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
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 250,000m³ 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

**LNG Composition**

<table>
<thead>
<tr>
<th>Component</th>
<th>Composition Range (mol%)</th>
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<tbody>
<tr>
<td>Nitrogen</td>
<td>0.00 – 1.00</td>
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<tr>
<td>Methane</td>
<td>84.55 – 96.38</td>
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<tr>
<td>Ethane</td>
<td>2.00 – 11.41</td>
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<tr>
<td>Propane</td>
<td>0.35 – 3.21</td>
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<tr>
<td>Isobutane</td>
<td>0.00 – 0.70</td>
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<tr>
<td>n-Butane</td>
<td>0.00 – 1.30</td>
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<tr>
<td>Isopentane</td>
<td>0.00 – 0.02</td>
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<tr>
<td>n-Pentane</td>
<td>0.00 – 0.04</td>
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<tr>
<td>HHV gas</td>
<td>1021 – 1157</td>
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<tr>
<td>Btu/scf (kJ/Sm³)</td>
<td>(38,000 – 43,090)</td>
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<tr>
<td>Wobbe number</td>
<td>1353 – 1432</td>
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<tr>
<td>GPM, on C₂⁺ basis</td>
<td>0.71 – 4.08</td>
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<tr>
<td></td>
<td>(0.094 – 0.543)</td>
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**Constituents**

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Molecular weight</th>
<th>Relative Density (Air = 1)</th>
<th>Gross Cal. Val. MJm⁻³(st)</th>
<th>Spontaneous Ignition Temperature °C</th>
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<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<td>Methane</td>
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<td>Hydrogen</td>
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<td>Petrol</td>
<td>80</td>
<td>3 to 4</td>
<td>174.5</td>
<td>280</td>
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</table>
LNG roll-over (2)

- LNG cargoes have different compositions
- Therefore, different LNG densities & vapour pressure
- Heat influx in the tank evaporates LNG
- Variations in $\rho_{\text{LNG}}$ fractions result in stratification ($\Delta \rho_{\text{LNG}}=1 \text{ kg.m}^{-3}$)
- ‘Lighter’ LNG components boil-off faster (‘aging’)
- $\rightarrow$ 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

![Concrete band wall diagram]
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 $\rho$ 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 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. 5MMm³ (2008) → 35MMm³ (‘07) → 55MMm³ (‘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 m³
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
Natural gas price

- CIF (Cost Insurance Freight) (average prices)
LNG exports

Source: BP Energy Outlook 2030

1 cubic foot = 0.0283 cubic metres
Major NG trade routes (2014)

Units: billion cubic meters (bcm)
LNG imports & exports

Top ten LNG exporters
2011, bn cubic metres

- Qatar: 103
- Malaysia
- Indonesia
- Australia
- Nigeria
- Trinidad & Tobago
- Algeria
- Russia
- Oman
- Brunei

Source: Eurasia Group, GIINL

LNG imports, bn cubic metres

- North America: 300
- Europe
- China: 200
- South Korea
- Japan: 100
- Other

Sources: Waterborne LNG; Oxford Institute for Energy Studies
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 = \( f(\text{laden trip days, sea state, ambient temp.}, \ldots) \)
Projected world LNG fleet for 2013:

Vessel sizes:
- Small: <120,000m³
- Standard: 120,000-175,000m³
- Q-flex: 216,000m³
- Q-max: 260,000m³

Major LNG shipyards S. Korea:
- Daewoo, Samsung HI, Hyundai

Japan:
- Kawasaki

Cost of LNG ships: $130M (138,000m³)
In 1995, same size ship cost: $280M
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

![Energy by Sea: The world's largest fleets of liquefied-natural-gas ships, by country](chart.png)

- Japan: 96 ships, $13.39 billion
- Greece: 65 ships, $11.68 billion
- Qatar: 35 ships, $6.95 billion
- U.K.: 43 ships, $5.47 billion
- Bermuda: 28 ships, $5.31 billion
- Norway: 36 ships, $4.31 billion

*Note: The chart shows the value in billions and the number of ships for each country.*
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 LNG)
  - 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

<table>
<thead>
<tr>
<th></th>
<th>Lc [m]</th>
<th>Lpp [m]</th>
<th>B [m]</th>
<th>T [m]</th>
<th>GT tys [t]</th>
<th>Vols thousands [m³]</th>
<th>type of tanks</th>
<th>vessel’s name</th>
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<td>151</td>
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<td>216</td>
<td>–</td>
<td>33</td>
<td>9.5</td>
<td>40</td>
<td>36</td>
<td>membrane</td>
<td>LNG Lerici</td>
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<td>239</td>
<td>226</td>
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<td>11</td>
<td>66</td>
<td>87</td>
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<td>5</td>
<td>270 / 275</td>
<td>260 / 265</td>
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<td>11 / 12</td>
<td>90 / 111</td>
<td>132 / 135</td>
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<td>7</td>
<td>289</td>
<td>–</td>
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<td>8</td>
<td>315</td>
<td>–</td>
<td>50</td>
<td>12.0</td>
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<td>216</td>
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<tr>
<td>9</td>
<td>340</td>
<td>–</td>
<td>54</td>
<td>12.0</td>
<td>–</td>
<td>270</td>
<td>membrane</td>
<td>Q-max</td>
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</table>
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, $\rho_{\text{LNG}} = 0.41$-0.5 t·m$^{-3}$ ($\rho_{\text{H}_2\text{O}} = 1$ t·m$^{-3}$ @ 25°C)
- Low dynamic viscosity, $\mu_{\text{LNG}} = 188 \mu$kg/m·s ($\mu_{\text{LNG}} = \sim 0.9$ mkg/m·s)
- Flammable cargo (within range of 5-15% in air)
- Colorless & odorless cargo
- Generates boil-off gas; BOG rises on top of tank: $\rho_{\text{BOG}} (@ -100^\circ\text{C}) < \rho_{\text{Air}}$
- 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
  - Possess 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 @ $-163^\circ$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. Free-standing or independent (Self-supporting)
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 $\Delta T$ 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 $-160^\circ$C
- Balsa wood tank insulation consists of wood strips, $\rho=40-340\text{kg/m}^3$
- Insulation bonded together with resorcinol glue
- Applied in varying grain orientations in prefabricated flat panels
- Panels measure $1\times3\text{m}$ by $0.25\text{m}$ 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 $\lambda$; Relatively low cost insulation
- PUF strength governed by $\rho$
- Membrane tanks require high $\rho_{\text{PUF}}$: 90-100kg/m$^3$
- Con: PUF readily absorbs moisture. Requires vapor 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 than 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 systems
- 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.

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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 2\textsuperscript{nd} line of defence against leak
- In case of leak there is sufficient time to discharge cargo in terminal
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)
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 m³ 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 vapor is flammable
  - LNG vapor 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 heavier 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 m³; ≈161MMm³ (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

- 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 1\textsuperscript{st} in the world
- Delivery date: 2017
- Cost: $5-6 bn
- 600,000 t | Length: 488m
- Hull floated on Dec. 3\textsuperscript{rd}, 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 H₂O 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:
  - CH₄, C₂H₆, C₃H₈, C₄H₁₀
  - Condensates, CO₂, H₂O, etc

Courtesy: Royal Dutch Shell
(a) Production of the LNG by onshore facility

(b) Production of the LNG by LNG FPSO
LNG FPSO
- Hull: 20% of LNG FPSO
- Topside: 70% of LNG FPSO
- Turret: 10% of LNG FPSO

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)

Fractionation process system (Separating the LPG into ethane (C2), propane (C3) and butane (C4) by compressing the LPG)

Liquefaction process system (Separating the LPG from the gas and liquefying the natural gas)

Utility system: Gas turbine, etc.

Flare tower

Turret (mooring)

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)

Living quarter
Prelude FLNG project (2)
- Cargo handling gear
- Onboard discharging equipment
- Sophisticated measuring, alarm systems & control electronics
- Loading arms
LNG safety issues
Properties of natural gas

- Natural gas is: odorless, colorless, 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
**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.

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Gravity (Air = 1)</th>
<th>Lower Flammable Limit (Vol %)</th>
<th>Upper Flammable Limit (Vol %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>0.55</td>
<td>5.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Ethane</td>
<td>1.04</td>
<td>3.0</td>
<td>12.4</td>
</tr>
<tr>
<td>Propane</td>
<td>1.52</td>
<td>2.1</td>
<td>9.5</td>
</tr>
<tr>
<td>n-Butane</td>
<td>2.01</td>
<td>1.8</td>
<td>8.4</td>
</tr>
</tbody>
</table>
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!