Objectives

- Provide background information on LNG production and transportation methods
- Provide response considerations
- Provide an overview of health and safety issues facing first responders
- Provide case studies of recent incidents

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2

Content and Speakers

- Mike Faulkner, EPA, NRT Executive Director
  - Welcome, Summary, and Moderator
- Aaron Mitchell, PHMSA - DOT
  - Transportation
- Dr. Phani Raj, FRA - DOT
  - Characteristics of LNG
- CDR Jason Smith, USCG
  - Natural Gas Lifecycle
- Christine Petitti, OSHA
  - Response Considerations and Health and Safety Issues

3

What is Liquefied Natural Gas?

- LNG is Natural Gas (predominantly methane) that has been converted to liquid form for ease of storage or transport
- LNG takes up about 1/600th the volume of Natural Gas in the gaseous state

4

Why do you need to know about LNG?

- Why the shift to LNG?
  - Cost, supply and environmental
- Why is this important?
  - Increased risks associated with **production** (terminals on and off shore), **use** of LNG as a fuel for transportation, power generation, commercial, and residential, and LNG **transits** (land and water)

5

Transportation

Aaron Mitchell
U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

DOT/PHMSA Authority over LNG Transportation

Office of Pipeline Safety

- LNG facilities connected to a 49 CFR Part 192 regulated Natural Gas pipeline
- 49 CFR Part 193 designed for Natural Gas storage facilities, applicable to LNG export facilities

Office of Hazardous Materials Safety

- Modal transportation in commerce of LNG
- Highway and vessel primary modes of transit, rail needs approval, air shipment not permitted

7

Hazardous Materials Regulations for LNG

- LNG, UN 1972, is classified for transportation as 2.1 Flammable Gas
- Bulk packaging authorized
  - Cargo tanks (MC-338) up to ~11,000 gallon capacity
  - UN Portable Tanks up to ~11,000 gallon capacity
- Transportation by rail in portable tanks is by Federal Railroad Administration (FRA) approval only

8

LNG by Highway

- Transported in tank trucks with double walled, vacuum insulated tanks and trailers
- Approximately 28K cargo tank trucks are in operation by carriers that haul LNG
- In the last 15 years:
  - 10 incidents involving LNG reported to PHMSA
    - 6 of 10 highway crashes
    - 3 listed no quantity released
    - 0 fire or violent explosive release

9

LNG by Railroad

- Rail transport is only permitted in intermodal portable tanks approved by FRA
- **Transporting LNG by rail would be vastly different from crude oil as a new tank car would need to be manufactured**
- The DOT 113 tank car is the only rail car insulated well enough to carry LNG, however retrofitting would not be feasible

10

LNG Basics & Hazards

Dr. Phani K. Raj
U.S. Department of Transportation
Federal Railroad Administration

Properties of Natural Gas

- Natural Gas at atmospheric pressure and temperature is lighter than air
- LNG vapor at 1 atm pr., and 111 K (-162 ^{o}C or -260 ^{o}F), has a density of 1.84 kg/m3 is heavier than air
- Pure LNG vapor at 162 K (-111 ^{o}C or -168 ^{o}F) is neutrally buoyant in air

12

Burning Characteristics of Natural Gas

1

Controlled burning of Natural Gas in a kitchen range

2

Uncontrolled, flare type burning of Natural Gas from a gas well

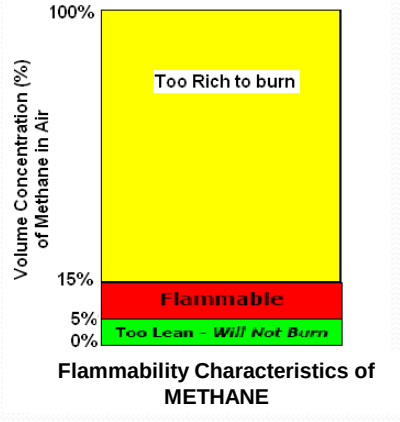
3

Uncontrolled burning of Natural Gas & oil mixture flared from an oil well

13

Flammability Characteristics

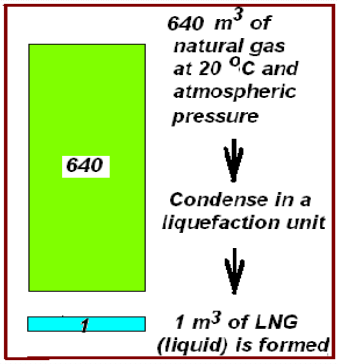
- Natural Gas is flammable in air in the volumetric concentration range
  - 5% Lower Flammability Limit (LFL)
  - 15% Upper Flammability Limit (UFL)



14

How is LNG made?

- Natural Gas cooled to 111 K (-162 °C or -260 °F) condenses to a liquid. This cold liquid is called Liquefied Natural Gas, "LNG"



- LNG occupies less than 1/600th volume of room temperature Natural Gas from which it is condensed
- LNG is used as a fuel since its vapors are flammable

15

What are LNG characteristics?

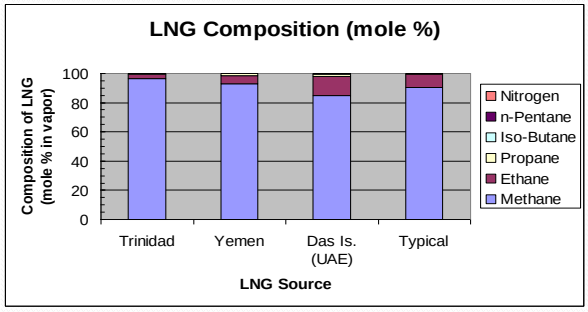
- LNG is a mixture, primarily consisting of methane with a small % of other hydrocarbons
- LNG is very cold. It will boil when it contacts any surface at normal atmospheric temperature
- Boiling LNG releases extremely cold (cryogenic) Natural Gas
- Unignited LNG disperses as a heavy gas at grade (ground or water) with highest vapor concentrations at grade

16

Composition of LNG

[Numbers in the table indicate mole % of components in liquid]

Source of LNG	Methane	Ethane	Propane	Iso-Butane	n-Pentane	Nitrogen
Trinidad	96.70	2.80	0.34	0.03	0.03	0.02
Yemen	92.80	5.90	1.10	0.08	0.09	0.03
Das Island (UAE)	84.82	13.39	1.34	0.28	0.00	0.17
Typical	90.33	8.95	0.34	0.02	0.02	0.34



17

Properties of LNG (liquid) and Its Vapor

Water density	1000 kg/m³	8.35 lb/ft³
LNG density	425 kg/m³	3.55 lb/ft³

- LNG spilled on ground will boil and then vaporize
- LNG is less dense than water; hence LNG spilled on water will, generally, float and spread (not miscible in water)
- LNG spilled on normal temperature water will boil vigorously and evaporate rapidly
- The vapor generated by LNG boiling has a density of 1.84 kg/m^3 (air density 1.2 kg/m^3); Therefore, it is a "Heavy Gas"
- An LNG spill on water may result in locally explosive boiling (rapid phase transition)

18

Boiling of LNG Contained in a Beaker

- LNG is colorless (looks like water)
- It is vigorously boiling in the beaker
- Warning: vapor is flammable

19

LNG Vapor Dispersion in the Atmosphere

- LNG vapor is cold and denser than air. It disperses at ground level
- The vapor cloud appears white due to water vapor from the air condensing into the extremely cold (cryogenic) LNG vapor cloud

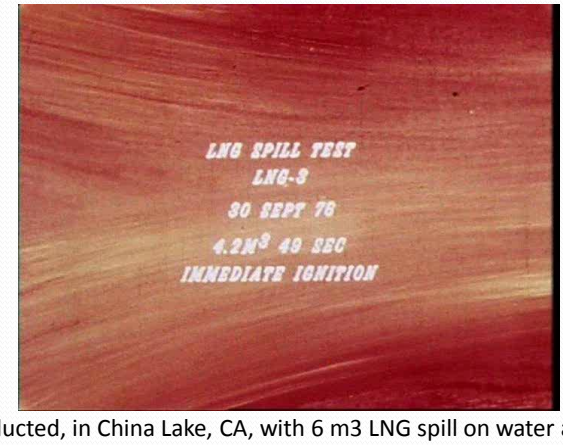
20

Flammability of LNG (vapor)

- **In its liquid state, LNG will not burn**
- **Vapor is flammable only when mixed with air** in the narrow range of 5% to 15% (vapor to air) by volume
- Vapors emanating from a pool of evaporating LNG can ignite to form a "Pool Fire"
- Dispersed vapor (cloud) generated by an evaporating LNG pool and ignited at a downwind location burns, in most cases, as flash vapor fire

21

LNG Pool Fire on Water



- Tests conducted, in China Lake, CA, with 6 m3 LNG spill on water and immediate ignition

22

LNG Pool Fire Characteristics at Different Burn Stages

1

2

3

4

23

Large LNG Pool Fire on the Ground

- 60,000 gal LNG spilled on to an insulated concrete dike of diameter 35 m and ignited at 4 diametrically opposite points
- Duration of burn = 400 s

24

Vapor Fires
Deflagration & Detonation

Deflagration – (technical) Combustion that propagates through a gas or across the surface of an explosive at subsonic speeds, driven by the transfer of heat

Detonation – (technical) Combustion of a substance that is initiated suddenly and propagates extremely rapidly, giving rise to a shock wave

www.OxfordDictionaries.com

- Normally, a dispersed LNG vapor cloud when ignited burns back to the source as a flash fire or as a deflagration fire at speeds of < 10 m/s
- A deflagration fire velocity increases if turbulence is enhanced by obstacles in the path. High velocity deflagrations (> 100 m/s) can cause blast damage in the near field
- A methane deflagration fire can transition to detonation (with velocities > 1 km/s) in very confined, long tunnels. Detonation can result in blast damage at significant distances from the vapor cloud (Vapor Cloud Explosions – VCE)
- No field tests have resulted in LNG vapor fires transitioning to detonation, when the cloud is ignited in the open

25

Vapor Fire Propagation

- Note: There may be LNG vapor beyond the limits of the visible vapor cloud as the LNG vapors disperse downwind of the source
- An LNG vapor cloud when ignited in the open will result in a propagating flash fire

26

Deflagration-Detonation Test Results

Note: This study involved the mixing of LNG with propane and a detonating charge was used. This is not a situation normally found in routine transportation of LNG

27

Rapid Phase Transition (RPT)

- Occasionally, a LNG spill on water surface results in locally explosive boiling. This is called RPT or “very fast evaporation”
- Note: shock wave caused camera shake below

28

Effect of Water Spray on an LNG Pool Fire

29

Summary of LNG Characteristics

3 behaviors of LNG

- Boils off if it contacts a surface
  - Vapor produced is heavier than air; disperses at ground level
  - Pool fire will result if vapor on top of the liquid is ignited
- If it is ignited after it is vaporized some distance from source, a vapor fire will flash back to the source
- Potential explosions due to the fire encountering turbulence or if the LNG is spilled on water, then you get the very rapid buffs of evaporation called rapid phase transitions

30

Natural Gas Lifecycle

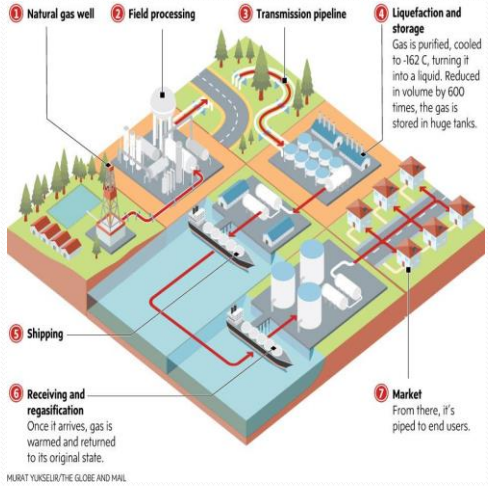
CDR Jason Smith
U.S. Coast Guard
Liquefied Gas Carrier National Center of Expertise

Natural Gas Lifecycle

- Natural Gas Well
- Field Processing
- Transmission Pipeline
- Liquefaction & Storage
- Transportation
- Regasification

Transmission pipeline

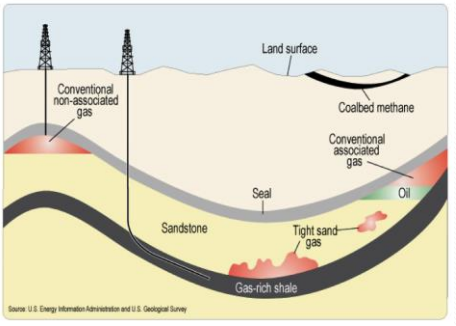
- Market



32

Natural Gas Lifecycle

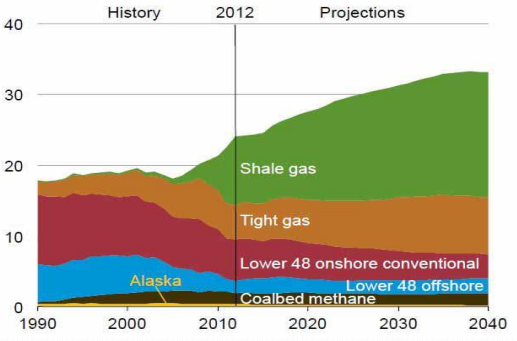
- Natural Gas Well
  - Associated
  - Non-Associated
    - Flare
    - Re-Injection
    - Processed
  - Exploration
  - Development
    - Conventional Drilling
    - Unconventional Drilling
  - Production
  - Abandonment



33

Natural Gas Lifecycle

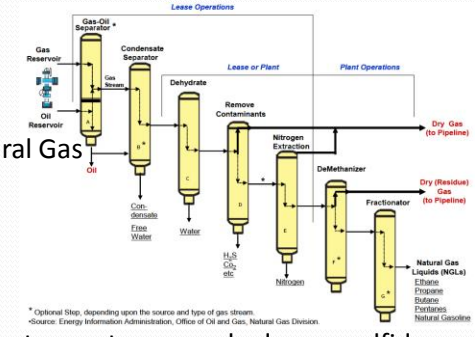
- Natural Gas Well
  - Shale Gas
  - Tight Gas
  - Conventional Gas
  - Coalbed Methane



34

Natural Gas Lifecycle

- Field Processing
  - Natural Gas
    - must meet specific pipeline quality measures
      - Specific gravities
      - Pressures
      - Btu content range
      - Water vapor levels
    - 7 steps used to clean Natural Gas
      - Heat exchangers
      - Mechanical separators
      - Absorption systems
      - Adsorption systems
      - Filter tubes
    - Separate out; oils, condensates, water vapor, hydrogen sulfide, carbon dioxide, helium, oxygen and Natural Gas Liquids (NGLs)



35

Natural Gas Lifecycle

- Transmission Pipeline
  - Gathering Lines
    - To processing plants, LNG facilities, & trunk lines
  - Trunk Lines (intra/interstate)
    - To underground storage, LNG facilities & distribution lines
  - Distribution Lines
    - To residential & commercial customers and peak shaving facilities.

State	TCF*	%
Texas	7.475	29
Louisiana	2.955	11.5
Pennsylvania	2.256	8.6
Oklahoma	2.023	8.4
Wyoming	2.022	7.4
TOTAL	16.731	64.9%

*Trillion Cubic Feet

36

Natural Gas Lifecycle

- Transmission Pipeline
  - Gathering Lines
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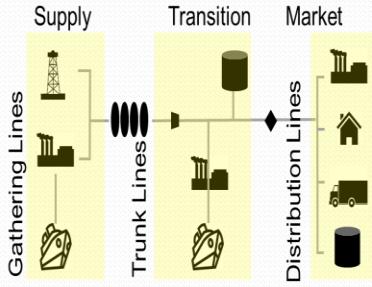
  - Distribution Lines
    - To residential & commercial customers and peak shaving facilities.

- Well Head

- City Gate

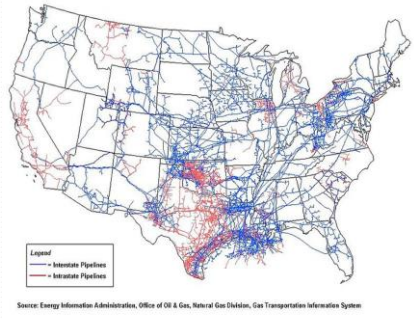


- Compressor Stations

37

Natural Gas Lifecycle

- Transmission Pipeline
  - 210+ pipeline systems
  - 210,000+ mi interstate pipelines
  - 90,000+ mi intrastate pipelines
  - 1,400+ compressor stations
  - 11,000+ delivery points
  - 5,000+ receipt points
  - 400 underground storage facilities
  - 24 hubs or market centers
  - 100 LNG peaking facilities
  - 8 import facilities
  - unknown number of export facilities

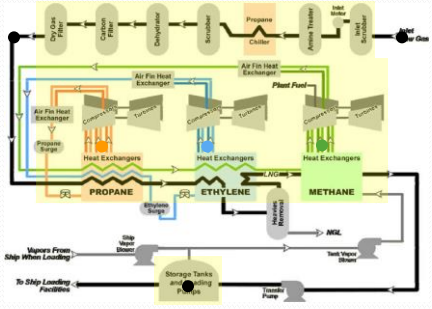


- Planners and responders should consult their Local Emergency Planning Committee (LEPC) or Area Contingency Plan (ACP) for additional information.

38

Natural Gas Lifecycle

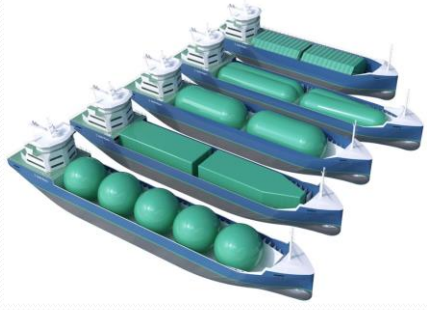
- Liquefaction & Storage
  - Further processing
    - Avoid damage to facility
    - Meet delivery point
  - Refrigerant
    - Cascade
    - Mixed refrigerant
  - Liquefaction (gas to liquid)
    - Atmospheric pressure
    - −162 °C (−260 °F)
    - 1/600th (approximately)
  - Storage
    - Design
    - Boil Off Gas (BOG)
  - FLNG: FLSO/FPSO



39

Natural Gas Lifecycle

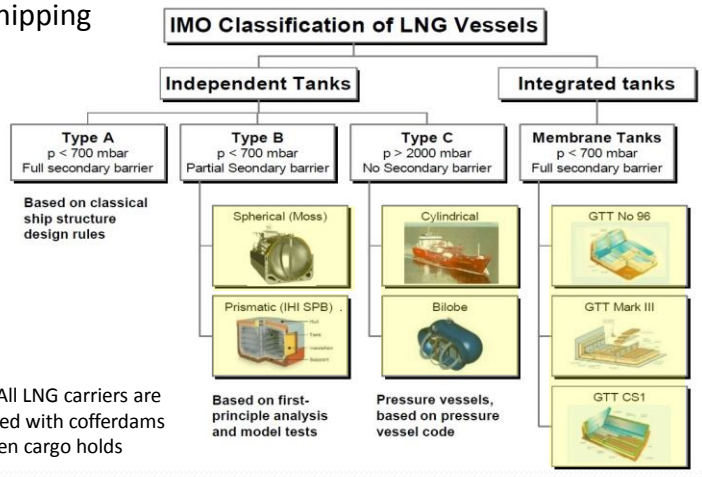
- Shipping
  - Methane Pioneer
  - Global Fleet: 400 (150+ on order)
  - Features
    - LNG as Fuel; Boil Off Gas (BOG)
    - Liquefaction*
    - Re-gas*
  - Safety Systems
    - Firefighting Systems
    - Gas Detection Systems
    - Emergency Shut Down (ESD)
    - Water Curtain
    - Training



40

Natural Gas Lifecycle

- Shipping

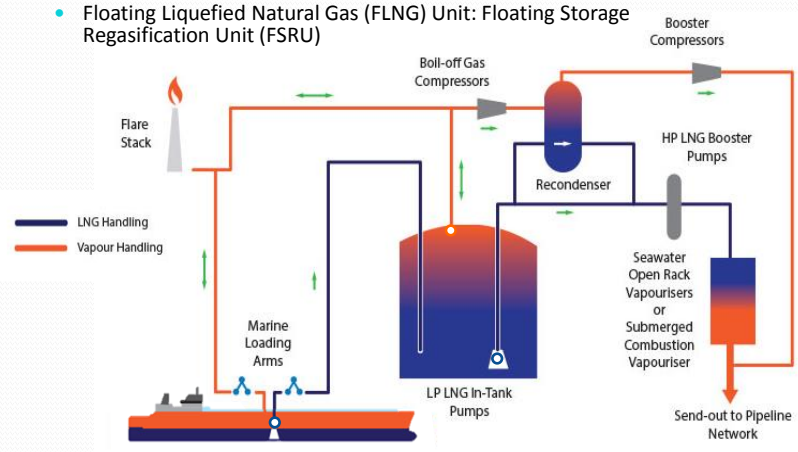


Note: All LNG carriers are designed with cofferdams between cargo holds

41

Natural Gas Lifecycle

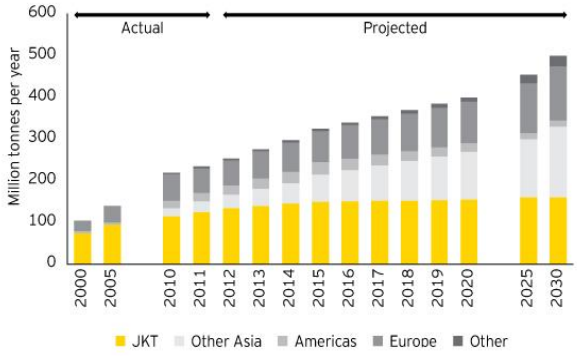
- Regasification (Offload, Storage, Send Out)
  - Floating Liquefied Natural Gas (FLNG) Unit: Floating Storage Regasification Unit (FSRU)



42

Natural Gas Lifecycle

- Market
  - Global LNG demand by Region

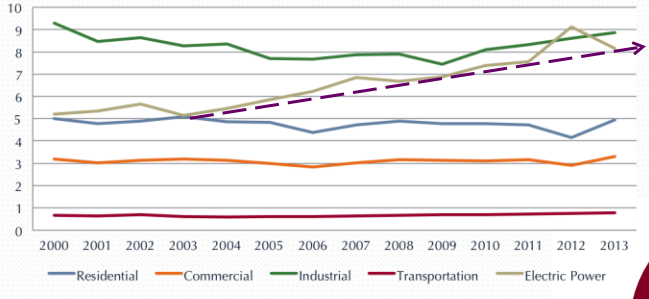


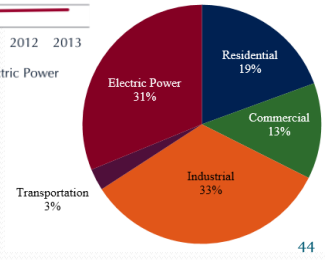
Source: EY: Global-LNG--New-pricing-ahead---LNG-demand-growth. http://www.ey.com/GL/en/Industries/Oil

43

Natural Gas Lifecycle

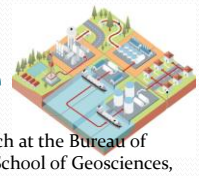
- Market (Demand by Sector)





44

Natural Gas Lifecycle



- Case studies
  - Facilities

Source: LNG Safety and Security Energy Economics Research at the Bureau of Economic Geology, Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin

Year	Name	Casualty	Description
1944	Cleveland, Ohio	128/225	Low-nickel alloy tanks
1965	Canvey Island, UK	1/0	Explosion during LNG transfer ops
1973	Staten Island,	40	LNG pipeline leaks at industrial facility causing fire
1977	Arzew, Algeria LNG	1	Releases from storage facility, causing fire and explosion
1979	Cove Point, MD	1	Fire and explosion
2005	Skikda, Algeria	27/74	Steam boiler explosion

  - Vessels

Year	Name	Casualty	Description
1979	El Paso Paul Kayser	0	Aground in Gibraltar
1984	Gaz Fountain	0	Three maverick missiles hit a prismatic tanker carrying butane/propane.

45

Response Considerations and Safety Issues

Christine Petitti
Occupational Safety and Health Administration

Remember, first responders should be aware of these conditions:

1) If LNG is released, it vaporizes into Natural Gas
   - If the Natural Gas concentration falls between certain percentages by volume (5-15 %) there is sufficient concentration for rapid phase transition and possible ignition
   - If an ignition source is present the vapors will ignite
2) LNG is not explosive and cannot burn. For LNG to burn, it must first vaporize, then mix with air in the proper proportions and then be ignited

47

However……

- An explosion would only occur if the Natural Gas vapors are within an enclosed area. If it is an open area, the result would be a large flame (unless it is a rapid phase transition)
- Remember, a dispersed LNG vapor cloud when ignited burns back to the source as a flash fire or as a deflagration fire

48

LNG Hazards – Worker Safety

- Liquid Natural Gas is at cryogenic temperatures; source of Rapid Phase Transition (RPT) issues
- Potential asphyxiation issues
- In an enclosed space or confined area: LNG vapor is more dense-than-air, but as it warms to ambient temperature, it is with air and can form flammable concentrations. When LNG mixes with air, the mixture (combined density) is heavier than air, resulting in the gas remaining close to the ground

49

Confined Space

- Potential for asphyxiation
  - Self-contained breathing apparatus (SCBA) is required for oxygen concentration below 19.5% (potential to lose consciousness)
  - The concentration of oxygen in a sealed LNG storage tank is zero
- Flammability is a hazard when Natural Gas evaporated from LNG accumulates in a confined space
  - Example confined space: 10 ft x 20 ft x 8 ft
  - A 1.4 gallon (5.4 liter) LNG liquid spill (evaporated) would reduce oxygen concentration to 19.5%
  - This concentration would be well above the LFL

50

Cryogenic Hazards

- Extreme Cold Hazard
  - UN 1972
  - Specialized PPE is required
- Refer to ERG 115 for appropriate PPE

GUIDE 115 GASES - FLAMMABLE (INCLUDING REFRIGERATED LIQUIDS)

PROTECTIVE CLOTHING

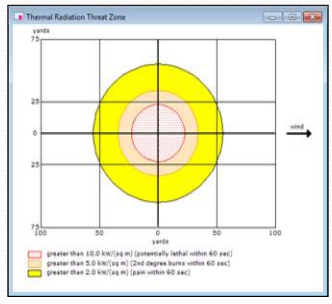
- Wear positive pressure self-contained breathing apparatus (SCBA).
- Structural firefighters' protective clothing will only provide limited protection.
- Always wear thermal protective clothing when handling refrigerated/cryogenic liquids.

51

Thermal Radiation Hazards

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation www.wikipedia.com

- Exposure of skin to 5 kW/m2 for 60 seconds will result in 2nd degree burns
- Structural damage
  - 30 to 37.5 kW/m2 will cause equipment damage
  - 12.5 kW/m2 for wiring damage



Source: Areal Locations Of Hazardous Atmospheres (ALOHA)

52

Summary
Question & Answer

Mike Faulkner
U.S. Environmental Protection Agency

Summary

- Asphyxiation a potential hazard (no odorant in LNG)
- Flammability is a hazard. There is an additional danger of explosion in a confined space.
- Cryogenic issues are important, particularly cryogenic burns
- Flammability leads to thermal radiation exposure
- Don't plan on putting out an LNG fire with water – it will substantially expand!

54

Thank you.

Feedback

We welcome feedback regarding this training.

Feedback should be submitted to Roberta Runge, NRT Training Subcommittee Chair, at Runge.Roberta@epa.gov.

Resources

CAMEO Chemicals
https://cameochemicals.noaa.gov/chemical/3757

USCG Liquefied Gas National Center of Expertise
lgcncoe@uscg.mil

Liquefied Natural Gas: Understanding the Basic Facts (DOE)
http://energy.gov/sites/prod/files/2013/04/fo/LNG_primerupd.pdf

Strategic Center for Nature Gas: Natural Gas Facts (DOE)
https://www.netl.doe.gov/publications/factsheets/policy/Policy023.pdf