Introduction
to
LNG as a Maritime fuel
The Good, The Bad, The Ugly

Gary W. Van Tassel

Argent Marine Companies

MAERSK LINE, LIMITED

Joint Venture

Our partnership brings a unique solution to the LNG value chain

Argent Marine

- Specialist in LNG marine vessels and related engineering services
- Advisor to domestic and international LNG marine operations
- Service provider to major oil & gas companies
- U.S. flag Jones Act qualified company

State-of-the-art marine/land-based technology for the safe and economical distribution of LNG

Maersk Line, Limited

- Ship design and engineering expert
- 28 years of experience in:
  - o Tanker operations
  - o Vessel management
  - o Maritime technical services
- Global intermodal capability
- Established U.S. flag network

Natural Gas As Fuel

- **Significant Contribution to Clean Fuel Effort**
- **Reduction of Crude Oil Imports**
- **Energy Security**
- **Most Business Friendly Option of Emissions Control**
- **Commercial Distribution Key**

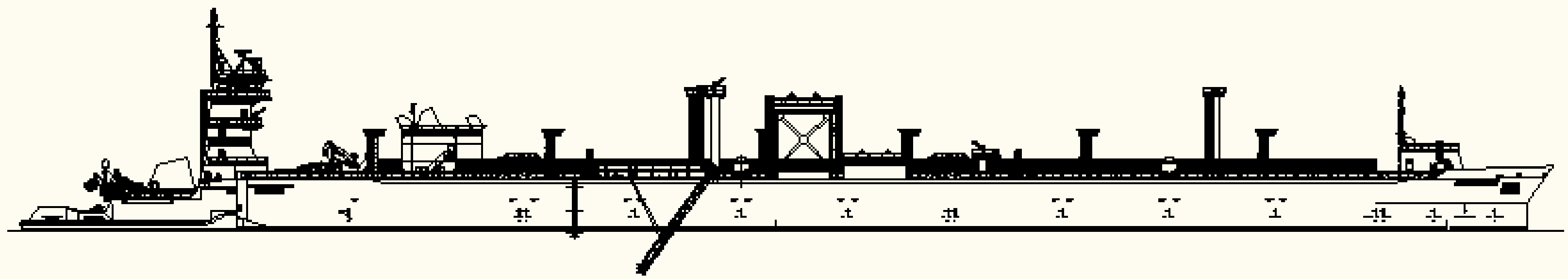
LNG as Transport Fuel

- **High Energy Density Liquid Fuel**
- **Current Technology**
- **Non Developmental**
- **Environmental Benefits**
- **Cost Advantage (Key Driver)**
- **Major Market Potential**

LNG Fuel Distribution

- Liquid Cargo Distribution
- Similar to Distillate Distribution
- Liquefaction Terminal to End User
  - Ports/Vessel Fueling
  - Fleet Yards
  - Refueling Stations
  - Other
- Independent of Pipeline
  - Complement
  - Alternative

Argent Marine/Maersk AT/B LNGC



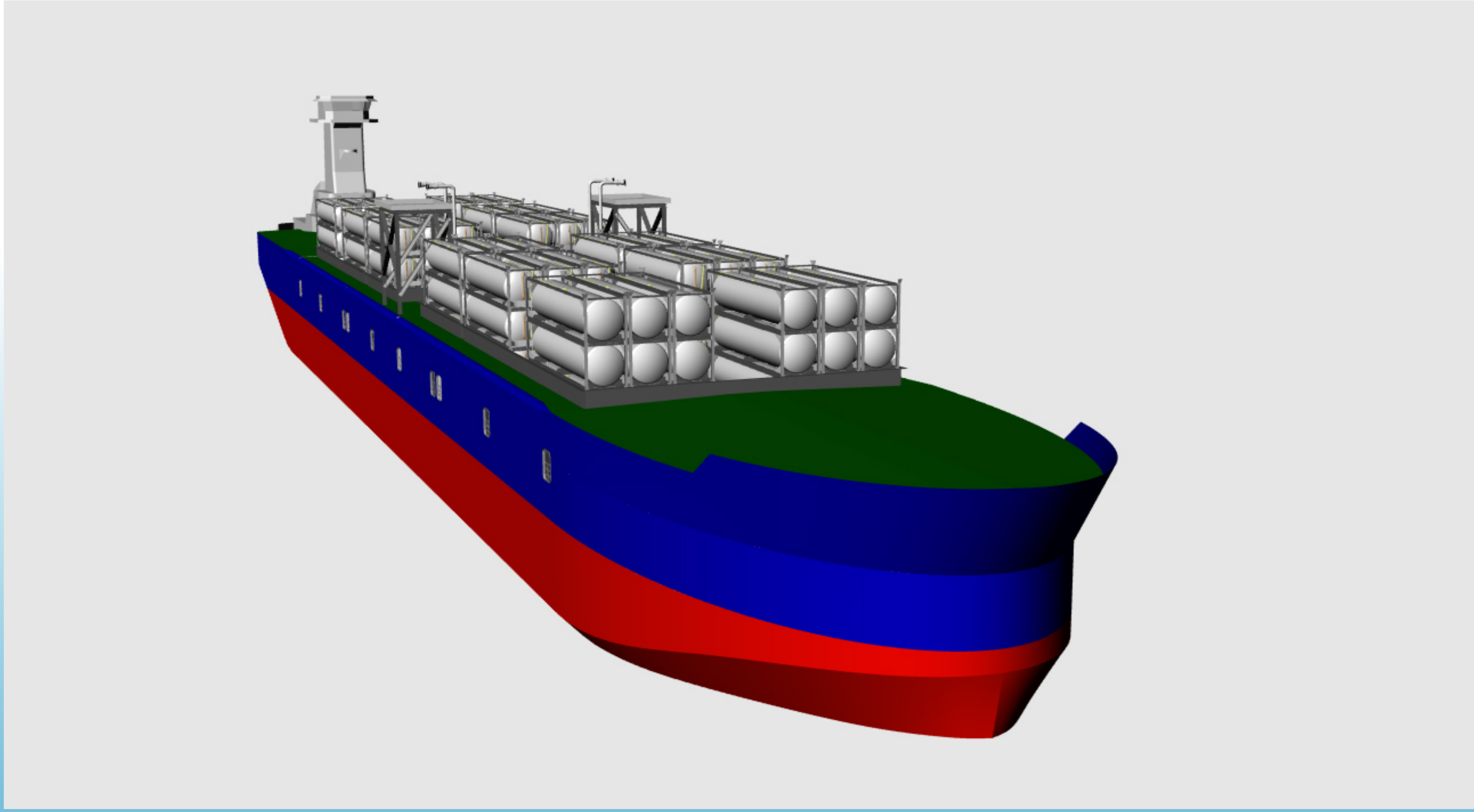
CARGO UNIT:

LOA:	516.4’ (157.4 m)
LWL:	506’ (154.2 m)
Beam:	78’ (23.8 m)
Depth:	40.6’ (12.4 m)
Design Draft:	20’ (6.1m)
Capacity	13,352 m^3

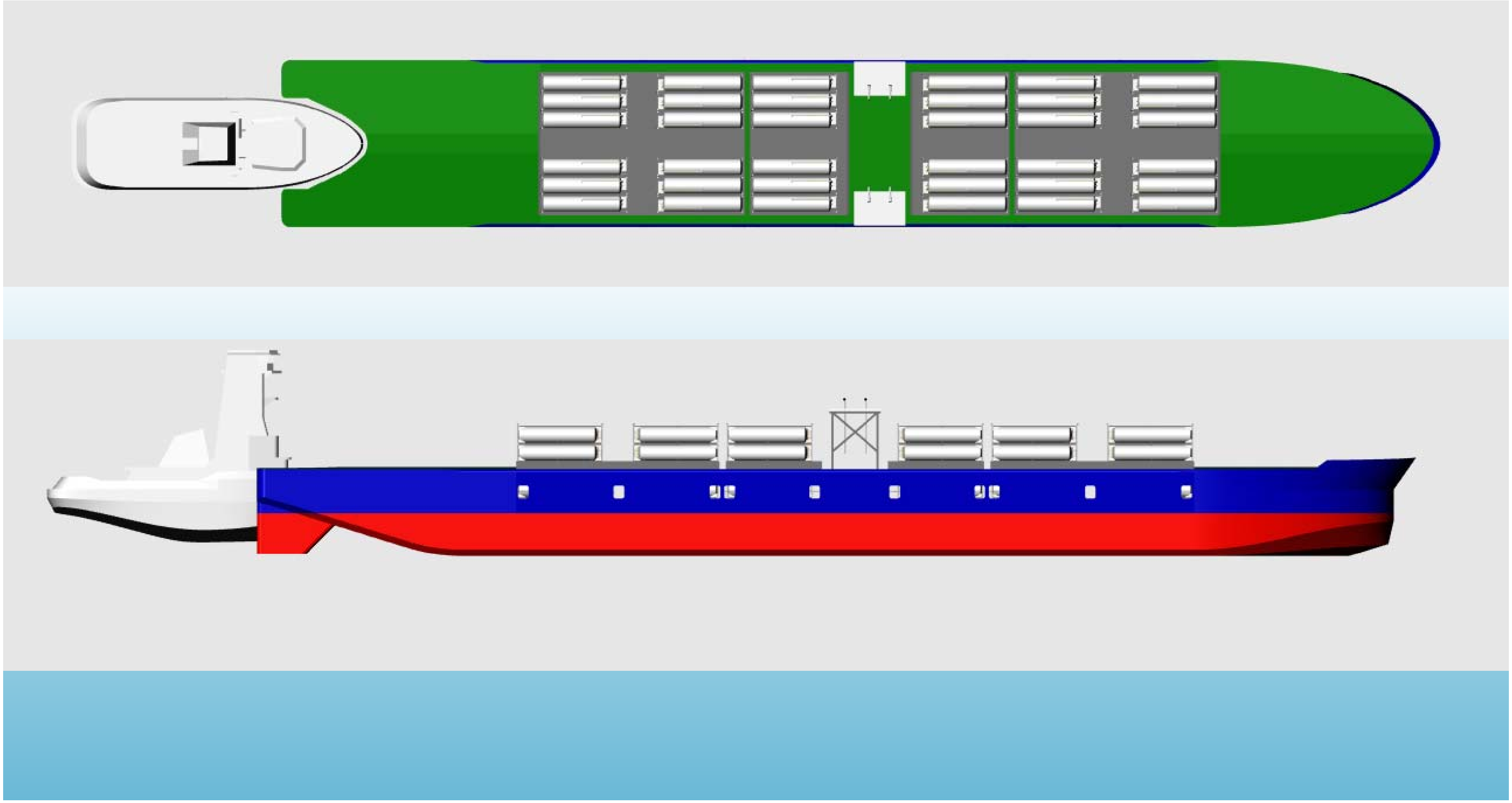
COMBINED VESSEL:

LOA:	591.1’ (180.2 m)
Loaded Draft:	20’ (6.1 m)
Service Speed:	12 Knots

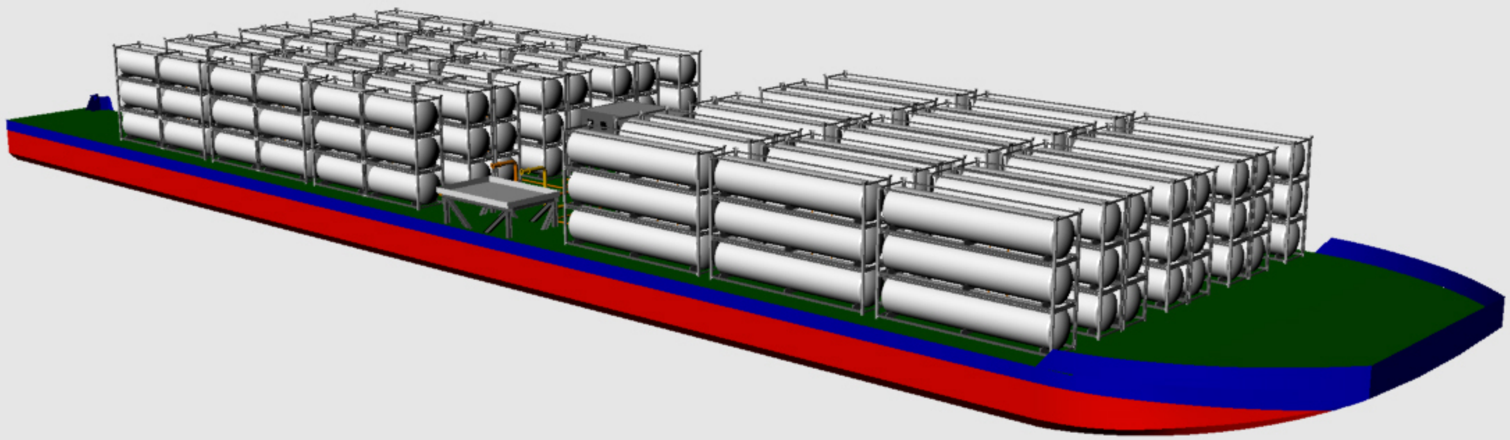
Intermodal LNG AT/B



Intermodal LNG AT/B



Intermodal LNG AT/B



Intermodal LNG System

ISO Tanktainers: efficient storage, loading and transport

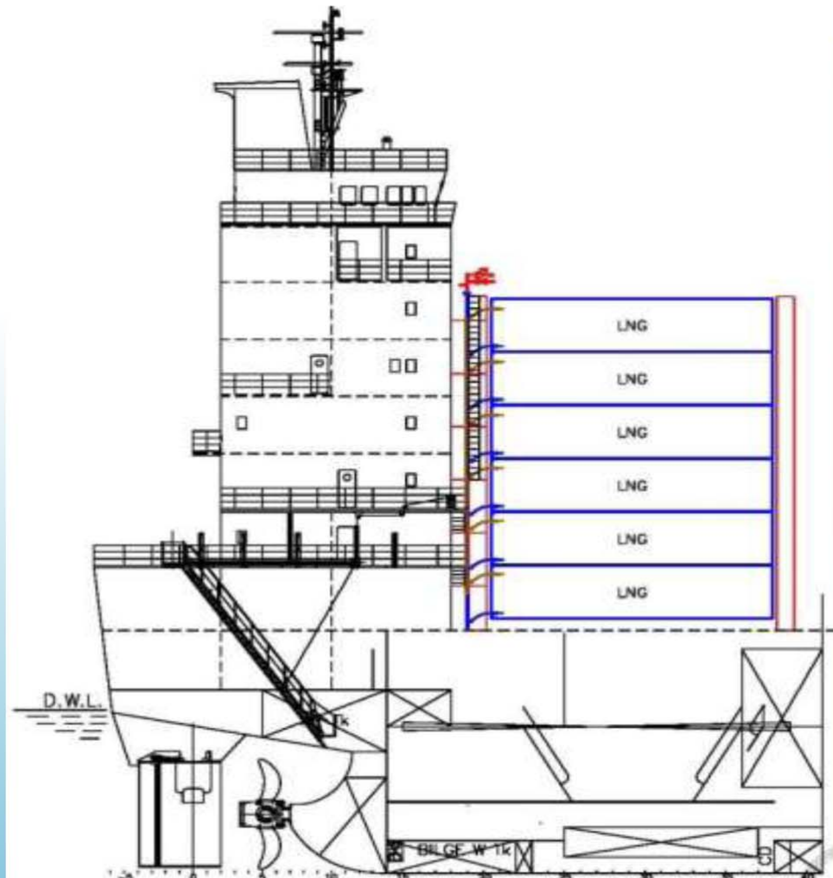
Trucking

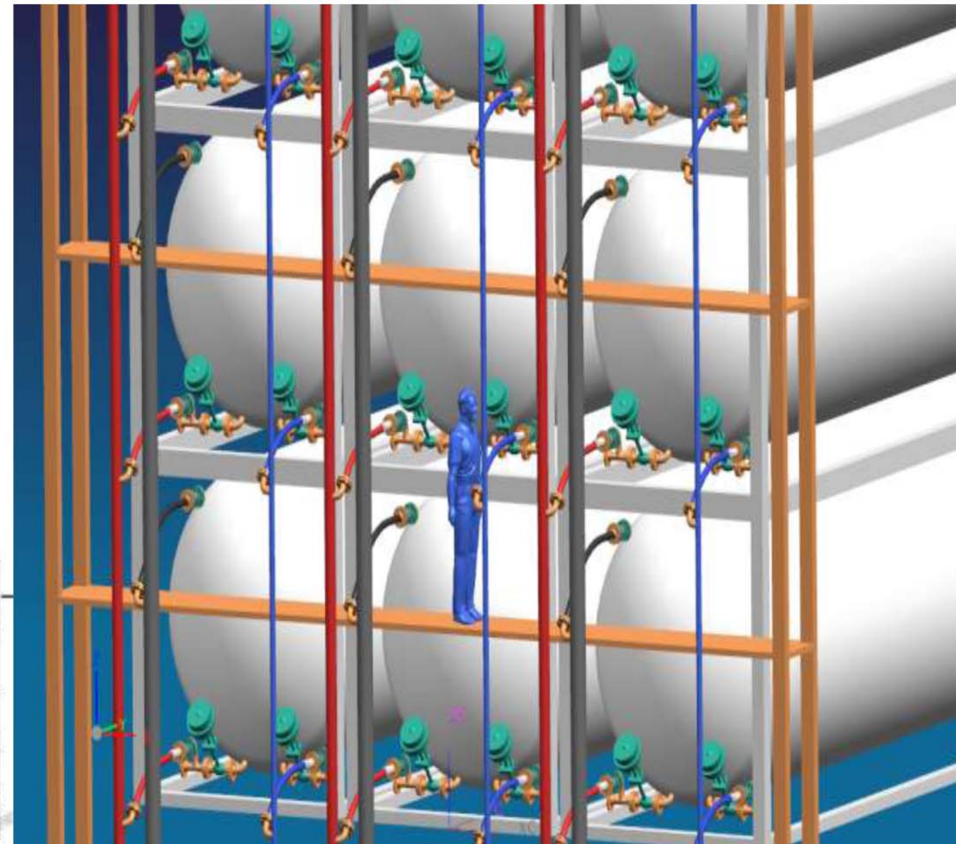
Rail

Intermodal LNG System

Intermodal System

Vessel Fuel Propulsion/Bunkering





Marine Services GmbH

Unit Challenged

- mmBTU = Decatherm = x 10^6 BTU
- MCF = x 10^3 ft^3 (STP: 60 ^oF , 14.696 psia)
- BCF = x 10^9 ft^3 (STP: 60 ^oF , 14.696 psia)
- m^3 LNG
- Nm^3 (0 ^oC, 1 atmosphere, 1.0135 bar)
- Gallons LNG
- mTPA = x 10^6 Tonnes Per Annum
- DGE
- GGE
- ??

Key LNG Properties

- Natural Gas
- Mixture of Gases
  - Methane - usually > 90%, CH_4, -257.8 ^oF
  - Ethane, C_2H_6, -127 ^oF
  - Propane, C_3H_8, -44 ^oF
  - Butane, C_4H_{10}, 31.1 ^oF
  - Nitrogen, N_2, -320 ^oF
  - CO_2 – Not in LNG, Dry Ice at -108 ^oF (no liquid state at pressures below ~ 5 atmospheres)

Key LNG Properties

Chemical	Formula	Low	High
Methane	CH_4	87%	99%
Ethane	C_2H_6	<1%	10%
Propane	C_2H_8	>1%	5%
Butane	C_4H_{10}	>1%	>1%
Nitrogen	N_2	0.1%	1.5%
Other Hydro-carbons	Various	Trace	Trace

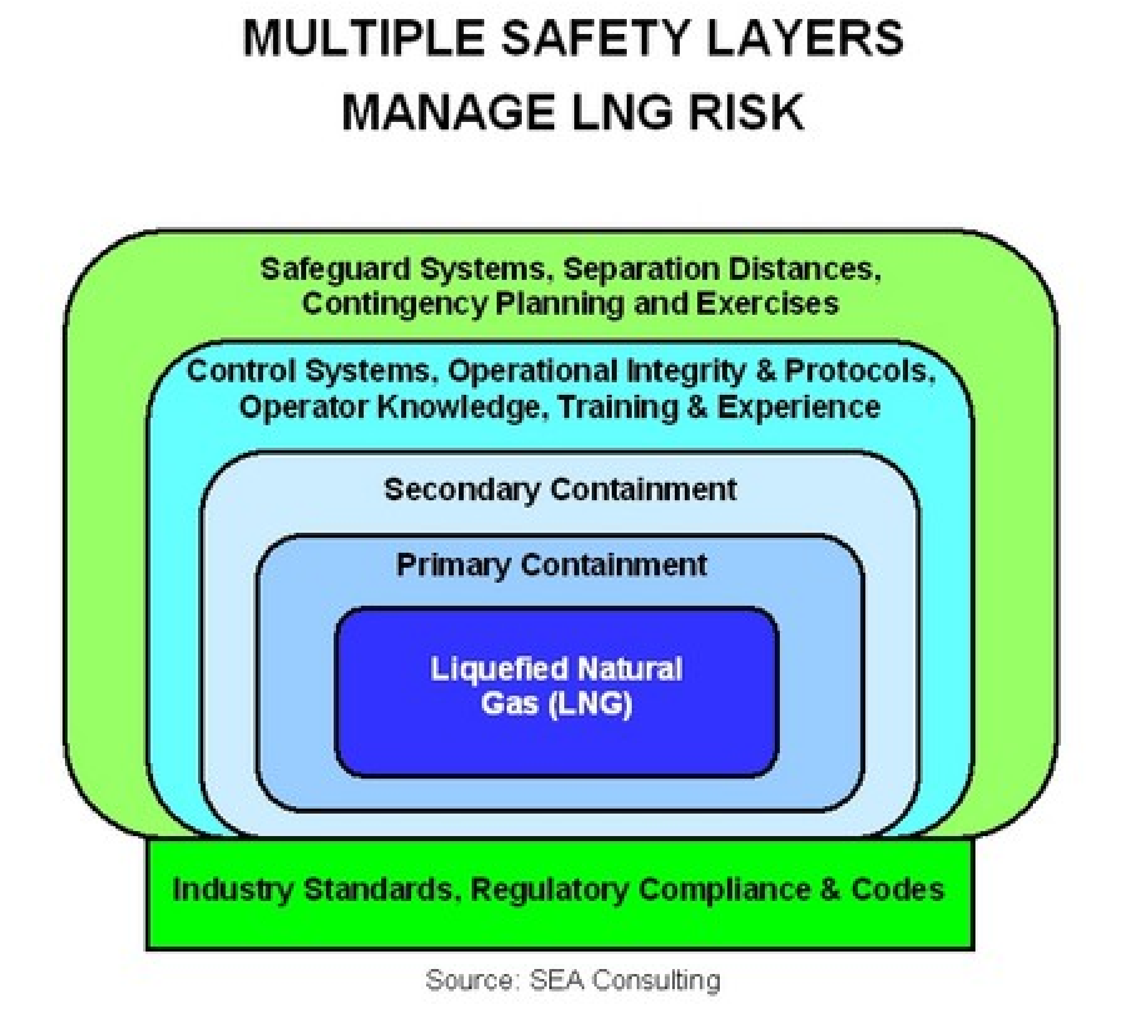
LNG Key Properties

Origin	CO_2	N_2	C1	C2	C3	C4+	HV
Algeria		0.9%	90.7%	7.7%	0.7%	0.0%	1077 BTU/scf
Nigeria		0.1%	91.3%	4.6%	2.6%	1.4%	1122 BTU/scf
Norway		0.8%	92.2%	5.3%	1.2%	0.5%	1018 BTU/scf
Trinidad		0.0%	96.8%	2.7%	0.3%	0.2%	1041 BTU/scf
Qatar		0.4%	90.1%	6.2%	2.3%	1.0%	1117 BTU/scf
Sakhalin		0.2%	92.7%	4.6%	2.1%	0.4%	
U.S. Mean	0.5%	1.5%	94.3%	2.7%	0.6%	0.4%	1035 BTU/scf
Marcellus	0.04%	0.26%	97.1%	2.4%	0.1%	0.1%	1032 BTU/scf
Appalachian	0.1%	2.4%	79.1%	17.7%	0.6%	0.1%	1133 BTU/scf
Eagle Ford	1.5%	0.2%	74.6%	13.8%	5.4%	4.5%	1307 BTU/scf

Key LNG Properties

- Discussions about the properties of LNG usually begin with "depending upon its exact composition"
- Important to understand that it matters
- Incorrect and risky to over simplify
- Important to distinguish LNG properties as a liquid from its properties as a cold vapor, from the properties of ambient natural gas
- LNG properties determine its behavior
- Influence **Management of RISK**

LNG - Management of Risk



LNG Key Properties

- Boiling Cryogen
  - Cryogenic liquids – boiling point < -100 ^{o}F
  - LNG boiling point ~ -260 ^{o}F (depending on composition)
  - LNG is one of the "warmer" cryogens
  - Most materials become "brittle" at cryogenic temperatures
    - Steel
    - Many plastics
    - Rubber (i.e. gaskets)
    - Skin
  - Suitable materials are known and available
    - Stainless Steel
    - Nickel Steel (9% Ni, Invar, etc.)
    - Aluminum

LNG Key Properties

- Cryogenic materials have higher tensile and yield strengths at Cryogenic vs. ambient temperatures
- Other common Cryogens
  - Ethane, -127 ^{o}F
  - Ethylene, -155 ^{o}F
  - LNG, -260 ^{o}F
  - Oxygen, -297 ^{o}F
  - Argon, -303 ^{o}F
  - Nitrogen, -320 ^{o}F
  - Hydrogen, -423 ^{o}F
  - Helium, -453 ^{o}F

Key LNG Properties

- Generally use CH_4 to represent LNG, be aware!
- Variances in HV and Density due to composition
- Atmospheric boiling Temp ~ -259^o F
- Critical Temp ~ -117^o F / 667 psia
- Rises in air when T> -157^o F, mixing with air, however, may delay vapor buoyancy until higher temperature is reached
- Typical(?) HV – 1086 BTU/Ft^3
- Expansion ratio – 621:1 (methane – LNG generally taken as 600:1, but can be as low as ~570:1)

Key LNG (CH_4) Properties

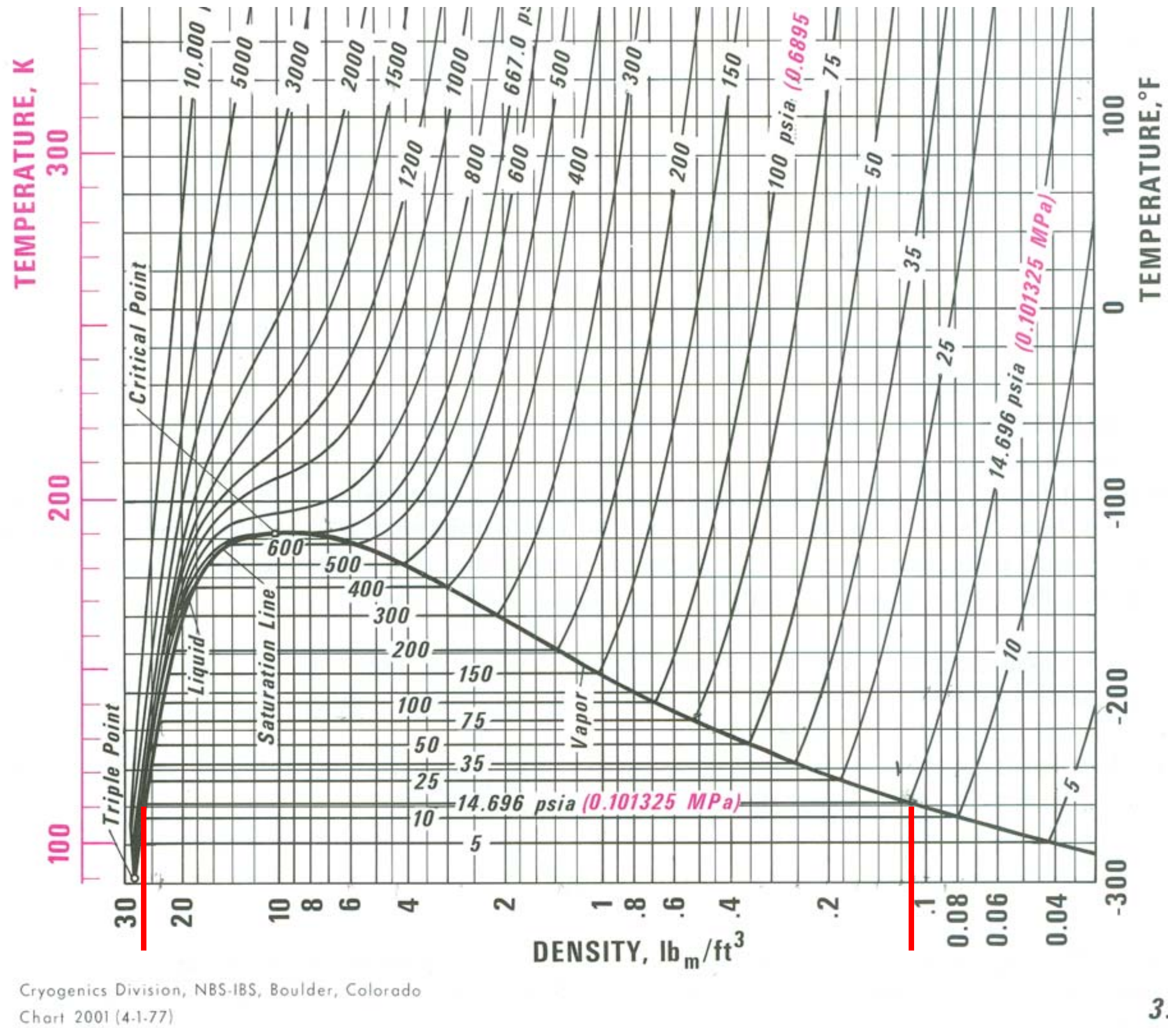
Critical Point:
-117 °F
667 psia

Normal Boiling Point:
Liquid Density 26.4 lbm/ft³
Vapor Density 0.11 lbm/ft³

Expansion Ratio ~240:1

STP Vapor Density
(60 °F , 14.696 psia)
0.042 lbm/ft³

Expansion Ratio ~621



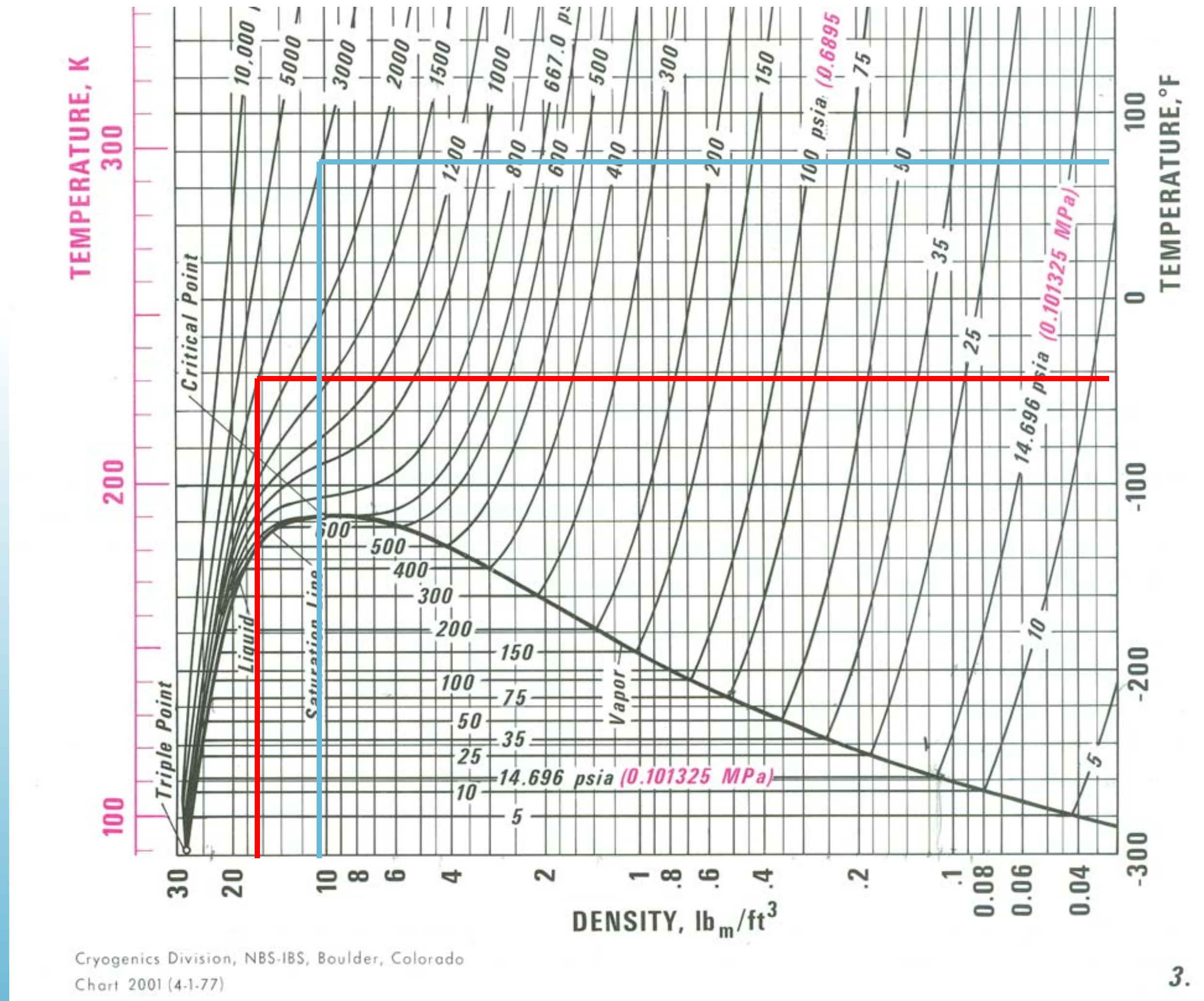
Cooled CNG

Volumetric Improvement:

3000 psia
70 ^oF
Density ~ 10 lbm/ft^3

TO

3000 psia
-40 ^oF
Density ~ 16 lbm/ft^3



Key LNG Properties

- Colorless
- Odorless
  - Mercaptan odorant
  - Solid at LNG temperatures
  - Added to gas
  - Not a good idea on an LNG fueled vessel
- LFL = CH_4 5% (Propane 2%)
- UFL = CH_4 15% (Propane 10%)
- Because LNG is boiling Cryogen – it does not want to stay a liquid

Key LNG Properties

- Auto-ignition (CH_4) ~ 1100 °F (increase in C+ lowers auto-ignition temperature)

	Natural Gas	Diesel Fuel	Gasoline
Auto-ignition Temperature	1110 °F (599 °C)	500-700 °F (260-371 °C)	438-880 °F (226-471 °C)

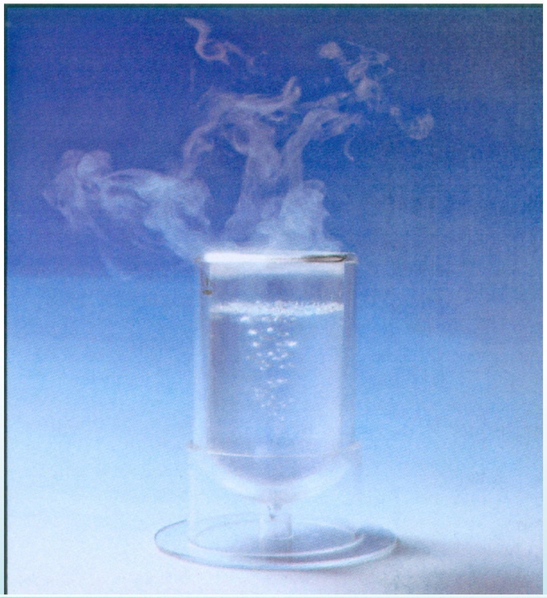
- Fast burn rate - ~ 3 x faster than gasoline

LNG Safety

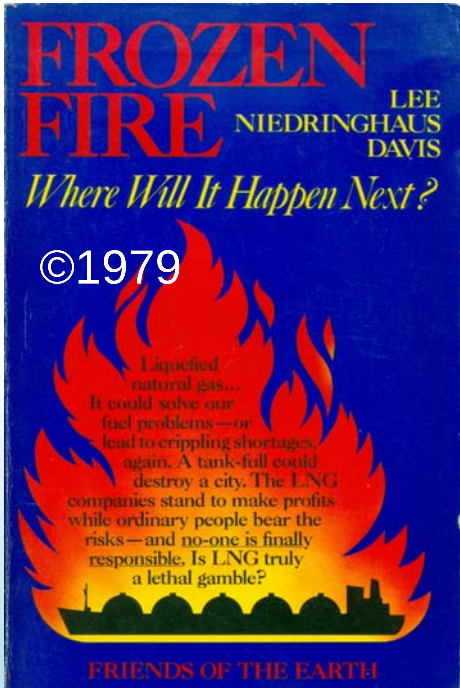
- Cryogenic
  - Personnel Hazard
  - Vessel Hazard
- Non-toxic
- Asphyxiant
- Non-Flammable as a liquid
- Low risk of <u>unconfined</u> vapor cloud explosion (VCE)
  - Slow flame front propogation
- Thermal radiation from combustion of released LNG
- Rapid Phase Transition (RPT or Flameless Explosion)
- Boiling Liquid Expanding Vapor Explosion (BLEVE)

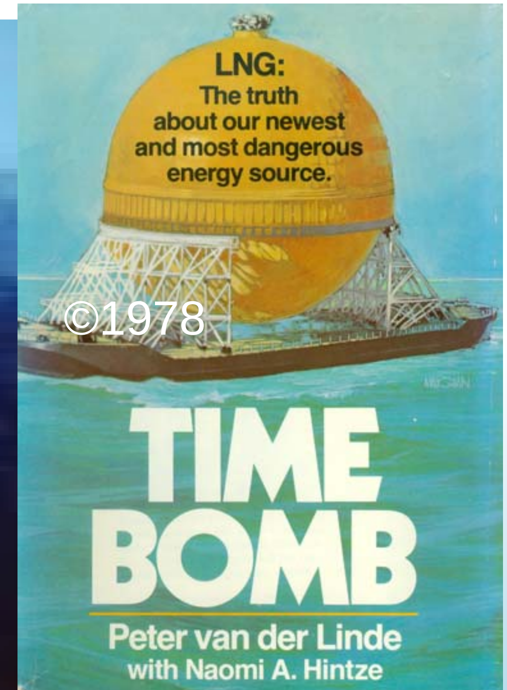
LNG Safety

- Relative Humidity > 55% - flammable cloud is “totally” included in the visible vapor cloud
- Relative humidity < 55% - flammable cloud can be partially or completely outside of the visible cloud
- Visible cloud is condensed water vapor not natural gas or LNG vapor



LNG Safety - Misinformation





"is a clear and correct indictment of the entire LNG program"

"LNG has the explosive force second only to a nuclear holocaust"

LNG Safety

- BLEVE (video)
  - Not an issue with LNG (Not so fast!)
- RPT (video)
  - LNG on water
  - Rapid increase in vapor produced
  - Pressures are not insignificant but not devastating
- Sandia Tests (video)
  - Basically validated existing simulation models
  - Fire will stay at center of pool, not burn out to the edges
  - Smoky at upper levels

LNG Safety

- LNG Industry Safety Culture
- SIGTTO
- SANDIA – radiation zones
- HAZID / HAZOP
- Accidental and Intentional Release Consequence Analysis
  - Credible Release
- Bunkering
  - Robust Procedures
  - Midstream Refueling (Inland rivers?)
- Personnel
  - Training

LNG Safety

<u>Prime Directive Number I</u>

Thou shall not let natural gas (LNG Vapor) and air (oxygen) in the same place at the same time.

LNG Safety

Prime Directive Number II

See Prime Directive Number I

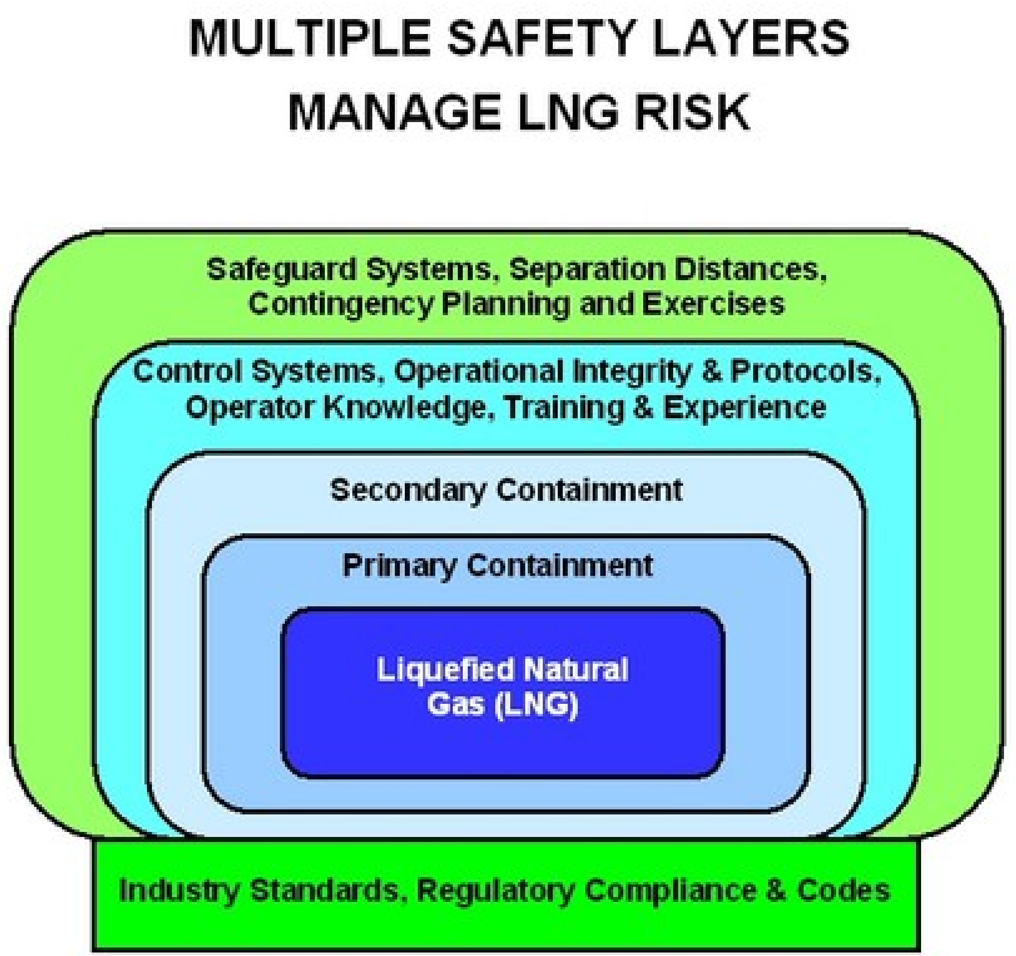
If, however, Thou has failed to comply with Prime Directive Number I, thou shall not provide an ignition source.

LNG Safety

Prime Directive Number III

Don’t let the Genie out of the bottle!

LNG - Management of Risk



Source: SEA Consulting

LNG Safety

- All tanks, pipelines, loading arms, hoses, etc. are inerted (O_2 levels <3%) prior to introduction of LNG (liquid or vapor)
- All loading arms, hoses, etc. are purged with inert gas to remove remaining LNG (liquid or vapor) prior to disconnect.
- Critical to ensure everything is not only purged of $O_{2,}$ but they are also dry.

LNG Safety

LNGC Tank Process

1. "Inert" - Inert and dry cargo tanks and pipelines with dry "inert" gas. (IG usually produced by stoichiometric combustion of diesel fuel)
2. "Gas Up" – purge inert gas with warm natural gas to remove CO_2 from tanks and pipelines
3. "Cooldown" – Introduce LNG to pipelines and cargo tanks to slowly cool down the system.
4. "Load" – Load LNG

LNG Safety

Gas fueled vessel process:

- Inerting and Drying of system likely to be done with N_2 derived from LN_2
- No CO_2 , so no need to “Gas Up”
- Go directly to “Cool Down”
- Need on board source of N_2 for general operational purging and inerting
  - Could be LN_2 system
  - Could be compressed N_2 in high pressure cylinders
  - Better approach is membrane type air separation plant which can be integrated with service and instrument air systems

Rules and Regs

- DNV – Gas Fueled Engine Installations
- IMO – Interim Guidelines on Safety for Natural Gas Fuelled Engine Installations in Ships
- IMO – Code of Safety for Ships Using Gas or Other Low flash-Point Fuels with Properties Similar to Liquefied Natural Gas (proposed at BLG 16)
- ABS - Guide for Gas Fuelled Ships
- Guidance Document - IGC Code (New Revision)
- USCG (Case by Case for now) ??????

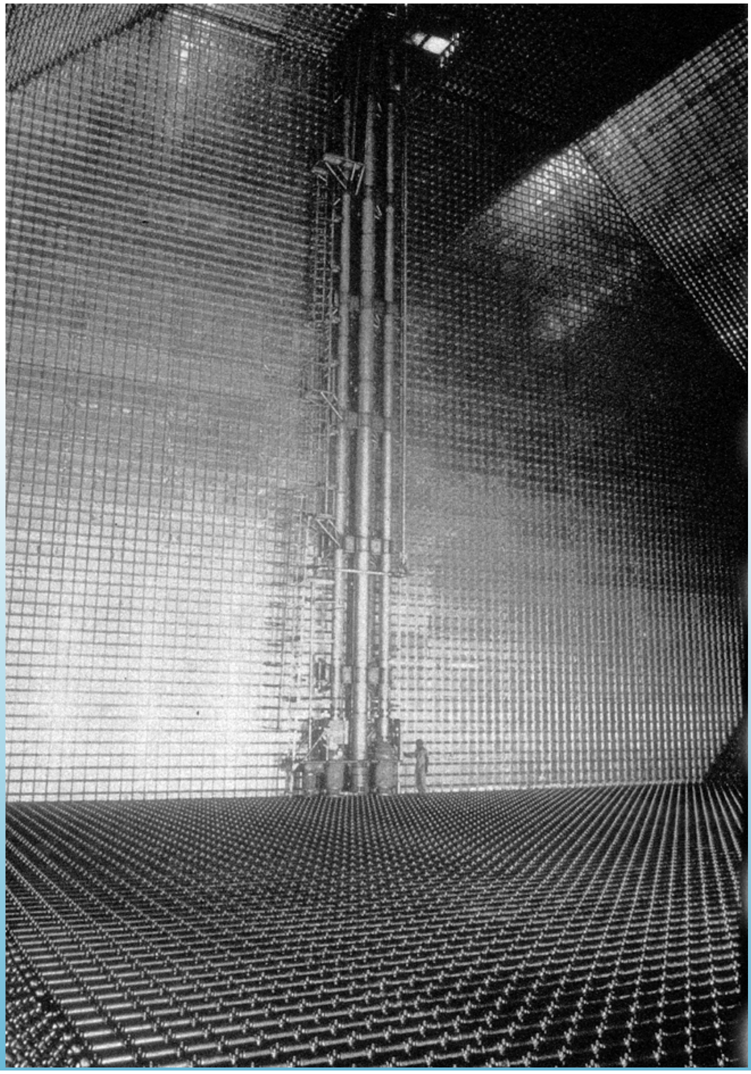
33 CFR 127

- "…applies to the marine transfer area for LNG of each … waterfront facility handling LNG…"
- Letter of Intent to COTP
- Waterway Suitability Assessment
- Accidental and Intentional Release Consequence Analysis
- Will 33 CFR 127 be applied as is to Bunkering?

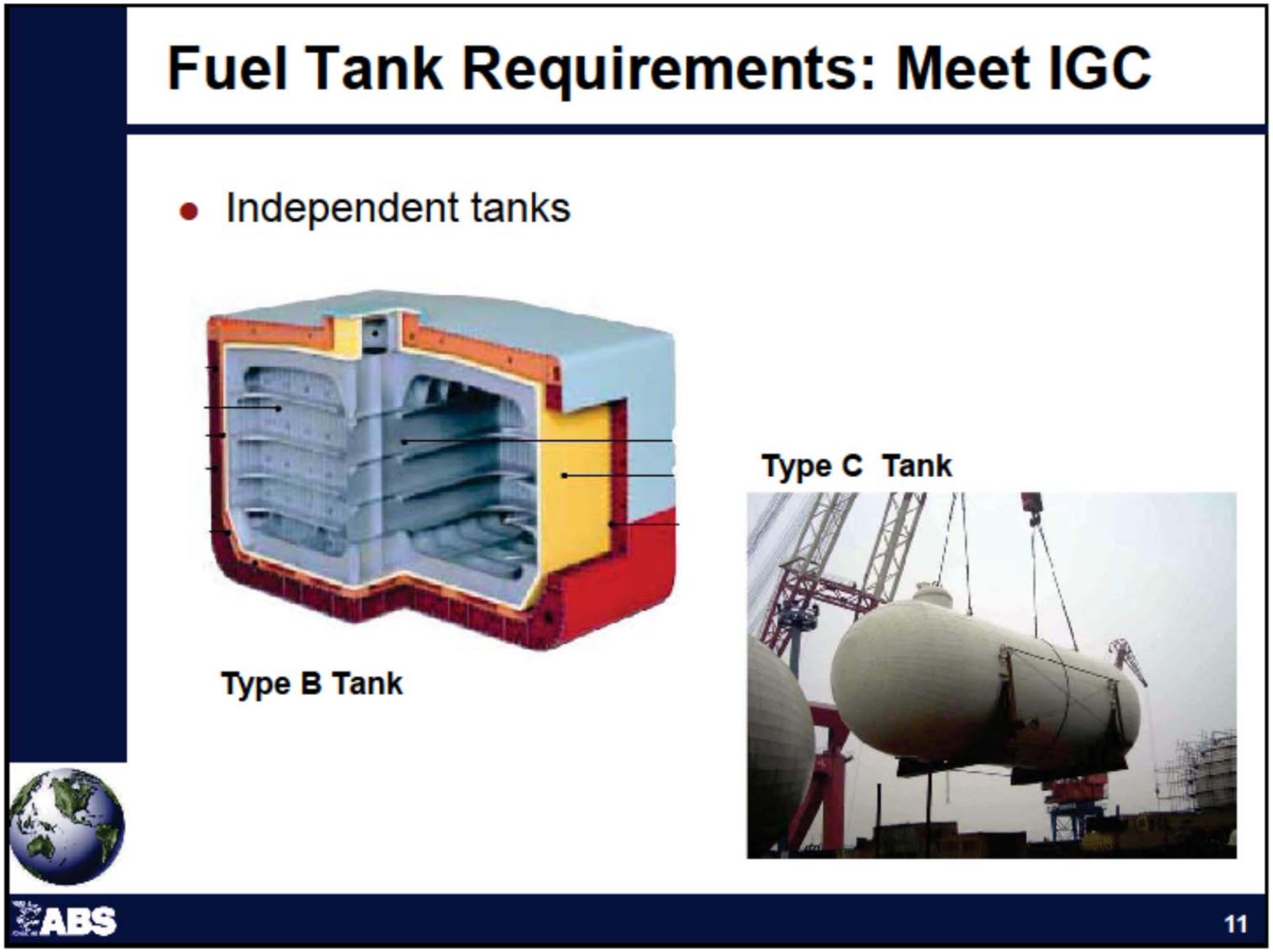
LNG Fuel Tanks For Gas Fueled Ships

- Interim Guide
  - 2.8.1 Liquefied gas storage tanks
  - 2.8.2.2 – The storage tank used for liquefied gas should be an <u>independent tank </u>designed in accordance with the IGC Code, Chapter 4
- IGC Code chapter 4 – Cargo Containment
  - 4.2.1 – integral tanks
  - 4.2.2 – Membrane tanks
  - 4.2.3 – Semi-membrane tanks
  - 4.2.4 – Independent tanks

Membrane LNG Tank



Type B and Type C LNG Tanks



LNG Fuel Tanks For Gas Fueled Ships

- IGC Code 4.2.4 – Independent tanks
  - Self supporting tanks
  - Type A – Prismatic (usually), classical ship-structural analysis procedures
    - Vapor pressure < 0.7 barg (10 psig)
    - Complete secondary barrier (IGC Code)
    - Conventional insulation
    - Early LNG Carriers were Type A ("Methane Pioneer", et. al.)
  - Type B – Prismatic, refined structural analysis (FEA, etc.)
    - Vapor pressure < 0.7 barg (10 psig)
    - Partial secondary barrier (IGC Code)
    - Conventional insulation

LNG Fuel Tanks For Gas Fueled Ships

- Type C – designed to recognized pressure vessel code and advanced analysis techniques (FEA)
  - ASME with additional requirements per IGC code, Class, Flag State
  - Can be vacuum insulated, lower boil off rate
  - No secondary barrier (IGC code)
  - IGC Code specifies a minimum design vapor pressure
  - Allow vapor pressure to increase as boil-off containment method
- Gas fueled ships to date are type C
- Not Limited to Type C, Type A & B are possible
  - Better space utilization within the vessel
  - BOG becomes critical issue
- Spherical LNG Carriers –Type C, classed as type B

LNG Fuel Tanks For Gas Fueled Ships

Type A and B Vapor Pressure Control

- Containment of boil off gas by "locking in" tank not viable.
- Can hold only for a matter of hours
- Since tank not vacuum insulated – boil off rate will be higher for same tank volume to surface area
- At sea – boil off sent to engines, plus additional forced vaporization (LNG weathering could be an issue)
- Reduced energy load – vapor pressure increases
  - Re-liquefaction
  - Gas combustor (enclosed flare)

LNG Fuel Tanks For Gas Fueled Ships

Interim Guide – 2.8.1.2

- Pipe connections to the tank should normally be mounted above the highest liquid level in the tanks. However, connections below the highest liquid level may be accepted after special consideration by the Administration
- Current designs utilize bottom connections for liquid withdrawal

Interim Guide – 2.8.4.3

- Requires secondary barrier regardless of tank type for under deck tank location
- Outer shell of vacuum jacketed tank plus “tank room” on end

LNG Fuel Tanks For Gas Fueled Ships

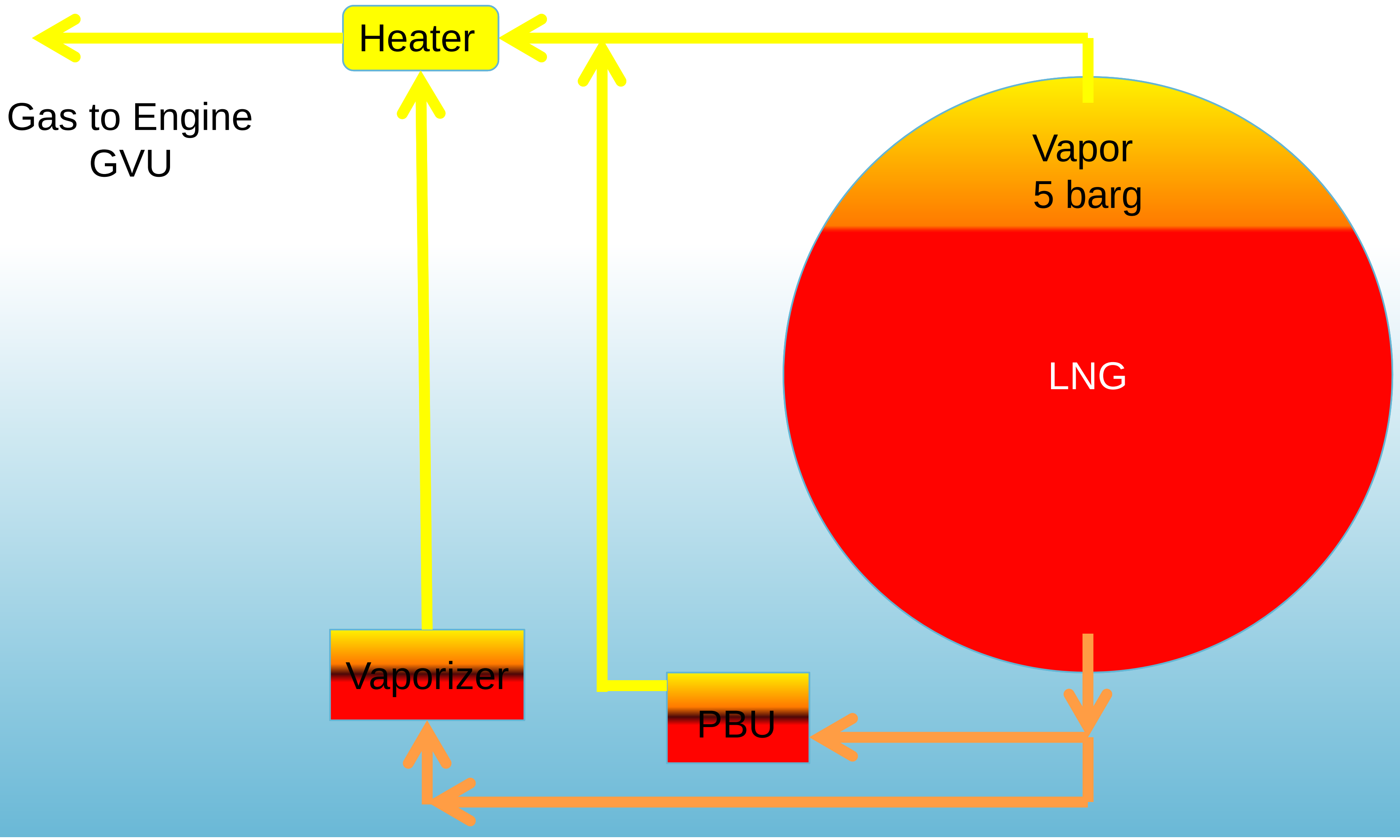
Tank Location

Interim Guide – 2.8.4.2

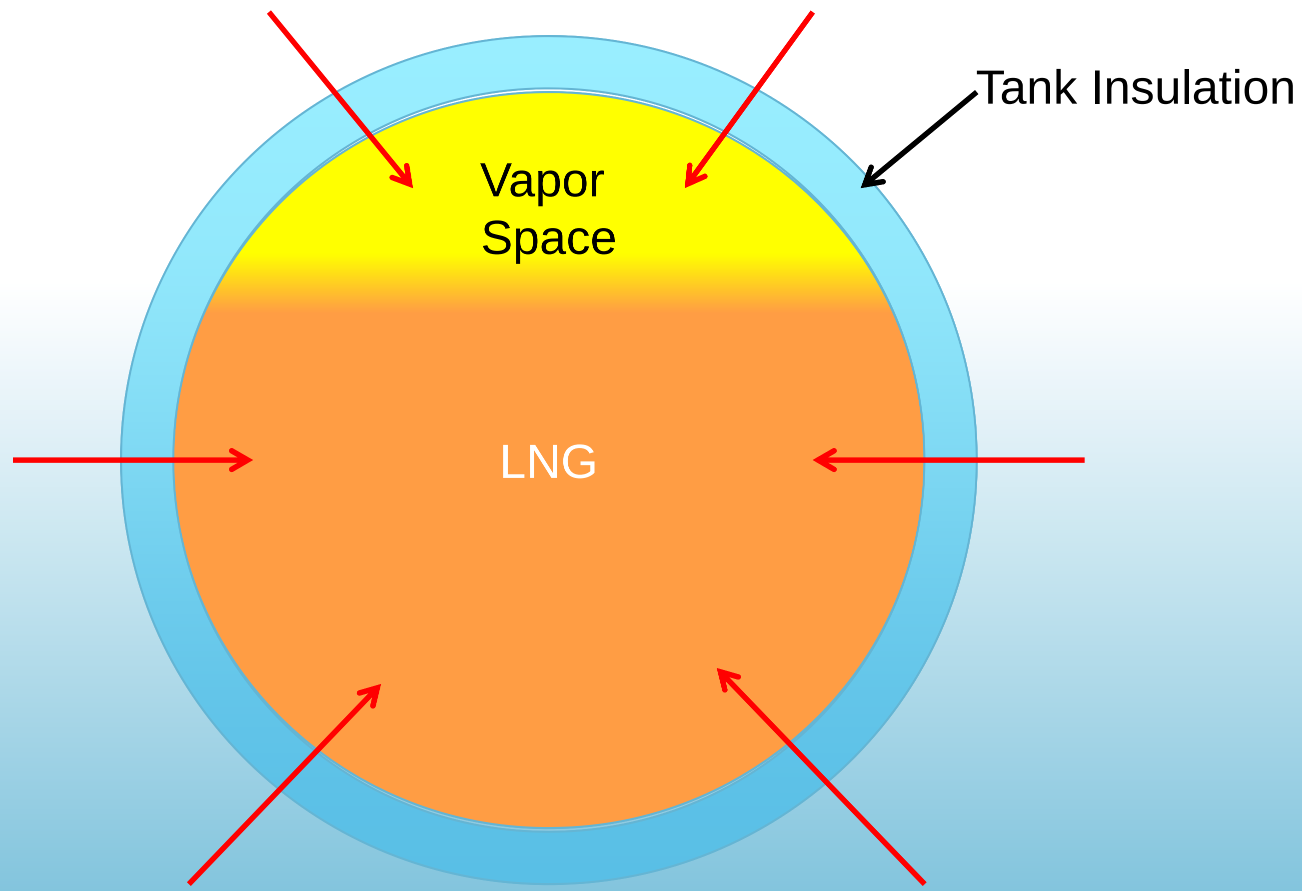
- Close as possible to centerline
- Lessor of B/5 and 11.5 m from ship side
- Lessor of B/15 and 2 m from bottom plating
- Not less than 760 mm from the shell plating
- For ships other than passenger ships and multi-hulls, a tank location closer than B/5 from the ship side may be accepted

LNG Fuel Tanks For Gas Fueled Ships

Gas Fuel System



LNG Equilibrium Conditions



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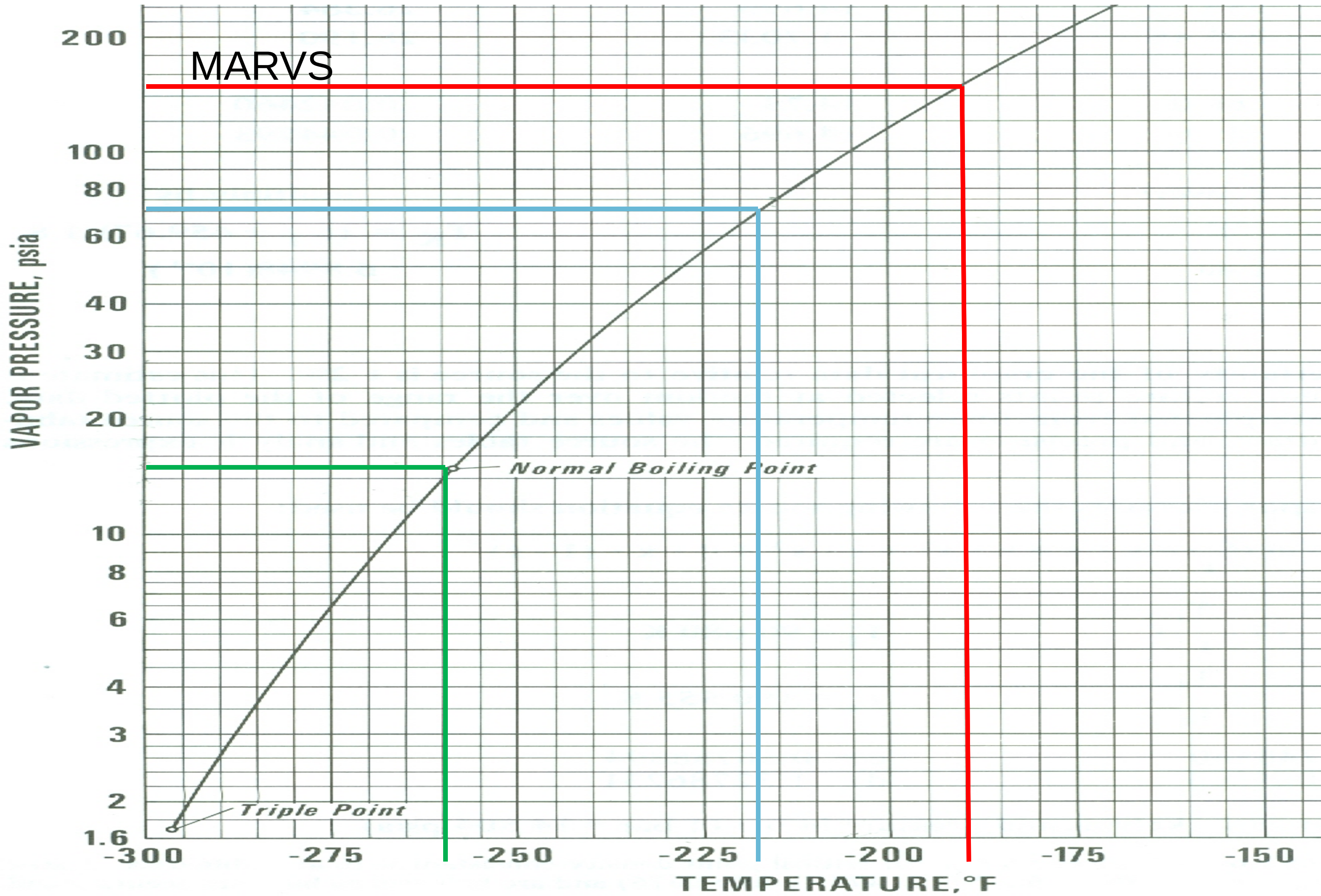

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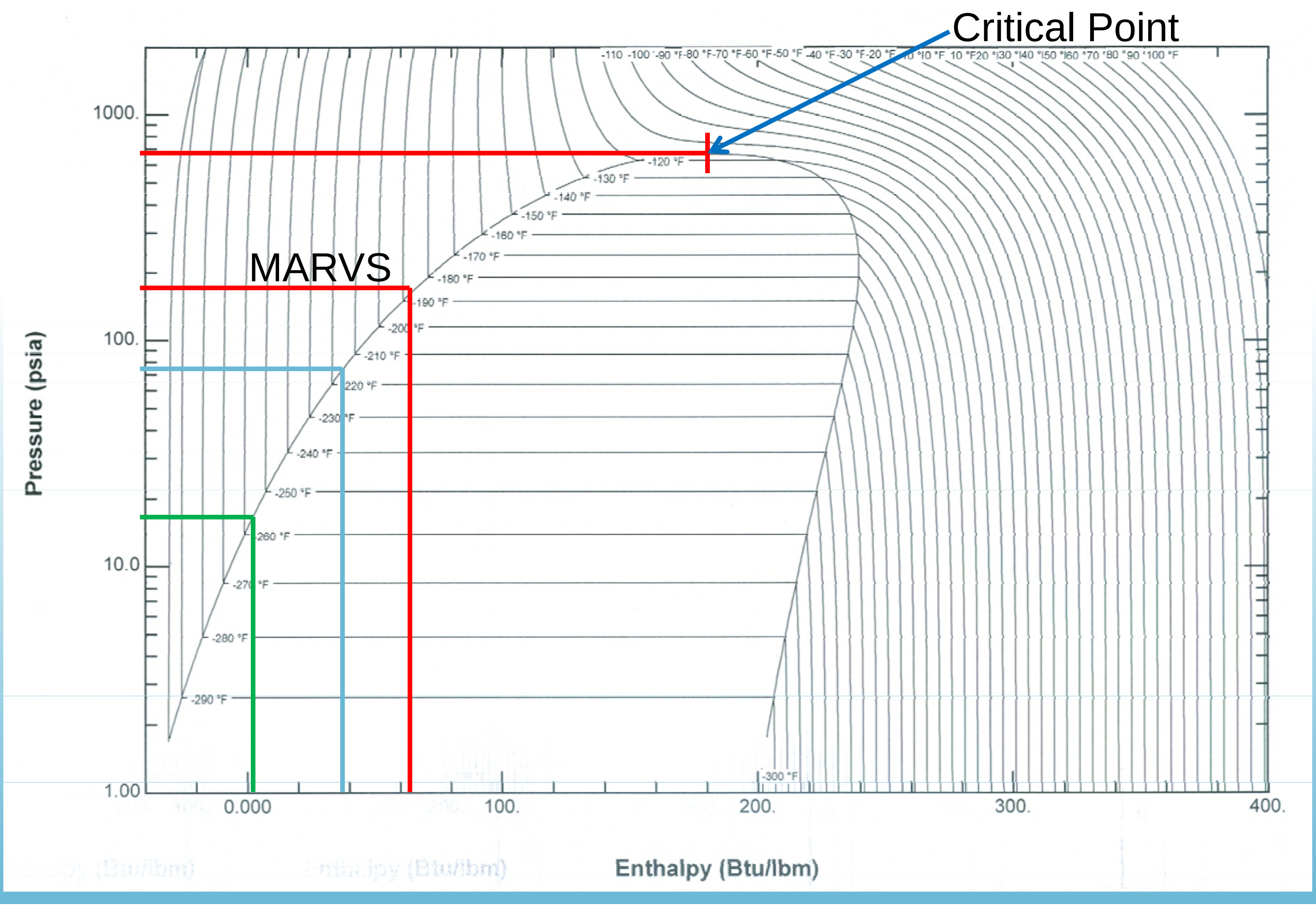

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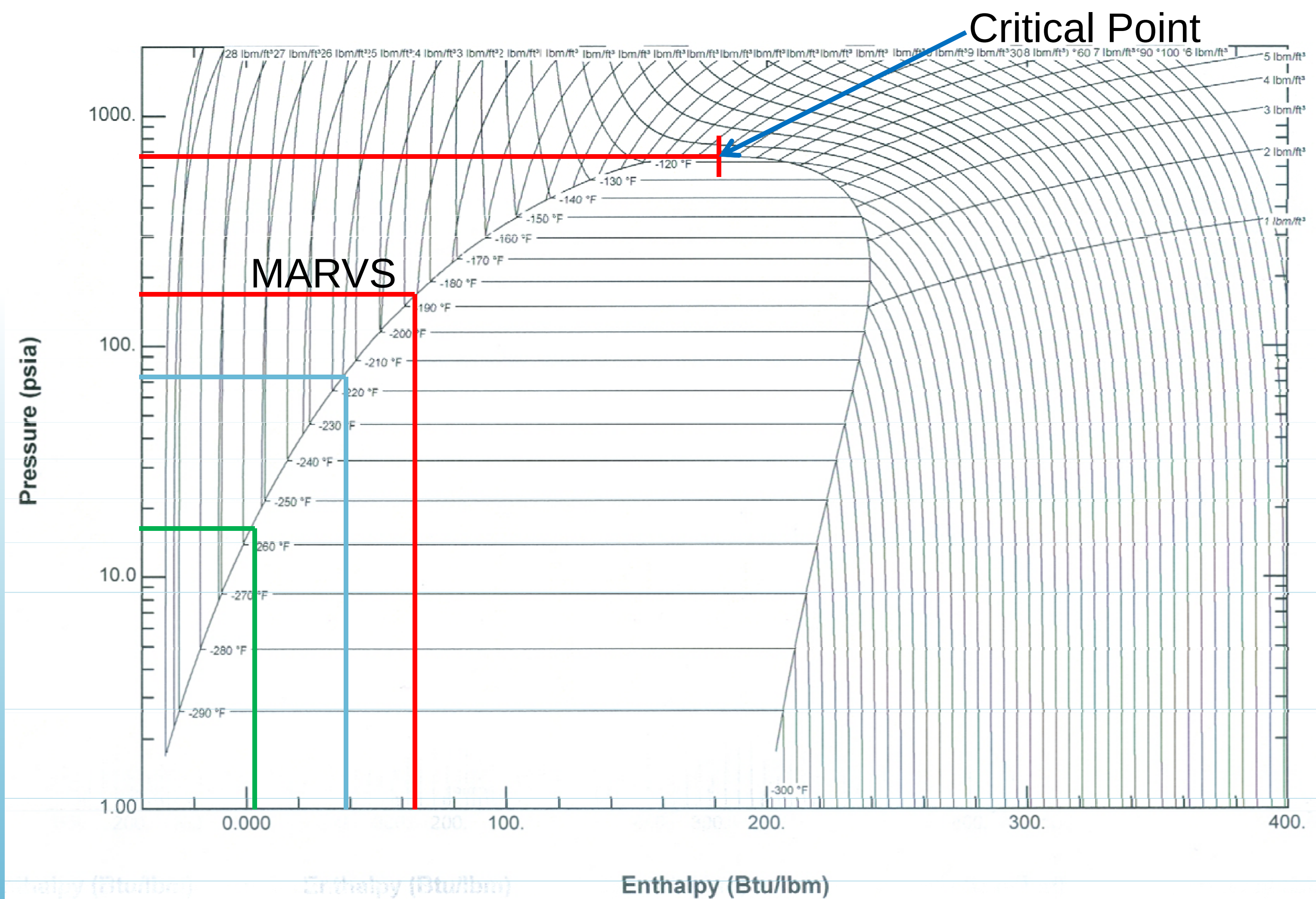


Pressurized LNG

- Typically LNG is carried at near atmospheric equilibrium conditions
  - Vaporization due to accidental release is limited to heat transfer into the LNG.
  - Released on water – higher vaporization rate
- Increased equilibrium condition of LNG
  - Higher energy content of LNG due to higher equilibrium pressure and temperatures
  - Significant increase in vaporization due to increased energy in released LNG
- Effect of "pressurized LNG" on process safety should be considered

LNG Equilibrium Conditions

- Typical LNG (Methane) Loaded Condition
  - Saturation Pressure = 15.4 psia
  - Equilibrium Temperature = -258^{o} F
  - Density = 26.3 lbm/ft^3
  - Enthalpy = 0.85905 Btu/lbm
- Increased Vapor Space Pressure
  - Engine Supply Pressure – 5 bars (72.5 psia)
  - Saturation Pressure = 72.5 psia
  - Equilibrium Temperature = -216^{o} F
  - Density = 24.0 lbm/ft^3
  - Enthalpy = 36.792 Btu/lbm

Additional Safety Issues

- Piping breach in Type C tank "Tank Room" with operational tank vapor space pressure and/or elevated LNG equilibrium conditions
  - Significant release volume due to tank pressure
  - Increased vaporization rate due to elevated LNG equilibrium conditions
  - "Tank Room" vent sized to handle the volume of vapor?
  - Location of vent discharge
  - Cryogenic Geysering
- Loss of vacuum in insulation space
  - Can system handle the increase in LNG boil off?
  - Significant reduction in LNG holding time

Alternate Approach

- Maintain vapor space to maximum extent possible at "normal" near atmospheric conditions
  - Resort to pressure build only when vessel not able to utilize full boil off
  - Pull vapor space pressure down once vessel power requirement increases again
- All tank connections over the top of the tank
  - Submerged pump to feed gas fuel vaporizer, pump develops required supply pressure, ~5 barg.
  - Gas compressor to increase tank vapor space pressure to required gas fuel supply pressure
  - Gas fuel heater to condition gas fuel temperature

LNG Tank Fill Limits

Interim Guide – 2.8.1.5

- Tank filling limit – 98% at reference temperature
- Reference Temperature – IGC Code 15.1.4
- Reference Temperature – MARVS (assume 10 bar)
  - 145 psia
  - -191.2^{o} F
  - 22.45 lbm/ft^{3}
- Loading Temperature / Density
  - Likely near ambient
  - Equilibrium Temperature = -258^{o} F
  - Density = 26.3 lbm/ft^{3}

LNG Tank Fill Limits

$V_L = (0.98)(V)(\rho_R/\rho_L)$

V_L = maximum volume to which tank may be loaded

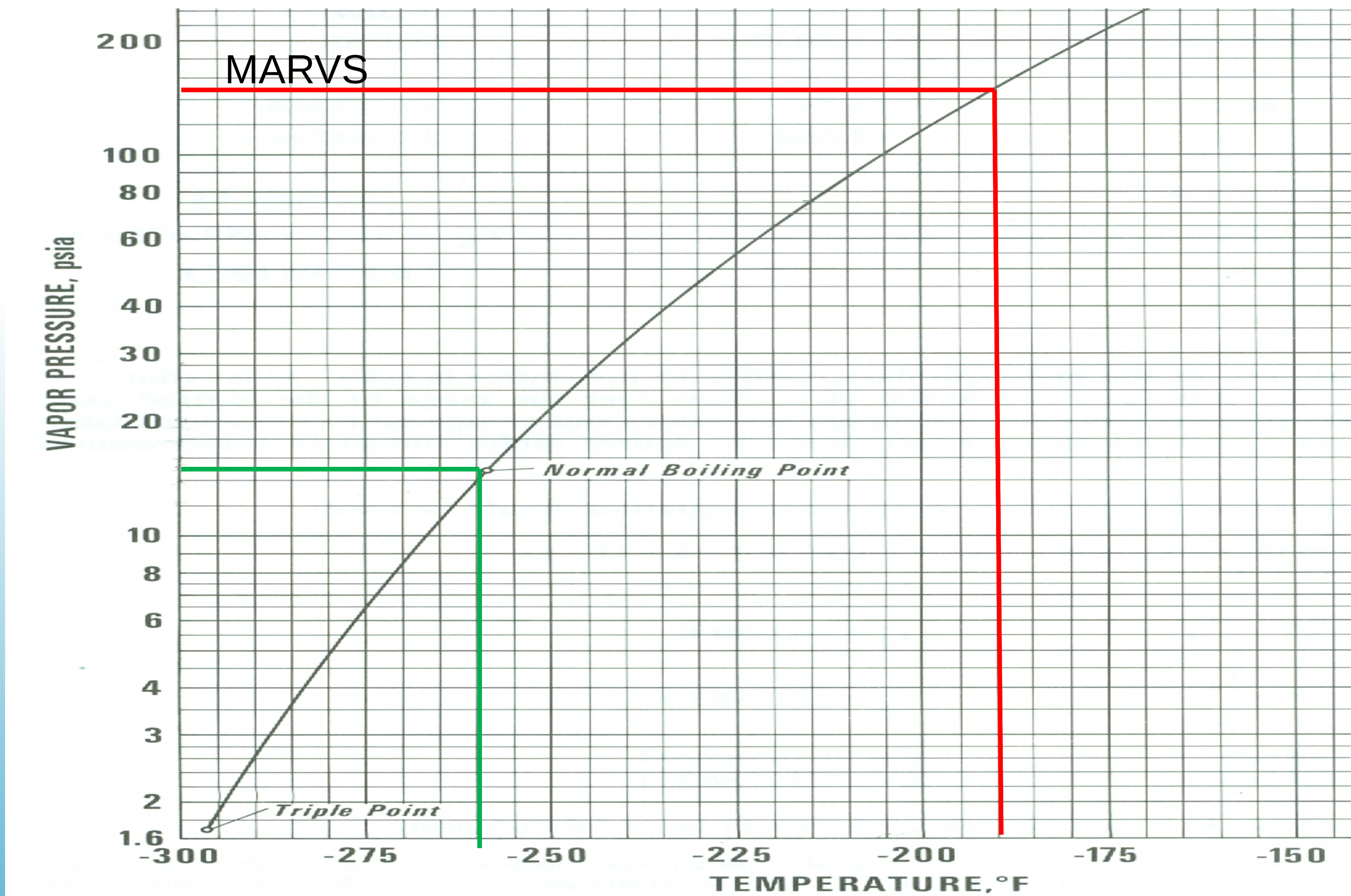
V = volume of tank (100% cold condition)

ρ_R = relative density of cargo at reference temperature

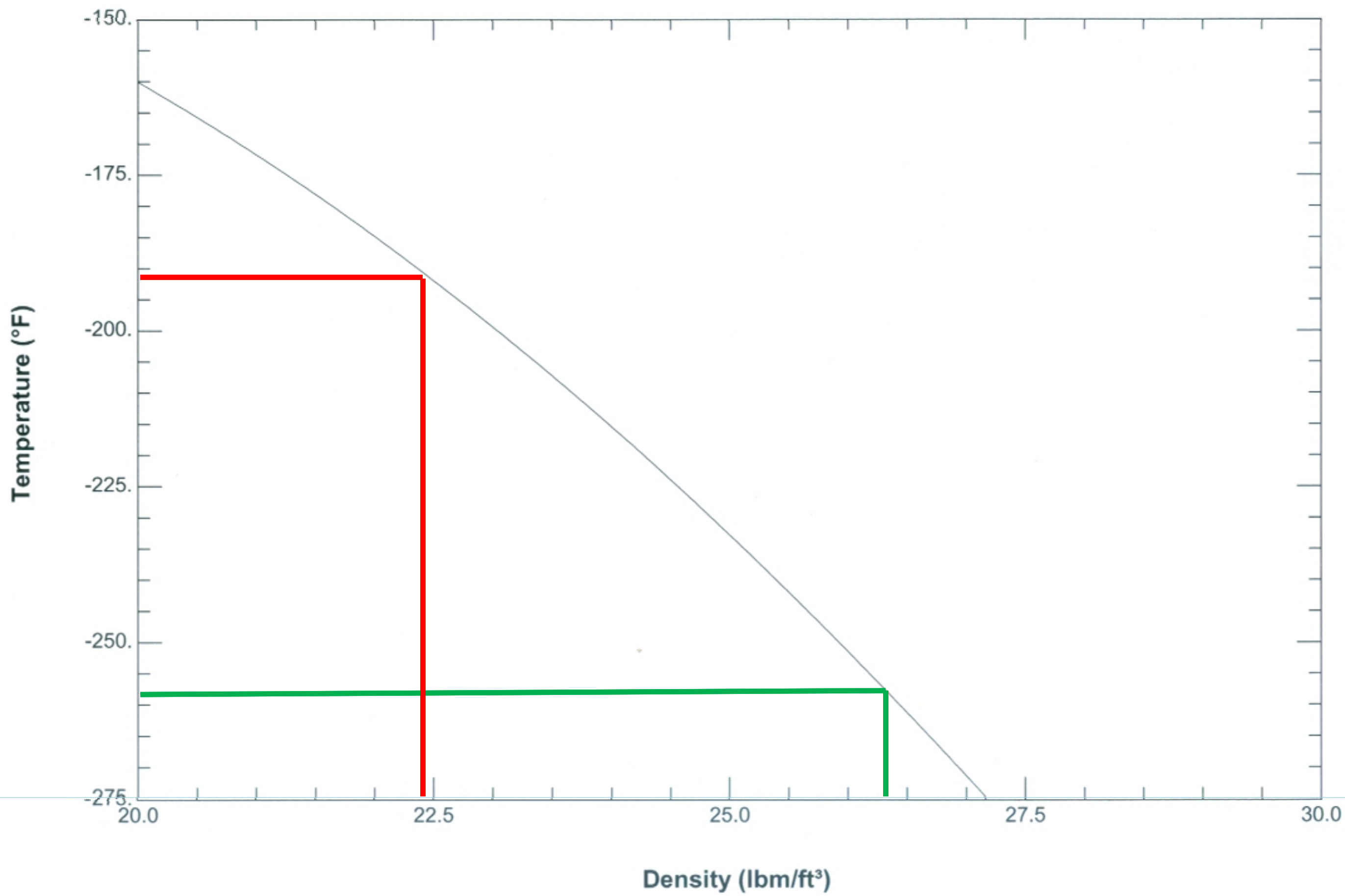
ρ_L = relative density of cargo at the loading temperature and pressure

Tank Load Limit = 84% (assumes pure CH_4)

LNG Tank Fill Limits



LNG Tank Fill Limits



LNG Weathering

- LNG enrichment with heavier hydrocarbons
- Preferential boil off
  - N_2 boils off first
  - CH_4 boils off next
- C_2H_6+ stays and increases in relative percentage
  - Nitrogen, N2, -320 ^oF
  - Methane - usually > 90%, CH4, -257.8 ^oF
  - Ethane, C2H6, -127 ^oF
  - Propane, C3H8, -44 ^oF
  - Butane, C4H10, 31.1 ^oF

LNG Weathering

- Increases heating value
- Decreases methane number
- Higher concentrations of heavier hydrocarbons in LNG supply aggravates the problem
- Ideally, “Fuel” grade LNG to be of high methane content, low nitrogen content and low heavy hydrocarbon content.
- Fuel from LNG imports could be a particular problem

Methane Number

- Analogous to gasoline Octane number
- Low methane number = increased potential for engine knock and/or engine de-rating
- Methane number does not equal percent of methane in the fuel gas stream
- Methane number is = to the percent of methane in a test fuel composed of methane and hydrogen

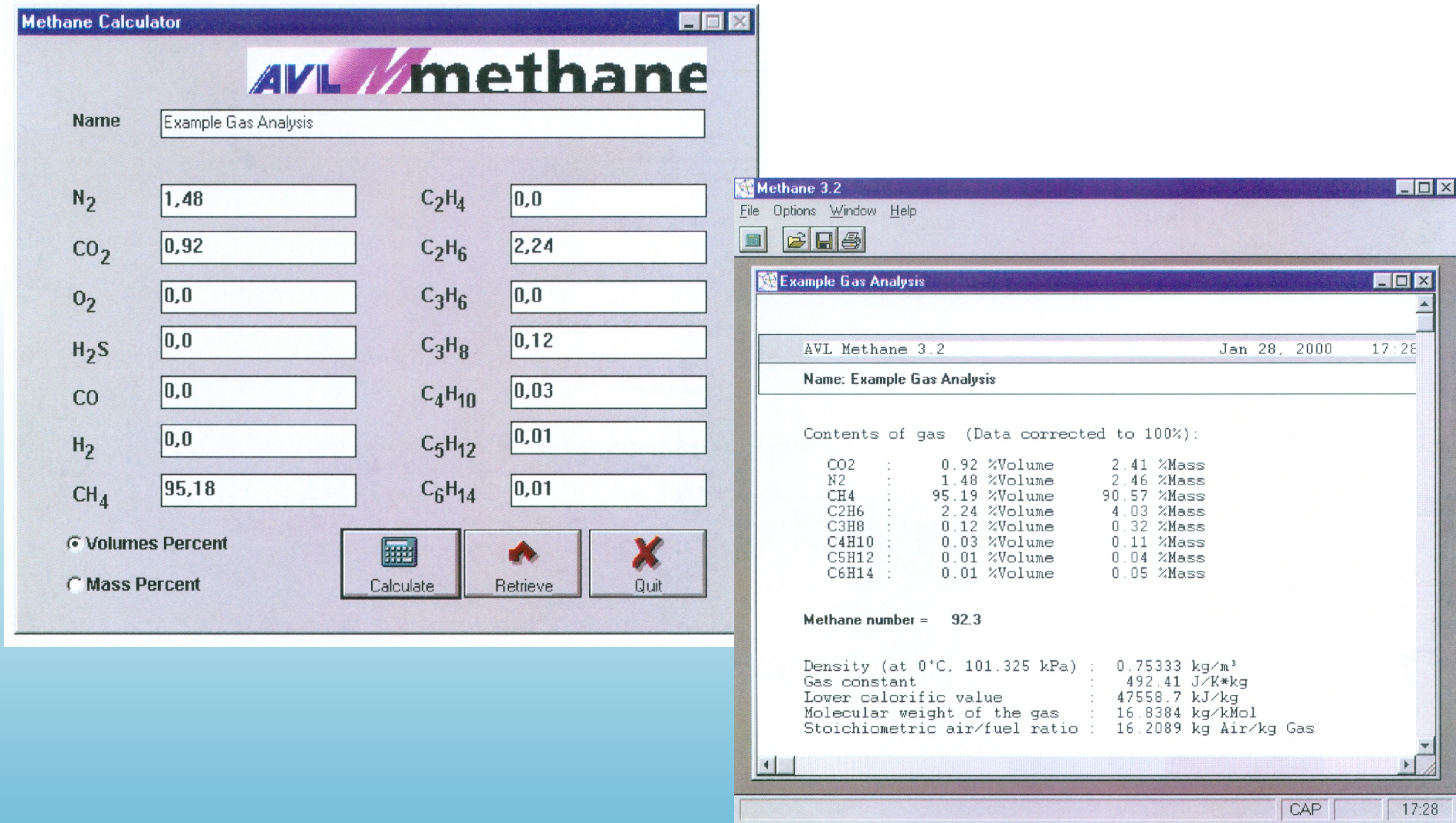
Methane Number

- Run candidate fuel in a test engine and increase compression ratio until knock occurs
- Substitute methane/hydrogen test fuel and decrease methane content until knock again occurs (compression ratio is not changed)
- Percent of methane in methane/hydrogen test fuel is the methane number for the tested gas fuel
- Not practical

Methane Number

- "AVL Methane" calculation software
  - Calculates methane number based on entered composition of gas fuel (not the composition of the LNG)
  - Estimation of methane number
  - Does not rigorously handle heavier hydrocarbons, C_4H_{10} (butane) and heavier are all treated as n-C_4H_{10}. Should not be issue with LNG derived fuel gas.
- Seek guidance from the engine manufacturer on fuel gas composition

Methane Number



Methane Number

Origin	N_2	C1	C2	C3	C4+	HV	MN
Algeria	0.9%	90.7%	7.7%	0.7%	0.0%	1077 BTU/scf	75
Nigeria	0.1%	91.3%	4.6%	2.6%	1.4%	1122 BTU/scf	66
Norway	0.8%	92.2%	5.3%	1.2%	0.5%	1018 BTU/scf	75
Trinidad	0.0%	96.8%	2.7%	0.3%	0.2%	1041 BTU/scf	87
Qatar	0.4%	90.1%	6.2%	2.3%	1.0%	1117 BTU/scf	67
Sakhalin	0.2%	92.7%	4.6%	2.1%	0.4%		71
U.S. Mean	1.5%	94.3%	2.7%	0.6%	0.4%	1035 BTU/scf	84
Marcellus	0.26%	97.1%	2.4%	0.1%	0.1%	1032 BTU/scf	90
Appalachian	2.4%	79.1%	17.7%	0.6%	0.1%	1133 BTU/scf	59
Eagle Ford	0.2%	74.6%	13.8%	5.4%	4.5%	1307 BTU/scf	42

Wobbe Index

- Index of combustion energy output of different fuel gases in an appliance (gas burner)
- If two fuels have same Wobbe Index then for given pressure and burner setting the energy output will be the same
- Not best index for gaseous fuel injection engines

$$I_w = HHV/(GAS_{sp\text{-}gr})^{1/2}$$

Commercial Considerations

- LNG Traditionally Sold on Heating Value
  - mmBTU ($/mmBTU)
  - Volume measured on ship (elaborate Custody Transfer protocols)
  - Gas sampled for analysis of heating value
- Vehicle Fuel sold on Volume Basis ($/gal)
  - Contract specification on fuel composition
  - Heating Value
  - Methane number
  - Some areas strict limit on ethane content
- Flow Meter for LNG Bunker Sales
  - Coriolis mass flow meters
- Methodology to Ensure Fuel is On Spec

LNG is a viable fuel alternative that can be managed safely

Thank You

Argent Marine Companies

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