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Safety in the Liquefied Natural Gas (LNG) Value Chain

An AIChE Live Webinar

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The presenters have considerable experience in LNG safety

Georges Melhem, Ph.D.

Dr. Melhem is President and CEO of ioMosaic. He is an internationally known pressure relief design, chemical reaction systems, and fire and explosion dynamics expert. Since 1988, Dr. Melhem has lead and participated in many LNG studies. These studies focused on issues associated with LNG siting, transportation, LNG hazard and risk assessments, and LNG public testimony.

Henry Ozog

Henry Ozog is the general partner of ioMosaic Corporation and is an expert in process safety and risk management. He had conducted LNG related work for FERC, the California Energy Commission, the Nova Scotia Department of Energy, the Canadian National Energy Board, as well as a number of LNG terminal operators and engineering companies.

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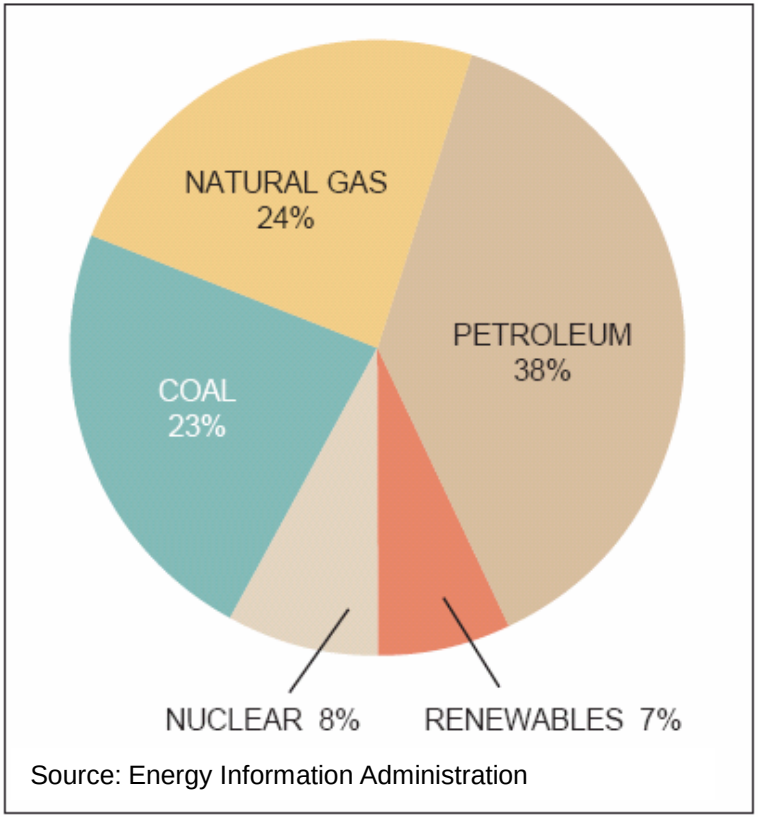
Natural gas is a popular fuel because it is environmentally clean, efficient, reliable, and economical

- Natural Gas (NG) meets 1/4th of the U.S. and worldwide energy needs
- NG is used as a fuel in:
  - homes
  - manufacturing plants
  - power plants
- NG is also a major raw material for the petrochemical industries



Source: Energy Information Administration

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Natural gas demand is increasing, but pipeline transport is not always economic or feasible

- Worldwide demand for natural gas increased 2.2% in 2011, primarily for power generation.
- Worldwide production of natural gas increased 3.1% in 2011 and 7.7% in the US.
- In the U.S. development of new “fracking” technology for recovery of natural gas from shale has changed the supply/demand balance so drastically that we have gone from building LNG import terminals to exporting LNG in less than a decade.
- When it is not economical to transport natural gas by pipeline, it is shipped as LNG.

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The objective of this webinar is to highlight safety hazards in the LNG value chain and possible mitigation options

- LNG has hazards that are common with other hydrocarbons, but is also has unique hazards
- We will discuss these hazards and the mitigation measures in place for each link of the value chain:
  - liquefaction,
  - transportation (marine tankers and trucks),
  - storage, and
  - re-gasification.

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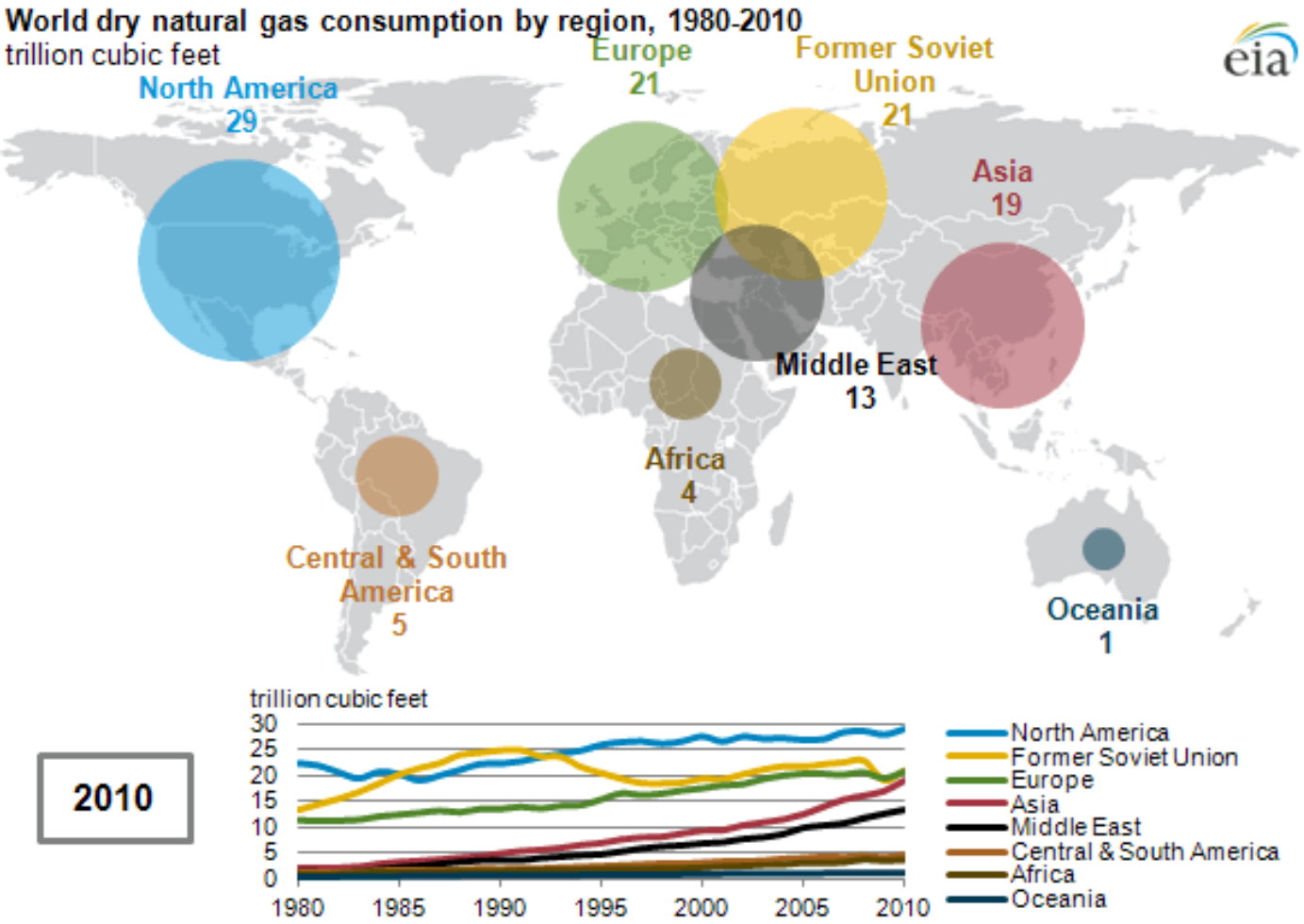
Natural gas demand worldwide is increasing



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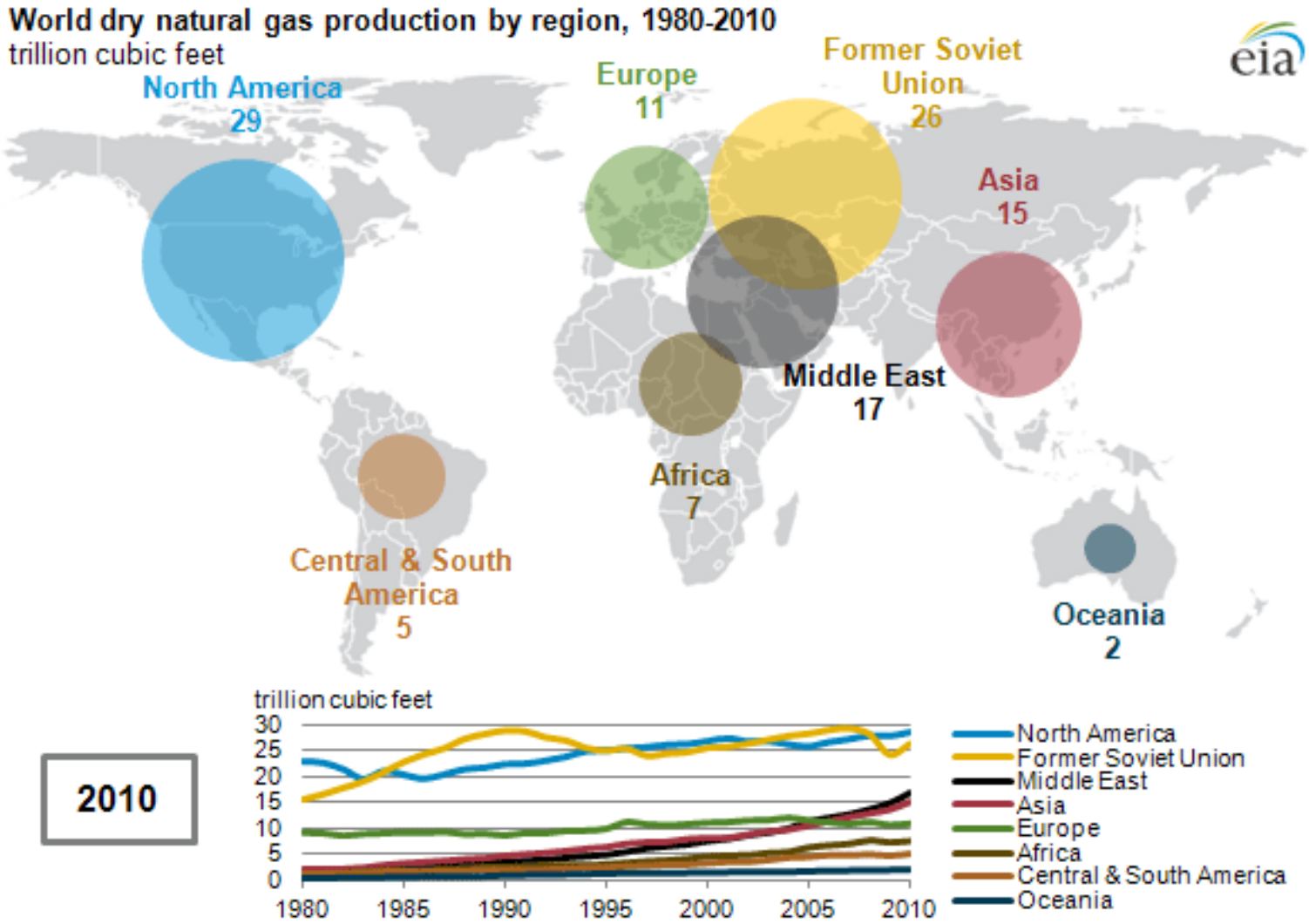
Natural gas production worldwide is increasing



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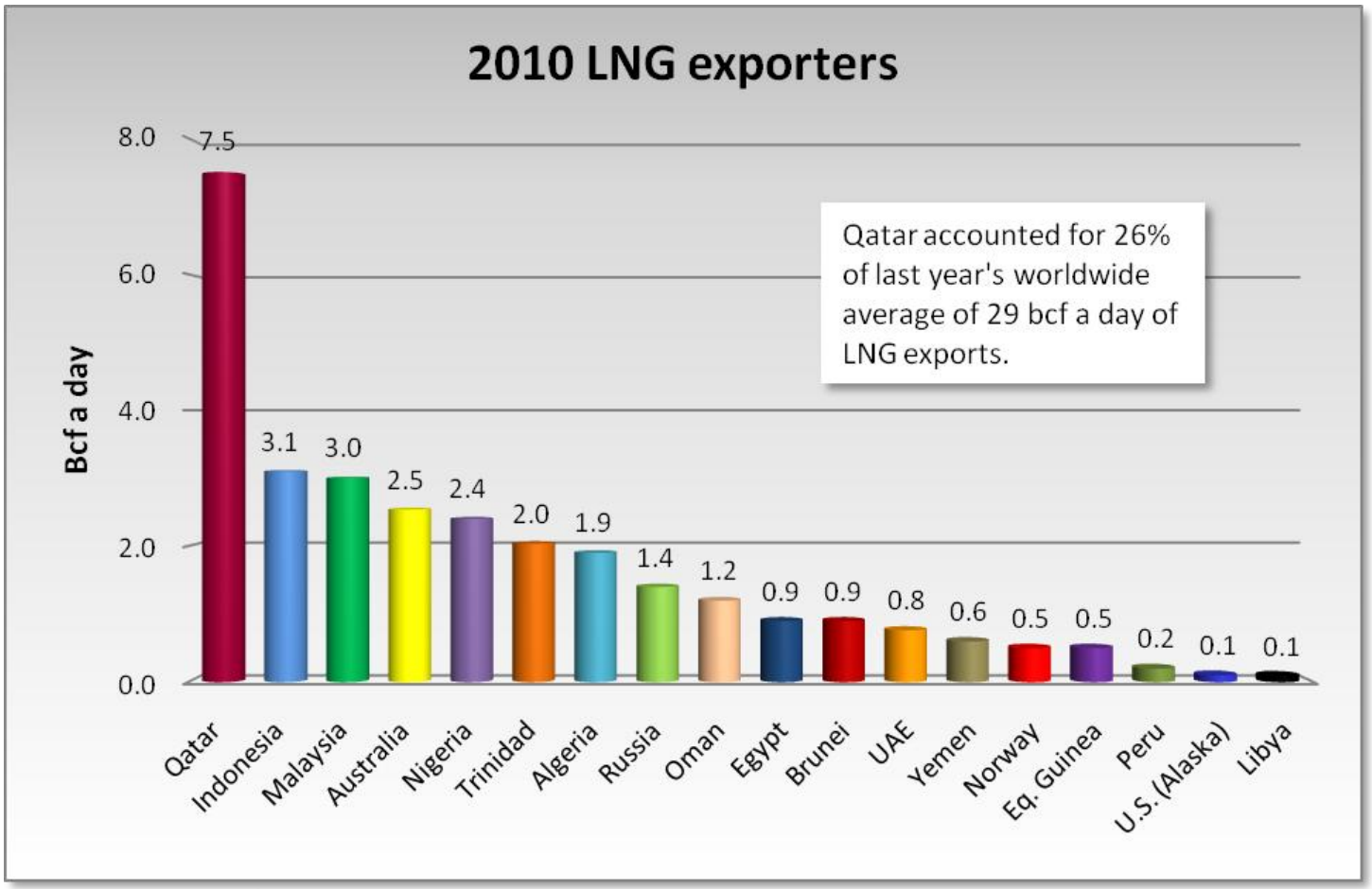
LNG production worldwide is increasing

- *LNG production increased by 42% from 2007 to 2010*



Source: International Gas Union

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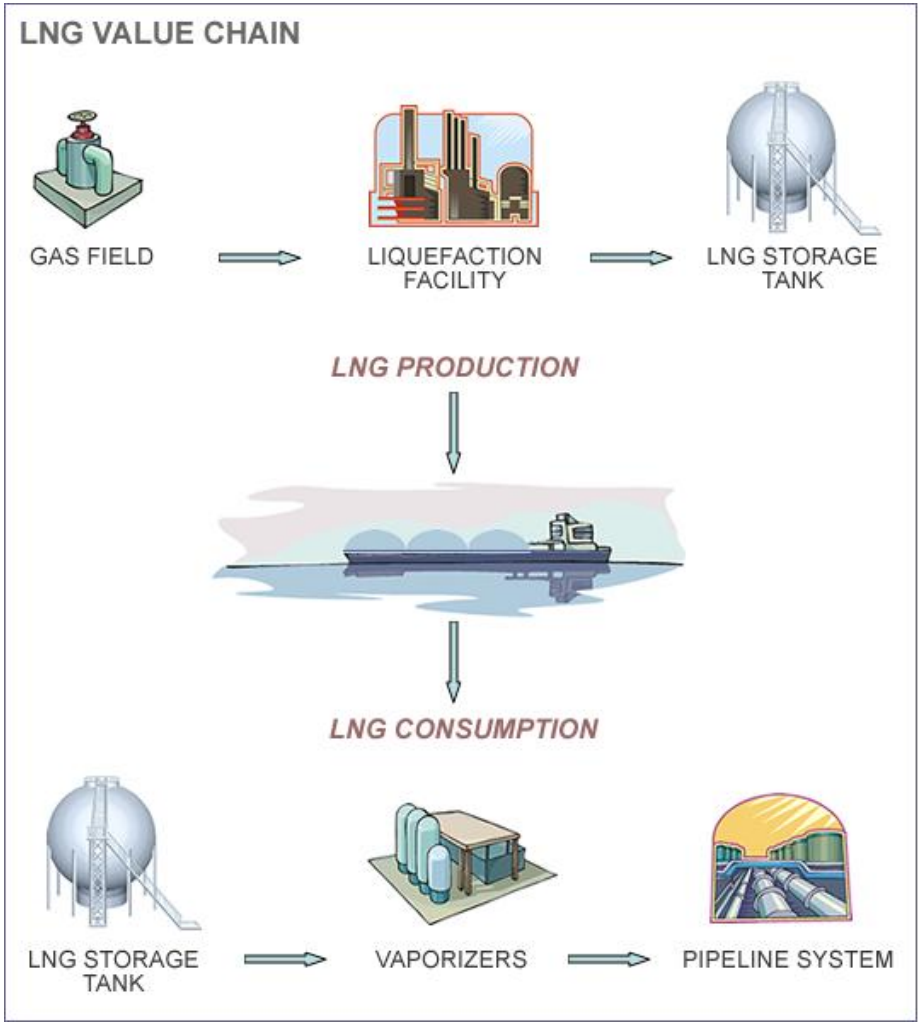
The natural gas value chain includes production, liquefaction, storage, transportation, re-gasification, distribution, and delivery to end users

- Liquefying natural gas reduces its volume by more than 600 times
- Once liquefied as LNG, natural gas becomes more convenient for storage and transportation to remote locations
- The risks of producing natural gas and pipeline transport of vaporized LNG are not significantly different than those associated with natural gas production



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LNG is dry natural gas, primarily methane, which has been cooled and liquefied

- Typical natural gas and LNG composition ranges

	Natural Gas	LNG
Methane	70-90%	85-97%
Ethane, propane and butane	0-20%	0-10%
Carbon Dioxide	0-8%	0%
Nitrogen	0-5%	0-1%
Hydrogen Sulfide	0-5%	0%
Oxygen	0-0.2%	0%
Rare Gases	Trace	Trace

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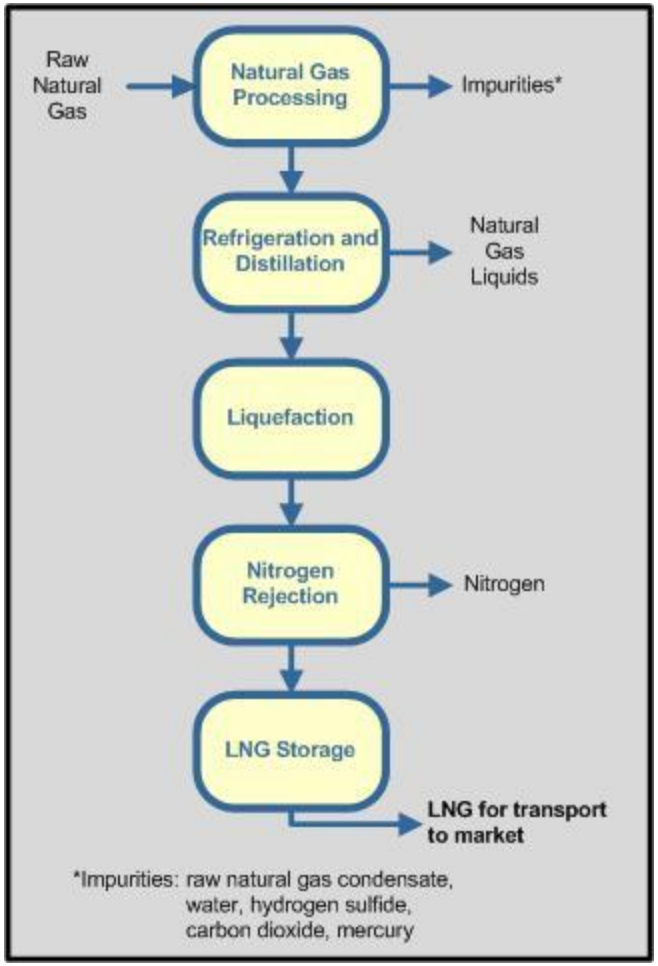
Hazards in the LNG value chain are summarized below

Hazard	Value Chain Segment
Cryogenic (-162 C)	All
Flammability (5-15% in air)	All
Natural gas liquids	Liquefaction, vaporization
Rollover	Storage tanks
Rapid phase transition	Marine transport

LNG liquefaction plants liquefy produced natural gas close to the source



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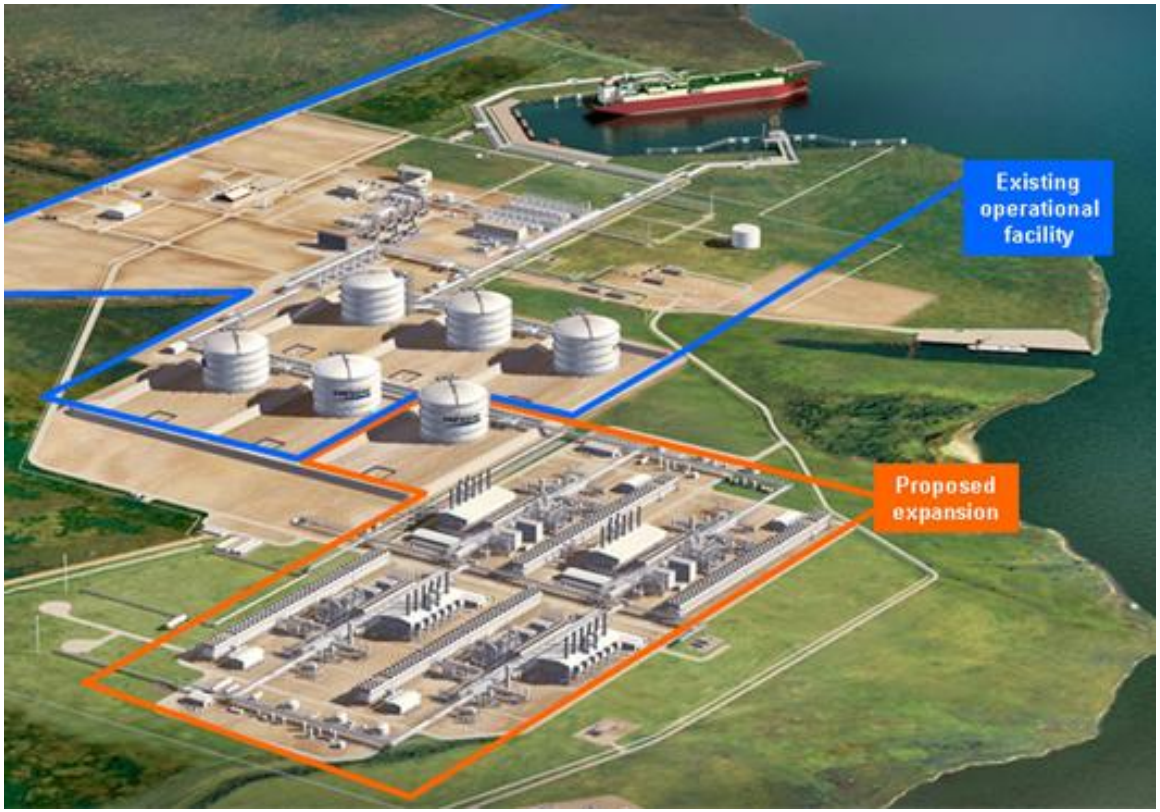
The Cheniere LNG import terminal in Sabine Pass, LA has been approved to build a liquefaction plant



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LNG liquefaction facilities typically handle large quantities of natural gas liquids

- Ethane, propane and butane may be recovered from the natural gas and stored under pressure or refrigerated
- These same hydrocarbons are used as refrigerants to liquefy the natural gas
- Natural gas liquids produce vapors that are heavier than air and more likely to explode
- LNG peak shaving facilities liquefy natural gas from the existing pipeline system and typically only need to remove water and carbon dioxide

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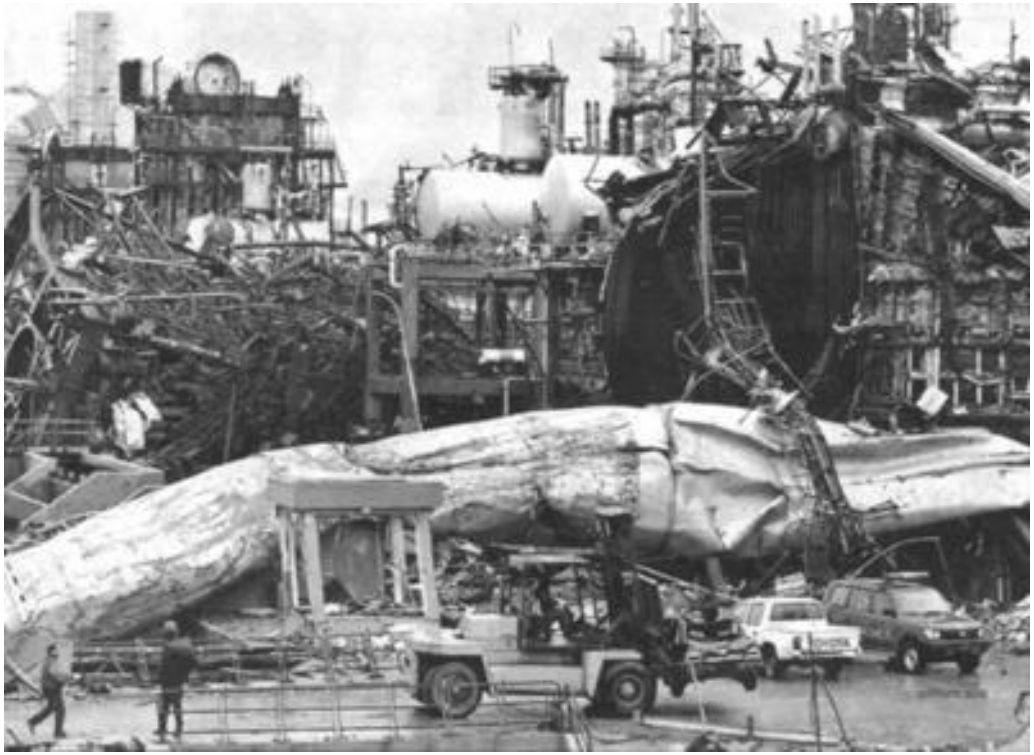
In 2004 an explosion occurred at the LNG liquefaction facility in Skikda, Algeria

- The explosion killed 27 employees and injured 72 others
- The vapors from a release of hydrocarbon refrigerant were drawn into a boiler and steam drum ruptured
- This ignited the original vapor cloud and caused a second explosion
- In the US FERC now requires combustible gas detection and shutdown of combustion air intakes for LNG facilities



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The first LNG liquefaction and storage facility was built in Cleveland Ohio in 1941

- In 1944 one of the LNG tanks failed due to brittle fracture because it was constructed of 3.5% nickel steel vs. current practice of 9%

- The tanks did not have adequate LNG secondary containment

LNG tank design and construction is now addressed in industry standards

- Since then various industry standards have been developed, including:
  - NFPA 59A (Standard for the Production, Storage, and Handling of Liquefied Natural Gas)
  - EN 1473 (Installation and equipment for Liquefied Natural Gas)
- These standards establish hazard zones for fire and flammable vapor releases and require containment for LNG spills
- For example, NFPA 59A sets the following limits at the fenceline:
  - 30 kw/m2 thermal radiation from storage tank impoundment fire
  - ½ LFL (2.5% in air) for flammable vapor dispersion from LNG tank impoundment

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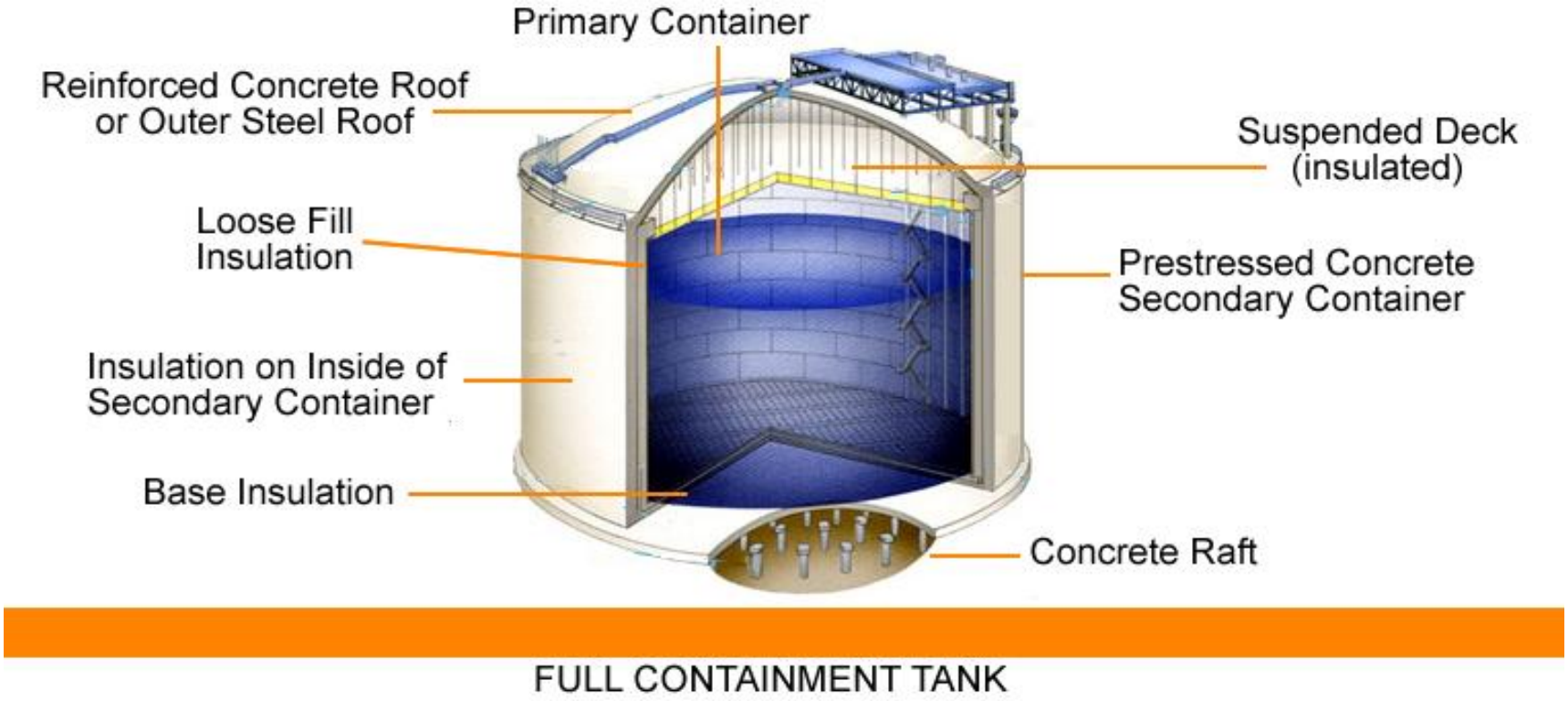
LNG is stored in insulated storage tanks at atmospheric pressure



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There are over 200 above ground LNG storage tanks worldwide

- Capacities range from 7,000 to 200,000 cubic meters
- Inner tank is 9% nickel
- Designed to withstand earthquakes and high wind
- Have multiple level indicators and alarms to prevent overfilling
- Storage tanks may experience “rollover” if LNGs of different densities form separate layers

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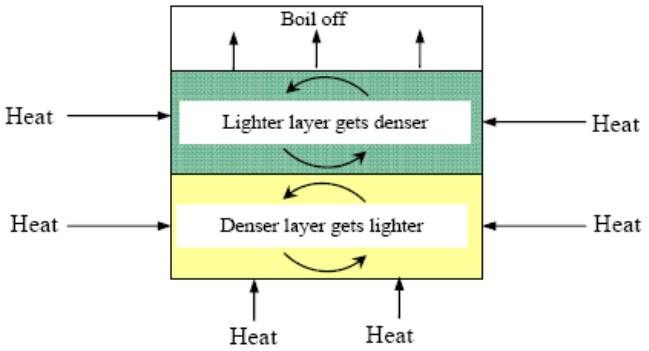
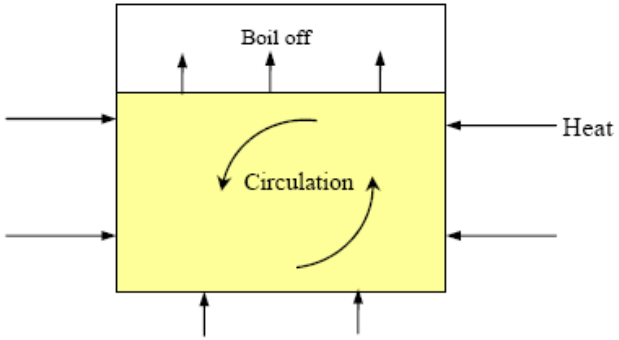
What is LNG "Rollover"?

- LNG "Rollover" refers to the rapid release of LNG vapors from a storage tank caused by stratification
- The potential for rollover arises when two separate layers of different densities (due to different LNG compositions) exist in a tank
- At some point the layers will mix and the superheated lower layer will cause vapors to flash
- Higher risk at peak shaving facilities where LNG may be stored for months before vaporization





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The worst LNG rollover event occurred in 1971 in La Spezia Italy

- 2000 tons of LNG vapor were released through the relief valves
- A study of 41 rollover events revealed that in most cases the peak vapor evolution rate is less than 20 times the normal boiloff rate
- Tank relief device sizing must consider rollover as a potential contingency
- Also common practice now to have the capability of both top and bottom filling and tank recirculation

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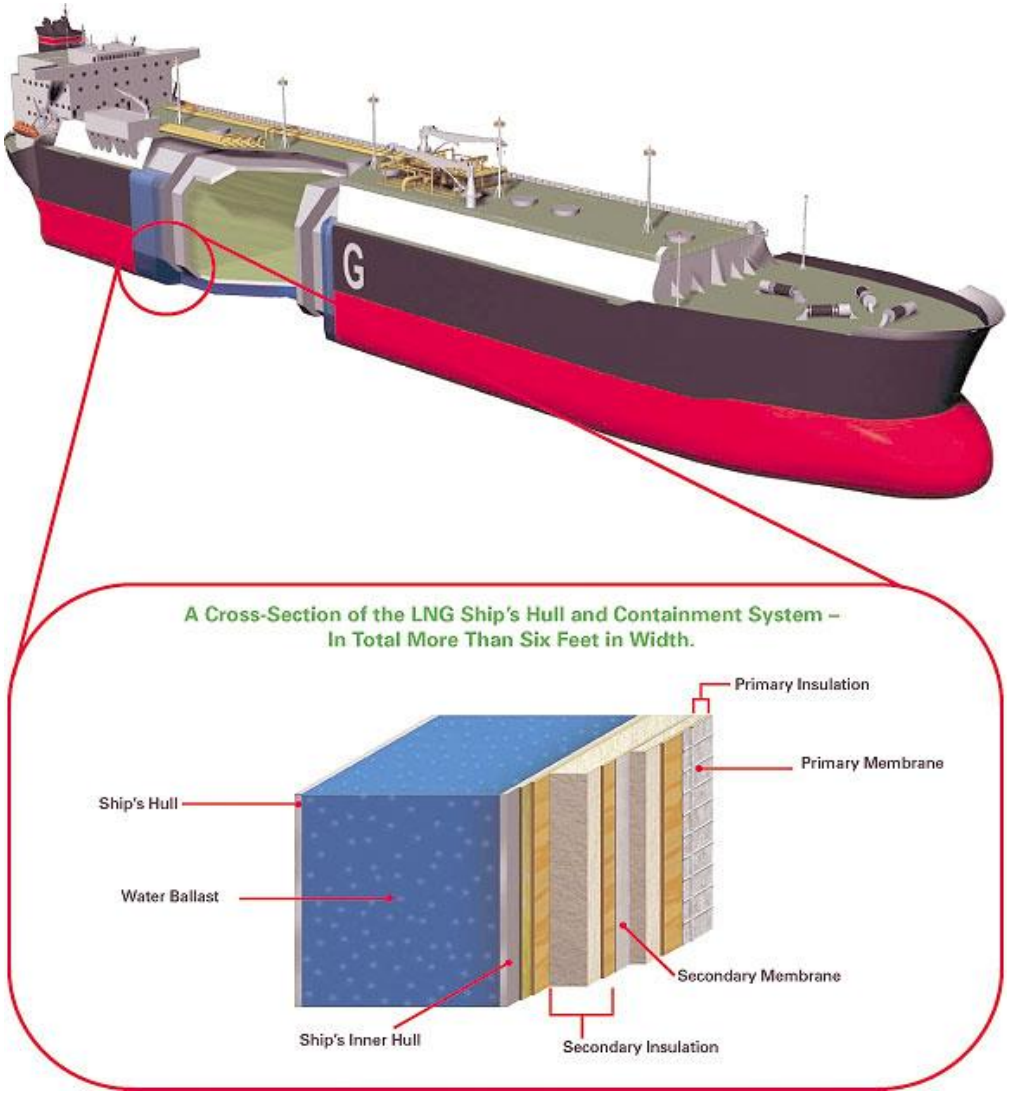
LNG Carriers – Two primary types are the Moss and Membrane types

▲ The two predominate types of LNG tankers: A Moss vessel (foreground) passing a membrane vessel.

Seaways February 2005

LNG Membrane Carriers have the LNG tanks formed to the shape of the hull



Source: BP Crown Landing website

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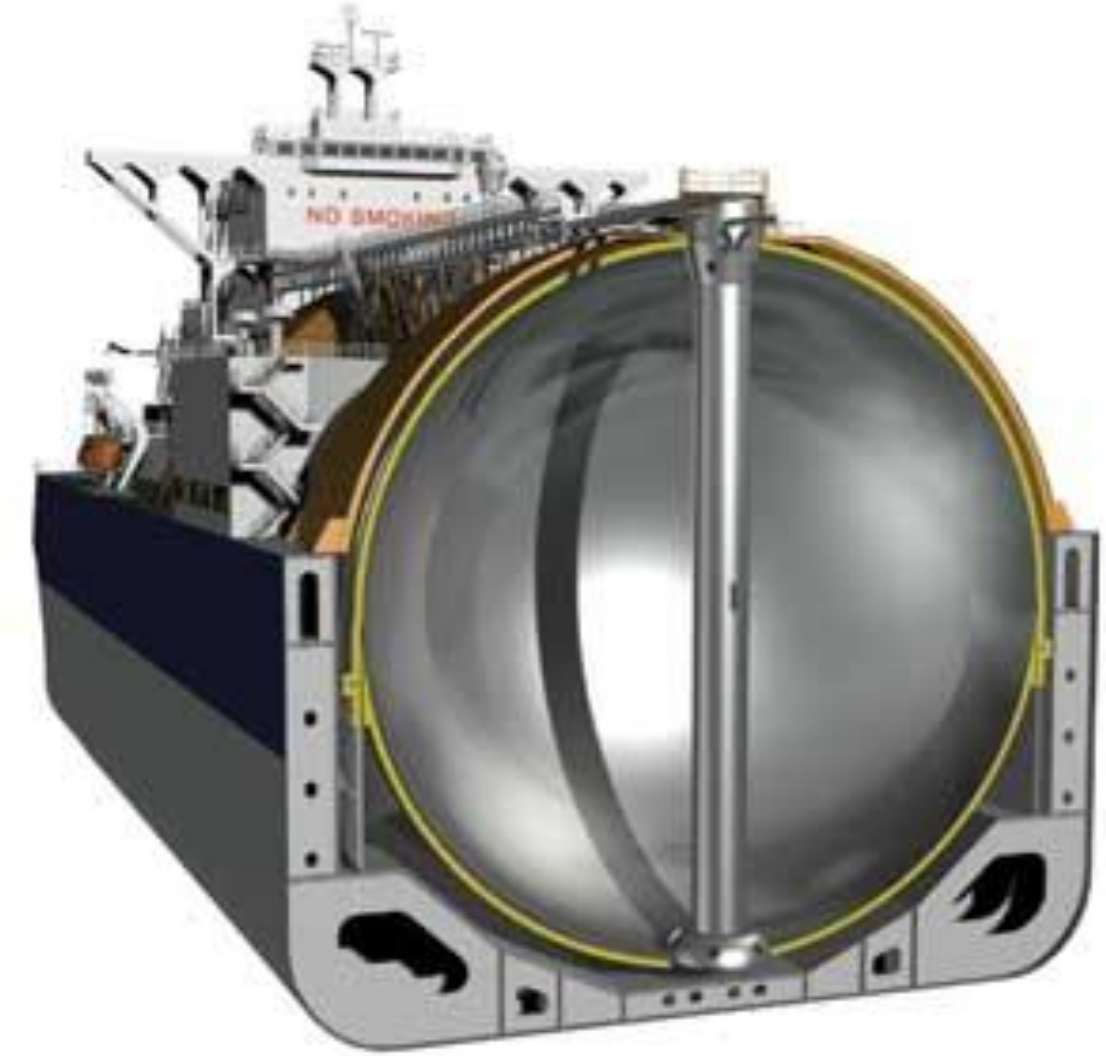
LNG Moss Carriers have individual spherical LNG tanks



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LNG Shipping Experience – LNG ocean tanker shipments have over 50-years of history

- Methane Pioneer's first voyage in January 1959 from Lake Charles, LA to Canvey Island in the UK
- More than 135,000 carrier voyages have taken place without a major accident involving a release of LNG or security issue
- There are currently over 200 LNG tanker ships
- Capacity ranges from 120,000 to 270,000 cubic meters
- Ships are constructed to the International Maritime Organization (IMO) standards which requires double hulls

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There have been a variety of incidents involving LNG tankers

- 1979 Two ship groundings (Japan and Gibraltar)
- 2002 Struck by a surfacing nuclear submarine (USS Oklahoma City near Gibraltar)
- 2006 LNG tanker pulled away from dock by wake of speeding ship while unloading at Elba Island
- 2008 Loss of propulsion at sea, heading toward Everett MA
- Small LNG spills during loading/unloading causing cracking of deck plate
- Spills of LNG on water can cause small explosions called rapid phase transition (RPT)

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Rapid phase transitions are physical explosions that do not involve combustion

- A physical explosion that does not involve combustion
- The temperature difference between the LNG and water causes the LNG to become unstable and vaporize too quickly
- Only a small fraction of the spilled LNG is involved
- Only observed in field tests
- More likely to occur with LNG containing ethane and propane
- Can damage lightweight structures in close proximity

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One of the biggest concerns has been either an accident or intentional attack on an LNG tanker

- The most vulnerable location is at the loading/unloading dock or within the port area
- In 2004 the International Ship and Port Security (ISPS) Code established responsibilities for detecting and mitigating security incidents affecting ships or port facilities involved in international trade
- In the US need to conduct a Waterways Safety Assessment to establish safety/security zones in transit
- US Coast Guard will escort ships and may board to inspect

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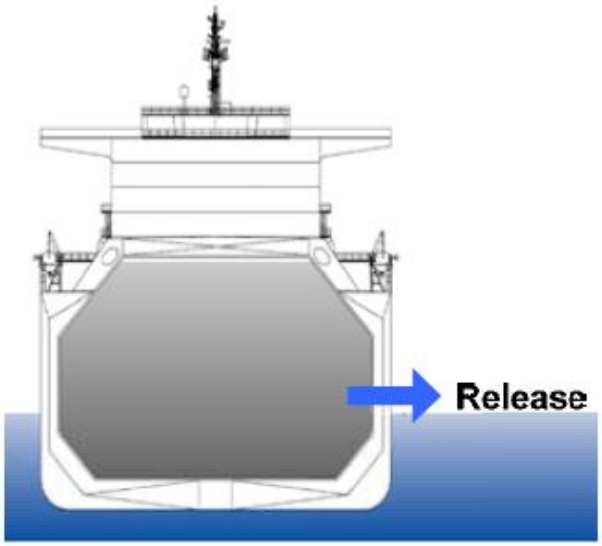
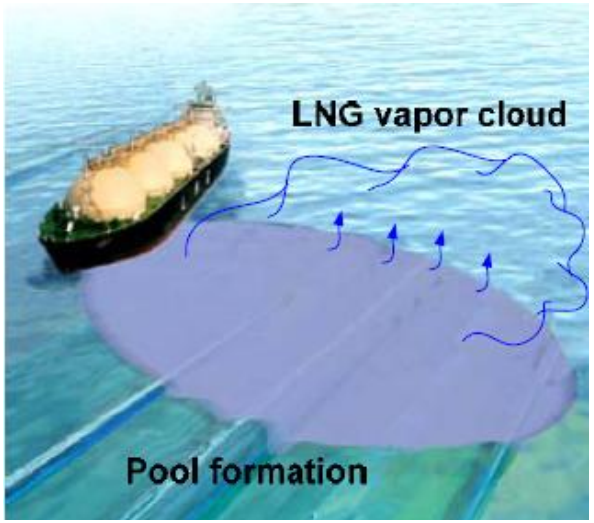
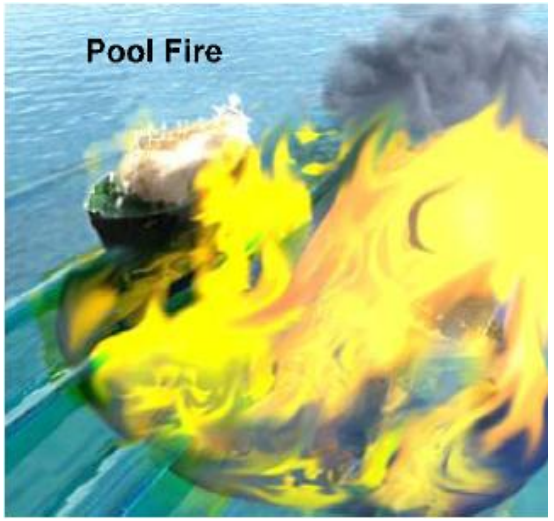
Following an LNG release from a tanker, the maximum pool size will depend on whether ignition is immediate or delayed







- Numerous studies have concluded a one meter hole is a reasonable assumption
- Maximum pool size is formed when vaporization/burning rate equals the release rate
- Concern is that the pool fire will engulf the ship

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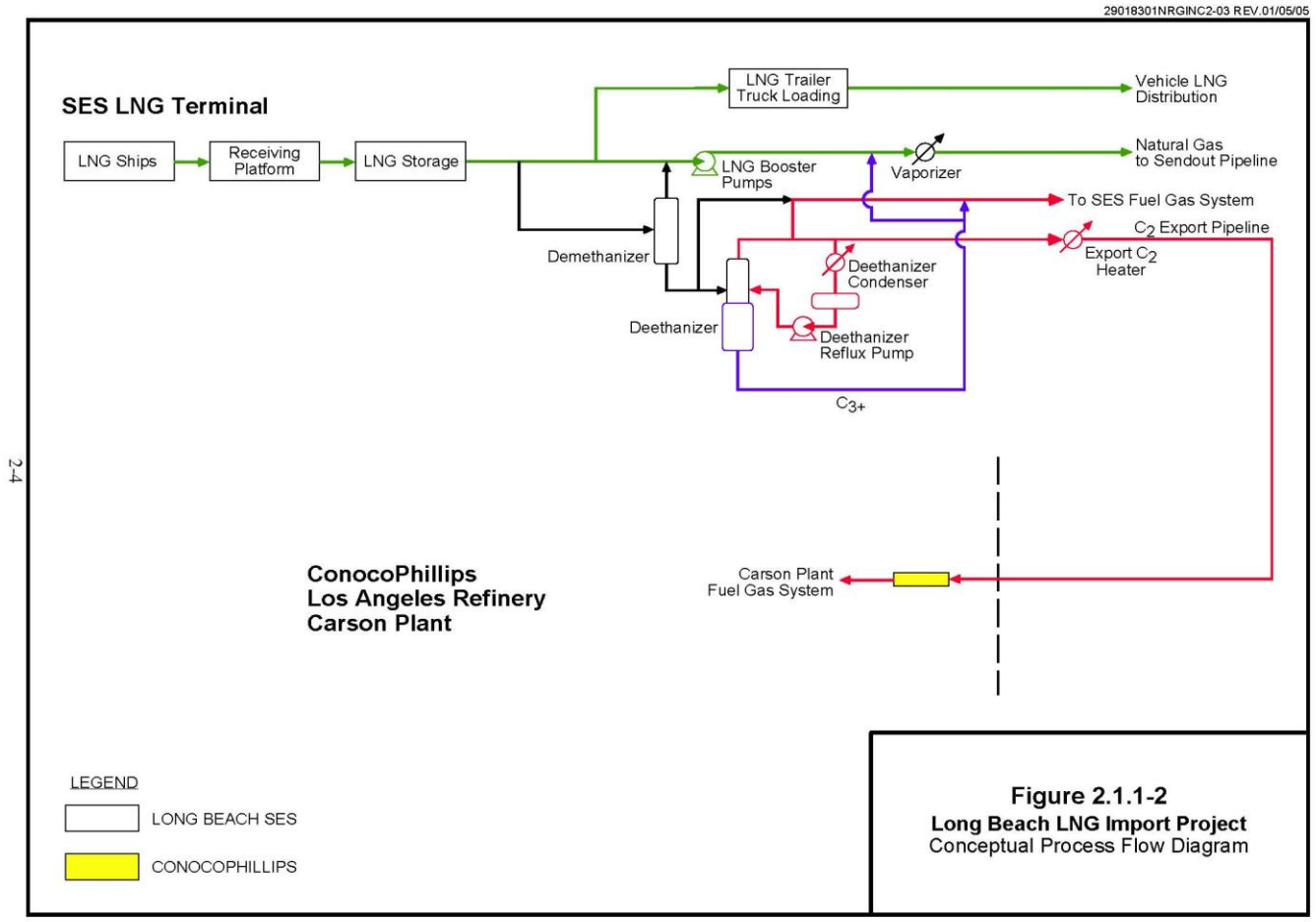
The following schematic shows a typical onshore LNG import terminal

Source: BP Crown Landing website

LNG that is rich in ethane and propane may require extraction of NGLs



Source: SES Long Beach DEIR

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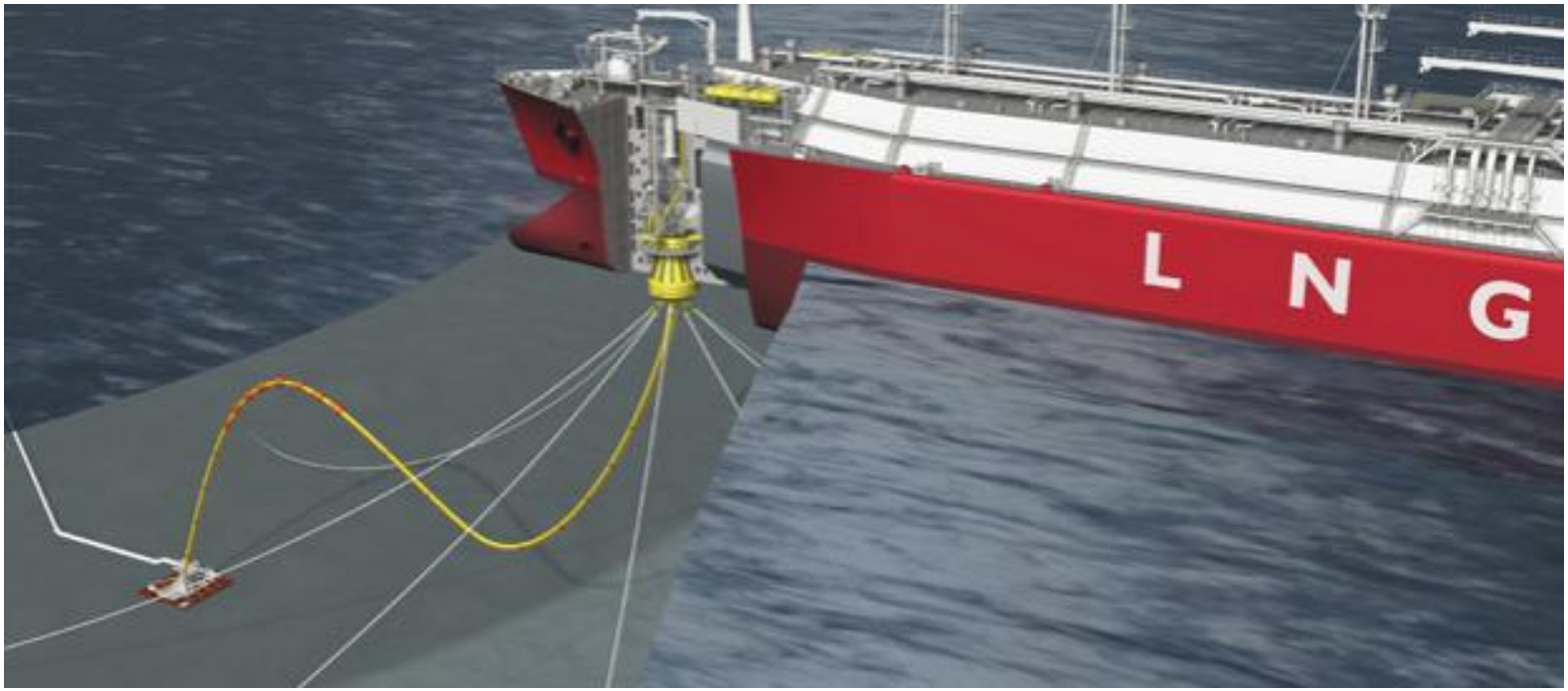
Due to concerns about siting of LNG terminals near populated areas, offshore LNG terminals reduce potential impacts to onshore facilities



Source: Northeast Gateway Deepwater Port, Excelerate Energy (offshore)

- Regasified LNG flows from the floating storage and regasification unit (FSRU) through the buoy and riser, the pipeline, and to shore.
- Regasified LNG must meet local natural gas specifications to avoid safety issues with combustion appliances, such as ovens.

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In addition to the incidents at Cleveland, la Spezia and Skikda, there have been other incidents at LNG terminals

- 1988 Everett MA: Ship unloading was stopped allowing the unloading lines to warm up and form vapor pockets in the piping
- When unloading was resumed, the lines experienced a hammering effect due to condensation of the LNG vapors
- LNG was released from the piping flanges and contained in the impounding area
- Approximately 30,000 gallons of LNG was released, but dispersed without ignition
- Procedures were modified to ensure unloading is resumed in a gradual manner for short shutdowns and normal cooldown required for longer shutdowns

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LNG Road Tanker Explosion

- Accident occurred on June 22, 2002 near Tivissa, Catalonia in Spain
- Tanker lost control going downhill, turned over and insulation was damaged
- Fire occurred almost immediately and the tires started to burn two minutes later
- Approximately 20 minutes later the tanker exploded (BLEVE)
- The driver was killed and two people located at approximately 200 m from the tanker location were burned
- Relief valves were undersized

Road tanker 2 minutes after the accident and approximately 18 minutes before the explosion. Car was left by one of the witnesses who fled the accident cite.

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LNG road tankers are used to transport LNG to peak shaving and LNG fueling stations

- The Department of Transportation (DOT) regulates the transportation of LNG as well as the drivers of the trucks (MC 338)
- The inner tanks of the trucks are made of thick aluminum designed to withstand up to 100 pounds of pressure
- There is a steel outer shell around the outside of the inner tank which is evacuated and filled with insulation
- LNG can be stored up to three days in the tanks of the trucks without losing any LNG through the boil-off process
- The tanks are designed to withstand most accidents that may occur during the transportation of LNG

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Other reported LNG road tanker incidents

- Ten other LNG truck incidents worldwide
- 2005 Nevada faulty valve caused release of LNG and fire which burned for a day

2006 MA resulted in a diesel spill

2008 Alaska closed highway for 24 hours due to venting of LNG vapors from relief valves

Natural gas produces fewer greenhouse gases when compared to diesel and gasoline

- Heavy duty truck and bus fleets, long haul trucks limited by fueling stations
- NFPA 52, Vehicular Gaseous Fuel Systems Code, is the applicable standard for LNG vehicles and fueling facilities
- Current code does not require thermal radiation or flammable vapor dispersion exclusion zones as NFPA 59A

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Natural gas is more economical as a ship transport fuel

- Ferries (Washington State recommended switch from diesel)
- In the US these ships must meet Coast Guard safety and security requirements similar to tankers

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Natural gas is more economical as a ship transport fuel

- In Norway the first LNG powered LNG cargo ship was operational in 2012

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The liquefaction, storage and handling of LNG has had a good safety record

- Industry standards have been developed to cover liquefaction and vaporization facilities, ship transport, vehicles and vehicular fueling stations
- These standards incorporate the lessons learned from prior accidents
- As the use of natural gas increases worldwide, LNG should continue to be an economical and safe method for transporting LNG

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LNG Organizations – Some organizations that provide information regarding LNG

- Society of International Gas Tanker and Terminal Operators (SIGTTO), www.sigtto.org
  - The Society is an international body, established for the exchange of technical information and experience between members of the industry, to enhance the safety and operational reliability of gas tankers and terminals
- Center for LNG, www.lngfacts.org
  - The Center for Liquefied Natural Gas has attracted more than 50 members, including LNG asset owners and operators, gas transporters, and natural gas end users
- California Energy Commission, www.energy.ca.gov/
  - Compilation of LNG information from various sources
- National Energy Board (Canada), www.neb-one.gc.ca
  - Compilation of LNG information and links to other websites
- Federal Energy Regulatory Commission (US), www.ferc.gov
  - Good overview of the LNG industry and LNG in the US

This ends the presentation, we now have some time to answer any questions

Questions?

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About ioMosaic Corporation

ioMosaic Corporation is the leading provider of safety and risk management consulting services, training, and software solutions. Whether you need pressure relief system design services, quantitative risk assessments, onsite training, or the latest in software technology, ioMosaic has the knowledge, experience, and resources to address your unique needs. At ioMosaic, we are delivering practical solutions for safety, risk, and business challenges facing our clients.

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