  - LNG vapour is flammable
  - LNG vapour is lighter than air
- Stratification in LNG tanks is a prerequisite for roll-over
- Reduction in BOG points to cargo stratification: 10%

LNG carrier roll-over (2)

- Non-uniform tank heat influx induces temperature inhomogeneities
- LNGs are not equipped with
  - Top-filling connections
  - Internal jet-nozzles

Countermeasures

- Avoid mixing different composition cargoes
- Bottom tank filling: recommended for lighter LNG fractions
- Top filling:
  - Suggested for heaver LNG streams
  - LNG ships do not usually possess top filling equipment
- If stratification is detected:
  - Transfer cargo from one tank into another
  - Circulate tank contents by jet nozzles
  - Recirculation of cargo within tank

Q-Max LNG class carriers

- World's largest (membrane type) LNG carriers
- 14 in operation; 14 sister ships under planning
- Capacity: 266,000 m^3; ≈161MMm^3 (gaseous state)
- Ship particulars: 345m×53.8m×12m
- Powered by twin propellers @ 91rpm
- Prime movers:
  - Twin-slow speed ICE
  - HFO powered
  - 2×21,770 kW

How many Q-Max shiploads suffice to meet Cyprus' electricity demand for 1 year?

Q-Max

- Estimated cost: 300m-400m USD
- Reputed to be 60% fuel efficient (vs steam powered vessel)
- Estimated 40% less carbon emissions
- Featuring on-board BOG re-liquefaction plants
- High volume of BOG economically justifies onboard re-liquefaction

Q-Max

Floating LNG

Floating LNG (FLNG)

- Innovation: onboard liquefaction & storage
- Petronas' Satu: 1.2mtpa ($10bn)
- Shell's Prelude: 3.5-4mtpa ($14bn)
  - 600,000 t; Length: 488m
- Working life: 30-40 yrs
- Issues: sloshing, maintenance, safety, energy footprint

Floating LNG

- Obviate need for submarine transmission pipeline(s)
- Innovation: onboard liquefaction
- 3.5-5.5 mtpa (2-3tcf)
- Working life: 30-40 yrs
- Issues:
  - LNG sloshing
  - Topsides: equipment miniaturization & access for maintenance
  - Hull: no dry-docking
  - Mooring systems: must not interfere with production & offloading
  - Safety considerations
  - Offloading: sea motions during transfer operations
  - Metocean design conditions: 100-year; 10,000 year load

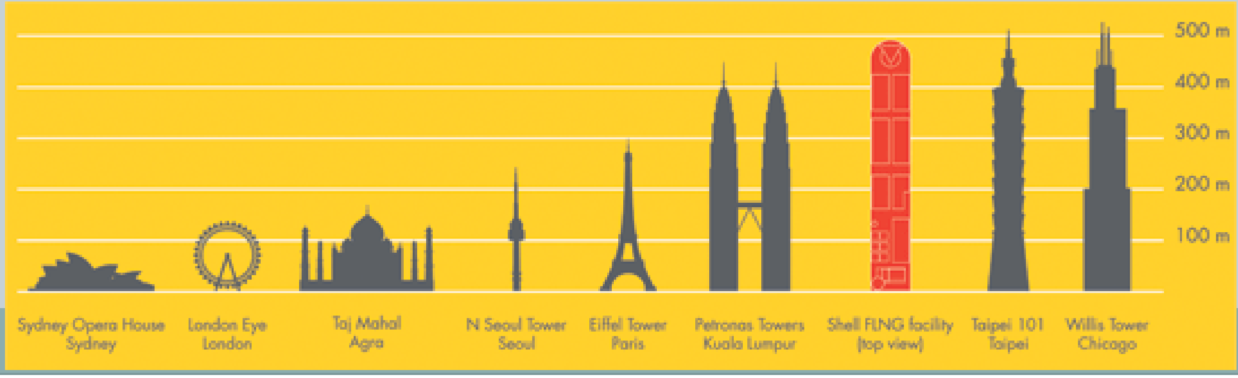
Courtesy: Royal Dutch Shell

Prelude FLNG project

- Expected to commence operation in 2017; offshore NW Australia
- Capacity: 5.3mtpa (3.6mpta *LNG*, 1.3mtpa *condensates*, 0.4mtpa *LPG*)
- Construction commenced in Oct., 2012
- FLNG Prelude 1st in the world
- Delivery date: 2017
- Cost: $5-6 bn
- 600,000 t | Length: 488m
- Hull floated on Dec. 3rd, 2013
- Build by SHI, S. Korea

Prelude FLNG in numbers

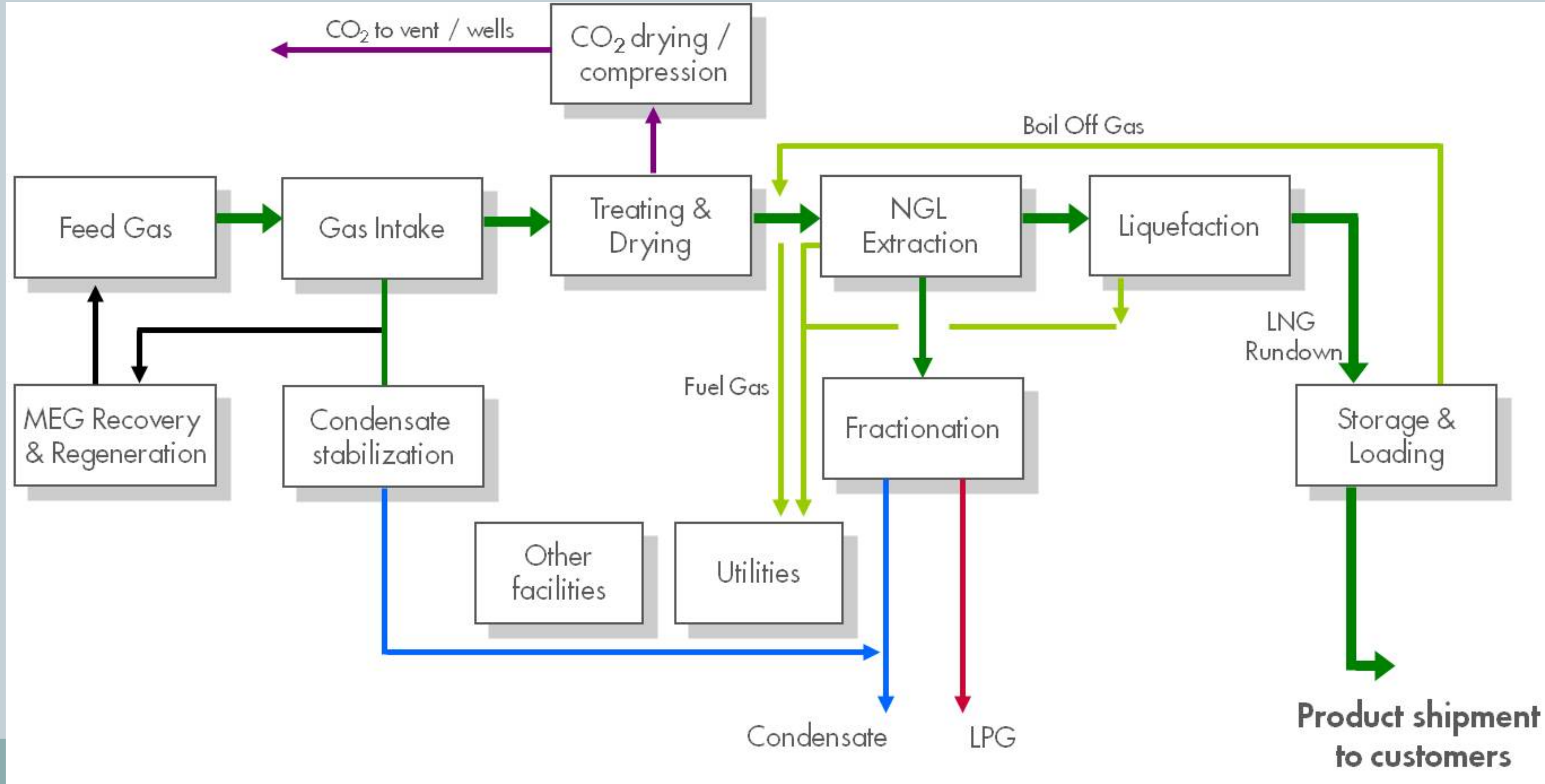
- **>600** engineers worked on the facility's design options
- **93m** by **30m** the turret secured to the seabed by mooring lines
- **50 tonnes/hr** cold H_2O to be drawn from the ocean to help cool the NG
- **20-25 years** is the time the Prelude FLNG facility will stay at the location to develop gas fields
- >**200 km** is the distance from the Prelude field to the nearest land
- **175 Olympic-sized swimming pools** could hold the same amount of liquid as the facility's storage tanks
- **6 of the largest aircraft carriers** would displace the same amount of water as the facility

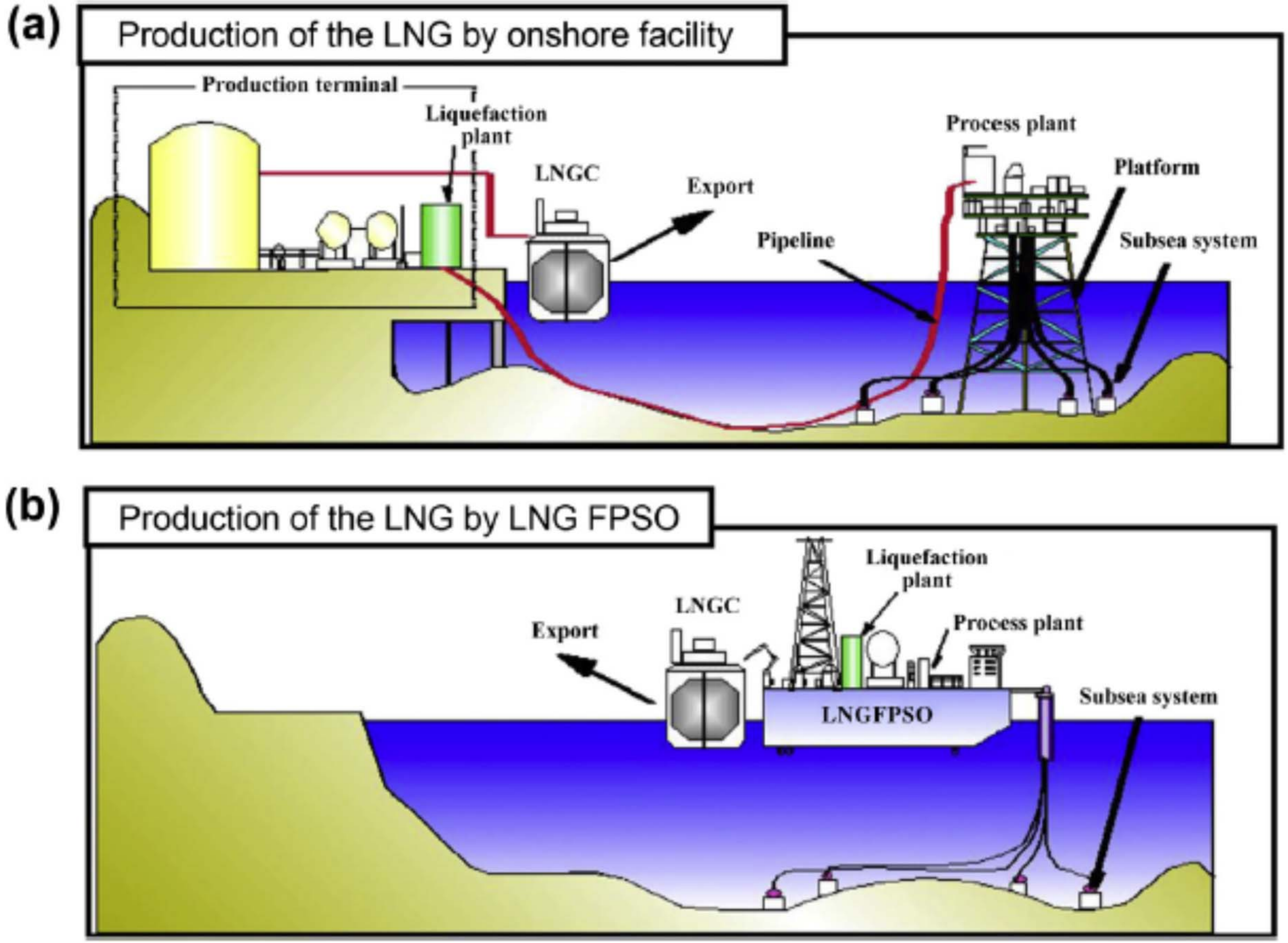


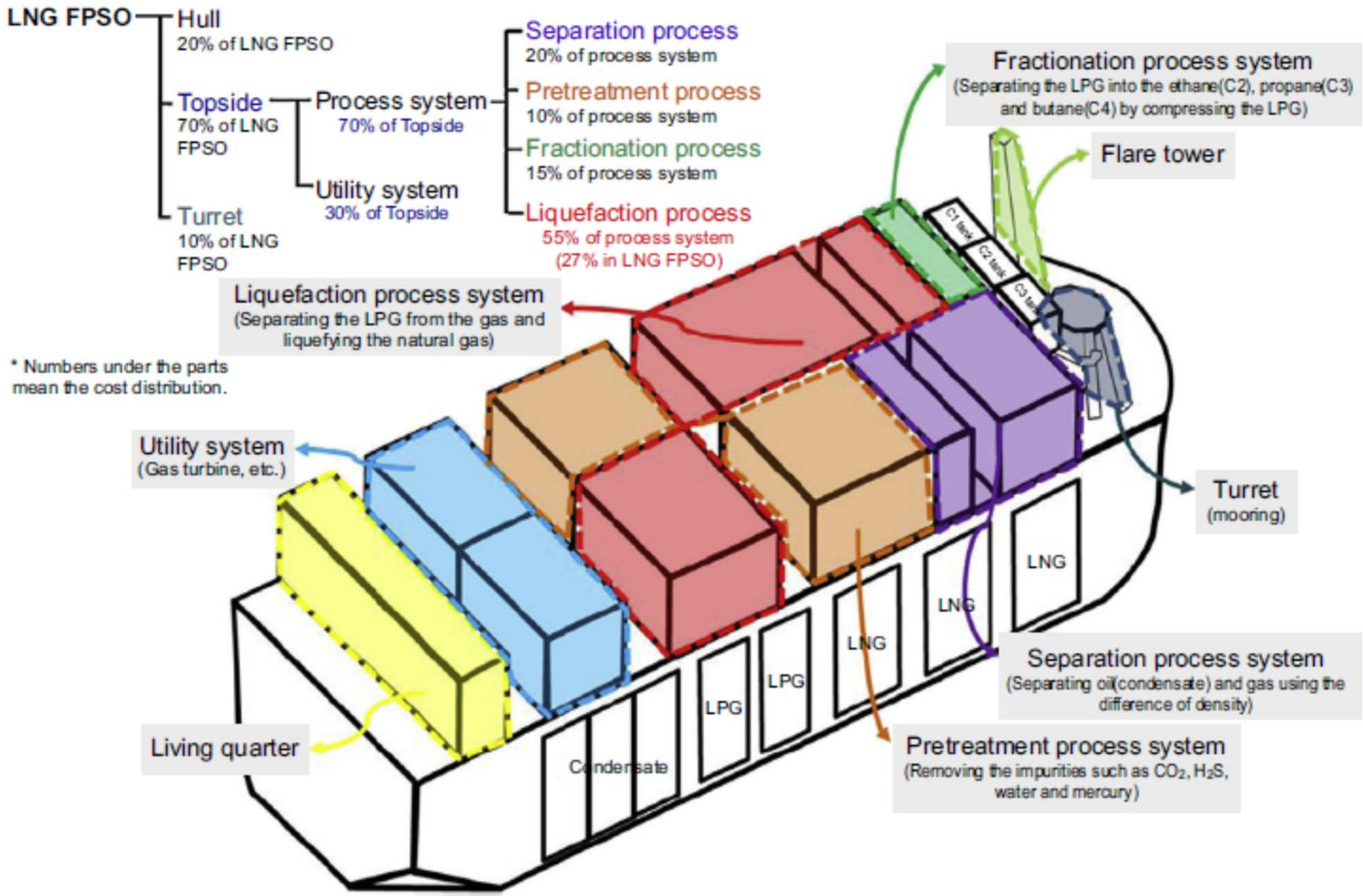
Floating NG liquefaction

- Fluids:
  - CH_4, C_2H_6, C_3H_8, C_4H_{10}
  - Condensates, CO_2, H_2O, etc

Courtesy: Royal Dutch Shell




(a)
Production of the LNG by onshore facility
Production terminal
Liquefaction plant
LNGC
Export
Pipeline
Process plant
Platform
Subsea system
(b)
Production of the LNG by LNG FPSO
Liquefaction plant
LNGC
Export
Process plant
Subsea system
LNGFPSO



LNG FPSO
Hull
20% of LNG FPSO
Topside
70% of LNG FPSO
Turret
10% of LNG FPSO
Process system
70% of Topside
Utility system
30% of Topside
Separation process
20% of process system
Pretreatment process
10% of process system
Fractionation process
15% of process system
Liquefaction process
55% of process system
(27% in LNG FPSO)
Liquefaction process system
(Separating the LPG from the gas and liquefying the natural gas)
* Numbers under the parts mean the cost distribution.
Fractionation process system
(Separating the LPG into the ethane(C2), propane(C3) and butane(C4) by compressing the LPG)
Flare tower
Utility system
(Gas turbine, etc.)
Turret
(mooring)
Living quarter
Separation process system
(Separating oil(condensate) and gas using the difference of density)
Pretreatment process system
(Removing the impurities such as CO2, H2S, water and mercury)
LNG
LNG
LNG
LPG
LPG
Condensate

Prelude FLNG project (2)

Importing LNG: Floating Storage & Regas Unit (FSRU)

- Total of 27 FSRUs & 3 FSUs
- FRSU capacity (2018): 84 mpta
- Proven, reliable, competitive & flexible
- Pros: lower costs, shorter time-to-market, fewer regulatory & permitting hurdles

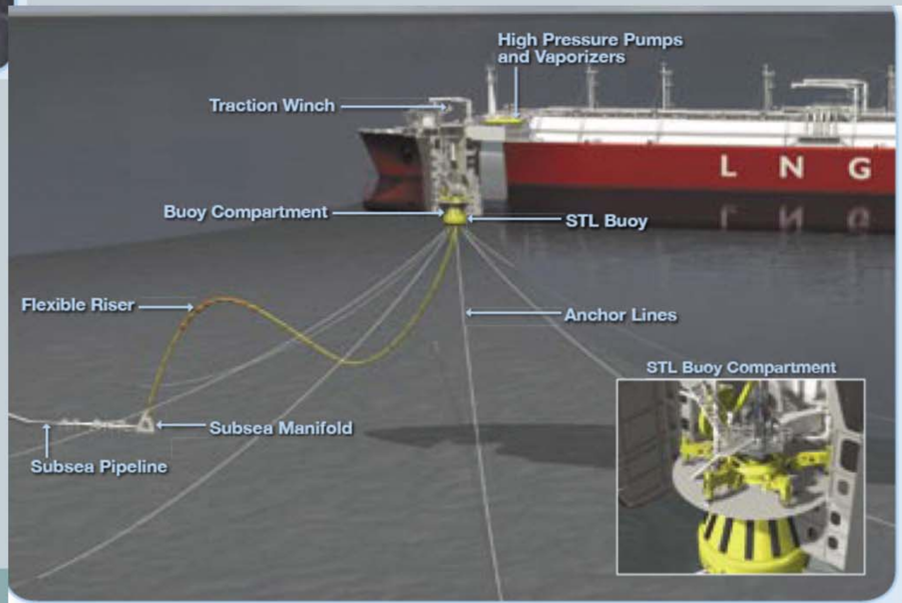
FSRU Toscana (Italy)

Floating Power Generation Plant (FPGP)

Source: Golar

Energy Bridge Regas Vessel (EBRV™)

Source: Excelerate



Pros & cons of RVs

- Advantages:
  - Alternative solution of onshore regas terminal
  - Does not require any onland space
  - Ensures safety of other land-based facilities
  - Intermediate “solution” before the arrival of Cyprus nat gas
- Challenges:
  - Temporary option e.g., 5 years
  - Short time frame for investment recovery
  - Contract terms
  - Viability of project depends on NG throughout

Next…

- Cargo handling gear
- Onboard discharging equipment
- Sophisticated measuring, alarm systems & control electronics
- Loading arms

LNG safety issues

Properties of natural gas

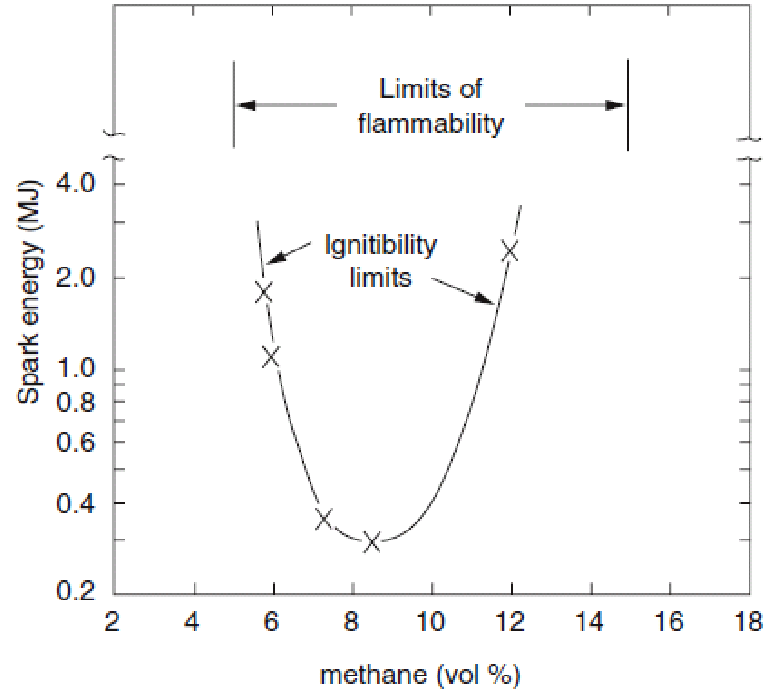
- Natural gas is: *odourless*, *colourless*, *tasteless*, *shapeless* & lighter than air *non-corrosive*, *non-toxic*
- Gas odorization helps detect gas leaks
- Mercaptans (or thiol) with a smell of rotten egg help smell the gas
- Smells due to *methanethiol*
- NG's flammable only in concentration 5-15% in air
- NG is lighter than air & rises up
- Consumers detect gas if conc ≈1% in air
- Burning of odorant does not liberate large sulphur amounts or toxicity

Properties	Value
Relative molar mass	17–20
Carbon content, weight %	73.3
Hydrogen content, weight %	23.9
Oxygen content, weight %	0.4
Hydrogen/carbon atomic ratio	3.0–4.0
Relative density, 15 °C	0.72–0.81
Boiling point, °C	−162
Autoignition temperature, °C	540–560
Octane number	120–130
Methane number	69–99
Stoichiometric air/fuel ratio, weight	17.2
Vapor flammability limits, volume %	5–15
Flammability limits	0.7–2.1
Lower heating/calorific value, MJ/kg	38–50
Stoichiometric lower heating value, MJ/kg	2.75
Methane concentration, volume %	80–99
Ethane concentration, volume %	2.7–4.6
Nitrogen concentration, volume %	0.1–15
Carbon dioxide concentration, volume %	1–5
Sulfur concentration, weight % ppm	<5
Specific CO_2 formation, g/MJ	38–50

Flammability limits

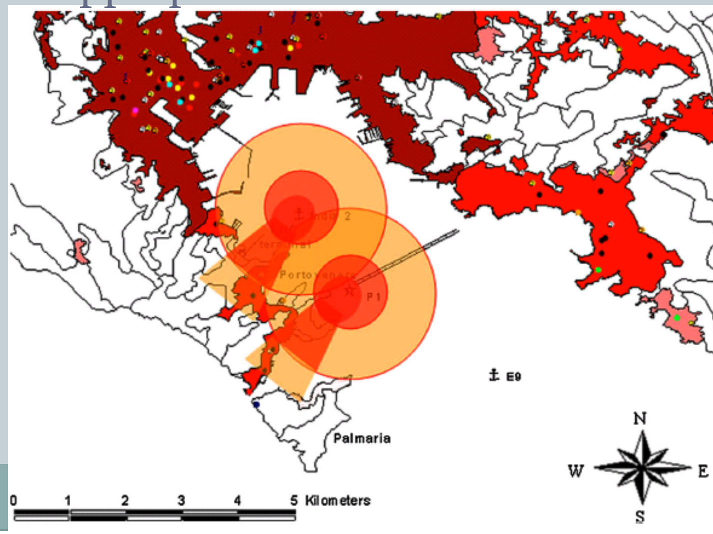
- Flammability limit: a mixture of combustible gases & air burn only if the fuel concentration (vol or moles) lies within well defined upper & lower limits
- Pure methane (CH_4) has flammability limits of 5%-15% in air
- Ignition likelihood also affected by ignition sources (y-axis)
- Ignition sources:
  - Fire heaters (stoves)
  - Open flames
  - Motor vehicles, etc

Material	Specific Gravity (Air = 1)	Lower Flammable Limit (Vol %)	Upper Flammable Limit (Vol %)
Methane	0.55	5.0	15.0
Ethane	1.04	3.0	12.4
Propane	1.52	2.1	9.5
n-Butane	2.01	1.8	8.4



Nat gas safety issues

- Methane is colorless, odorless, non-toxic, non-corrosive
- Can be detected using "methanethiol"
- LNG is non-flammable in its liquid state
- Nat gas burns only in:
  - Presence of a spark, oxygen and within flammability limits
- Safety levels:
  - Flare nat gas, layout of LNG plant & equipment
  - Division of the LNG plant into blast zones & use of appropriate materials
  - Use of fire or explosion resistant materials, firefighting systems, leakage detectors
  - Leakage & explosion simulations



Thanks for your attention!