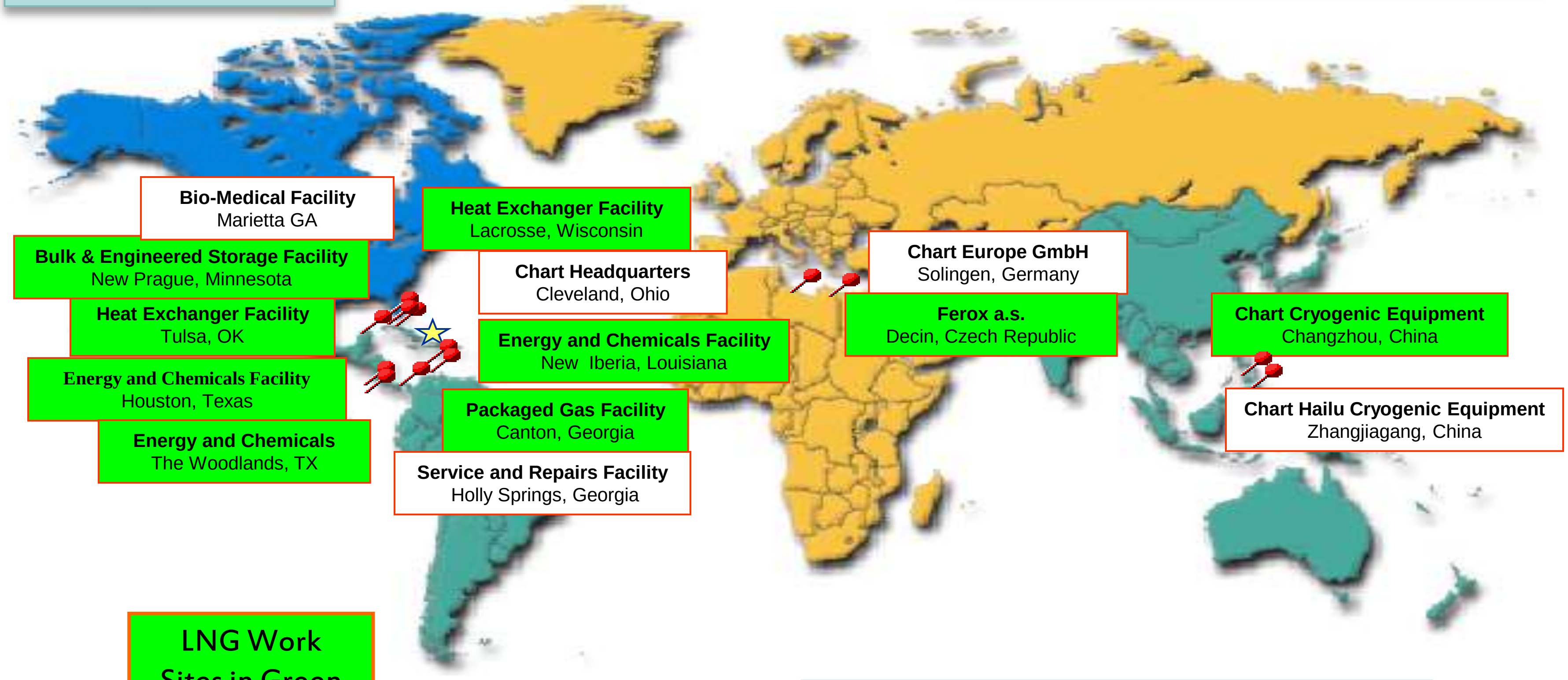
A SHORT PRIMER ON CRYOGENIC TANKS

The Society of Naval Architects and Marine Engineers

Great Lakes and Great Rivers Section, February 23 and 24, 2012

Chart started to build LNG systems in the early 1990's.

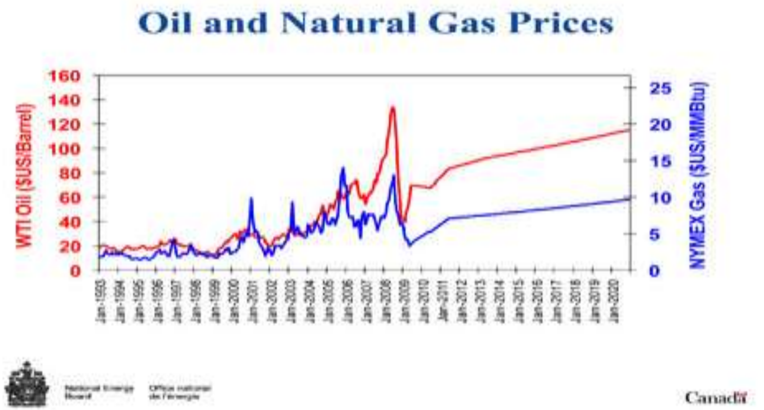
A bit about us....

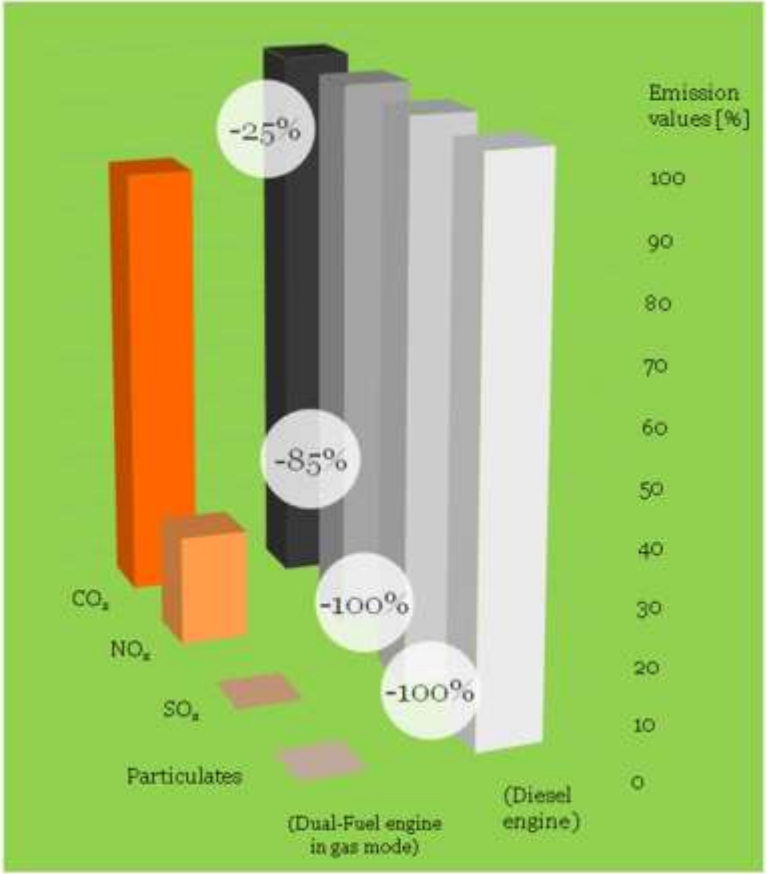


LNG Work Sites in Green

- We designs LNG tanks on three continents
- We design and build liquefiers in the US
- We design and build ship LNG tanks on two continents.

16 largest ships emit as much as all 800 million cars in the world. One ship can emit 5000 tons of sulfur per year
(source: The Guardian)

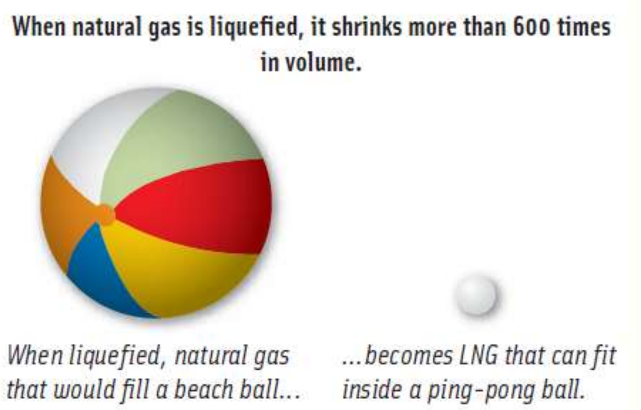




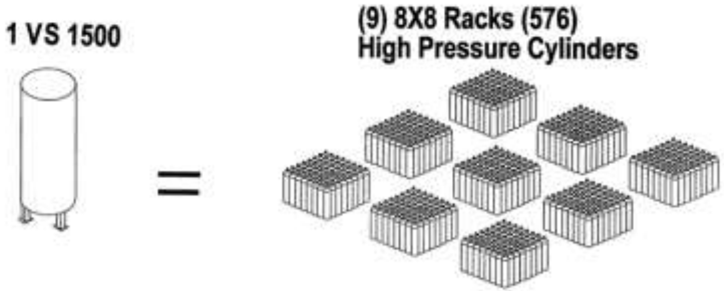
Why LNG?

- The *main* reason to liquefy a gas is for ease of storage and transportation.
- It lowers storage costs, since cryogenic storage is at low pressures.
- It is easier to pump a liquid than to compress a gas.
  - A 15 HP cryogenic pump replaces a 175 HP compressor.

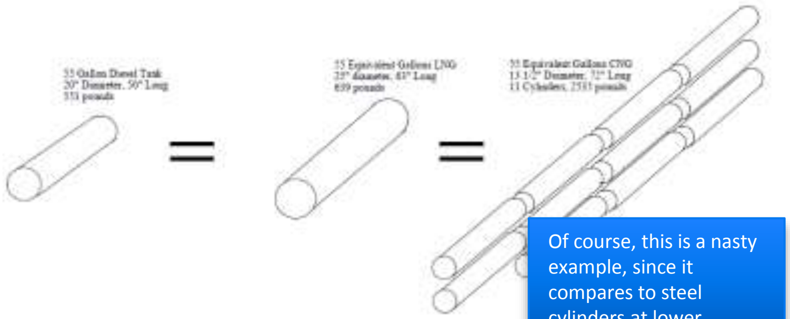
Volume reduction makes it easier to transport



Why Industry has switched to cryogenic storage…



And energy density applies to vehicle fuels…



Of course, this is a nasty example, since it compares to steel cylinders at lower pressures.

But of course, if you compare to Type IV cylinders, they'll take up only 3 to 4 times the space, and cost maybe 40% more.

Remember all fuels burn – or they wouldn't be a fuel…

Fuel	*Unit Energy Content* *BTU/US Gal*	*Mj/Liter*
No 2 Diesel	128,000	35.68
Biodiesel (B20)	117,000	32.61
Gasoline	109,000	30.38
LPG	84,000	23.41
Ethanol (E85)	80,000	22.30
LNG	73,500	20.49
Methanol (M85)	56,000	15.61
CNG (Compressed)	33,000	9.20
Hydrogen (Liquid)	30,500	8.50

Some fuel densities

Some basic notions

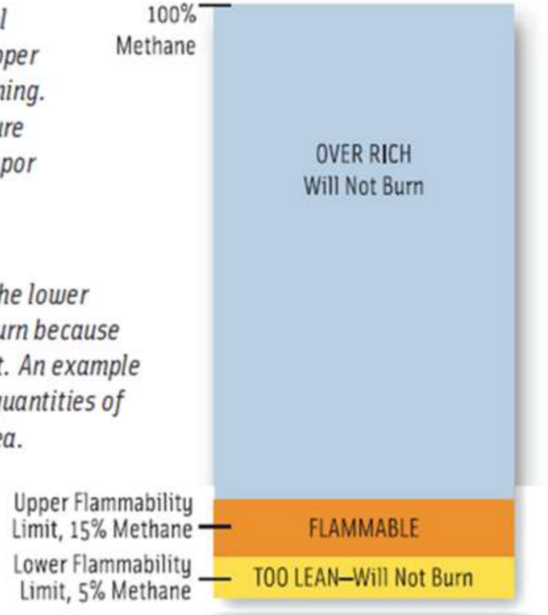
- LNG is primarily liquefied methane, with some ethane and propane.
    - Is has no moisture, oil, or <u>odor</u>.
- It is stored at a temperature of around -259 °F and pressures less than 250 PSIG.
- At room temperature it is lighter than air, and <u>quickly</u> dissipates.
- Primary hazards are:
    - It's very cold!
    - It can displace oxygen and act as an asphyxiant

LNG vapor has a limited flammability range.

The physical and chemical properties of LNG render it safer than other commonly used hydrocarbons.

Lack of oxygen prevents fuel concentrations above the upper flammability limit from burning. An example would be a secure storage tank with an LNG vapor concentration at or near 100 percent methane.

Fuel concentrations below the lower flammability limit cannot burn because too little methane is present. An example would be leakage of small quantities of LNG in a well-ventilated area.



http://www.fe.doe.gov/programs/oilgas/publications/lng/LNG_primerupd.pdf

The "Flat Bottomed" tank

- Stores very large volumes at no pressure. Generally cheapest at volumes above 3 billion gallons.

The Mobile Tanker Designed for Road or Rail

- Road tankers, ISO containers, Rail cars.

The Shop built Storage Tank.

- Vertical or horizontal pressure vessels.
- Volumes larger than 250,000 gallons are costly or impossible to transport.

Specialized tanks

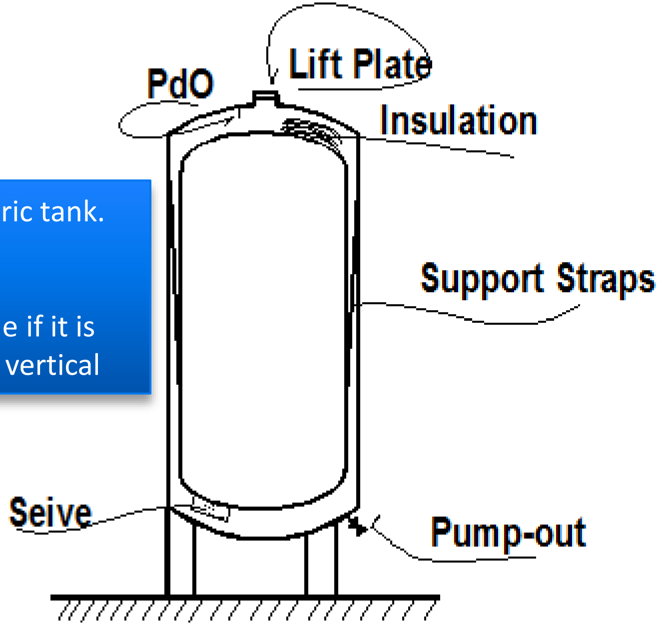
- Ship tanks, Vehicle tanks

KEY PARTS OF A CRYOGENIC TANK.

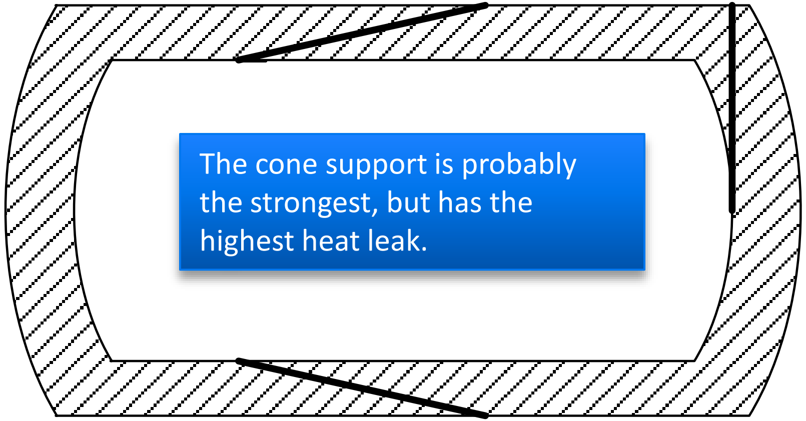
- Inside it is -256 °F, outside it is room temperature or higher. A difference of more than 300 degrees.
- Heat will transfer:
    1. By mechanical conduction – the bracing between the inner and the outer tank, and the piping between them.
    2. By Convection – i.e. the gas remaining in the Annular space. We reduce that by pulling a vacuum.
    3. By radiation – by using shine surfaces to reflect the radiation.
- So in tank design we make the mechanical components as thin as possible – just strong enough for the required conditions.
- We pull a vey high vacuum – less than 1 millionth of an atmosphere.
- We minimize radiating by applying multiple layers of reflective materials.

This is a generic tank.

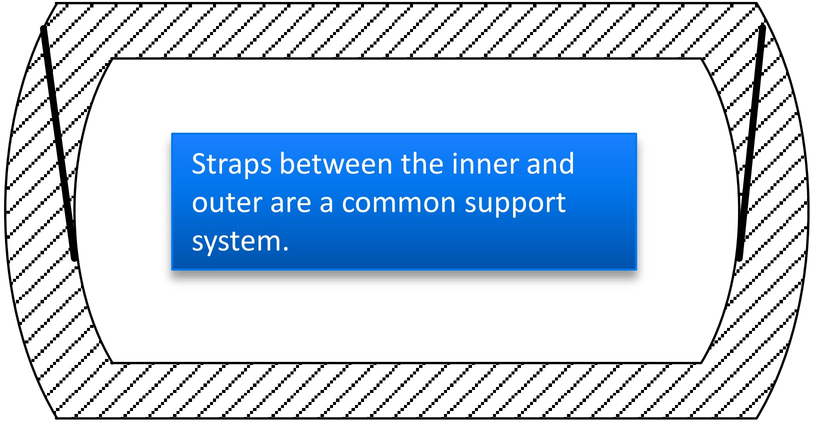
It is the same if it is horizontal or vertical



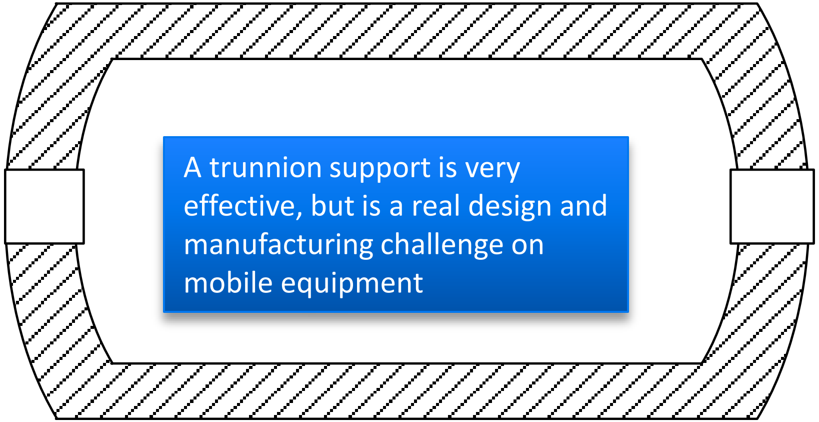
- **Most often used on mobile equipment**



- **Most often used on stationary tanks**



- **Used on mobile equipment and stationary tanks**



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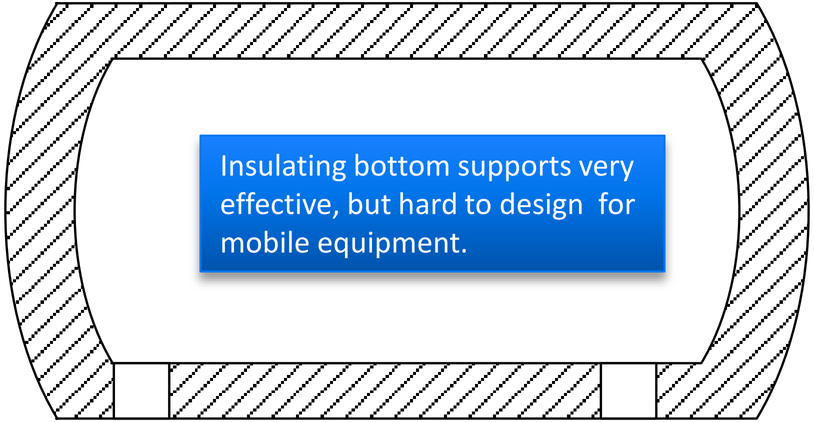
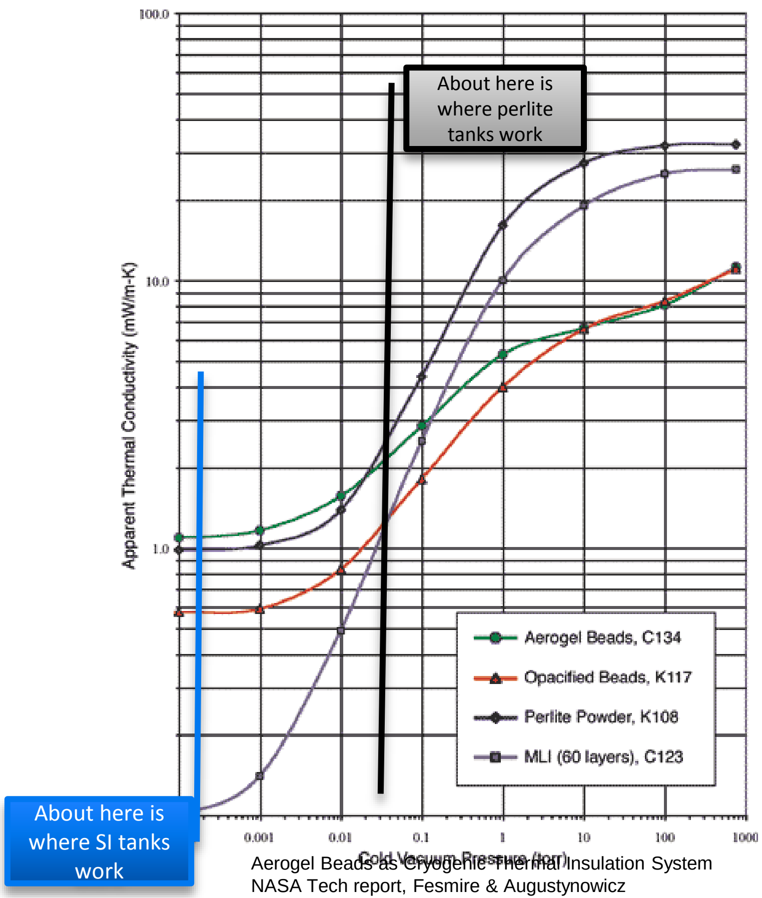


- To the right are the classic curves showing the effect of various types of insulation at various levels of vacuum on heat leak.
- The all follow a similar pattern…
  - At atmospheric pressure they are all poor insulators, though Aerogel is about twice as effective as perlite and SI.
  - As vacuum increases, they become rapidly more effective, with SI being most effective by a factor of 100 at the low ranges.
- Very low vacuum levels are achieved in a "cold" vacuum, when absorbents and getters in the vacuum space are most effective.
- Less effective insulation needs to be <u>thicker</u> to get the same insulating effect.



Aerogel Beads as Cryogenic Thermal Insulation System
NASA Tech report, Fesmire & Augustynowicz

Common insulations

Insulation	R value
Fiberglass without vacuum	6.4
Foam without vacuum	8.3
Powder without vacuum	6.2
Vacuum	25
Evacuated Perlite	60
Superinsulation	170

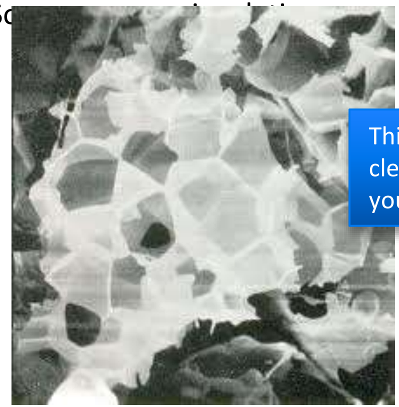
Cryogenic Insulations for the Distribution of Liquefied Gases. H. M. Lutgen, IOMA 1053

• Superinsulation

Lots of manufacturing
Technology needed
To do it right

• Perlite

- Sc



This is the same stuff – but cleaner and dryer – that you use in your garden.

• Foam

Foam insulation is generally prefabricated

- **All Tanks NEED…**

1. A liquid container of materials appropriate for low temperature.
2. Insulation to keep the liquid at that low temperature.
3. Safety devices to make sure that pressure's don't get higher than the container can handle.
4. A method to get the liquid into the tank
5. A means to get the liquid out of the tank.
6. A method to get excess gas out of the tank.
7. Instrumentation to find out what's happening.
8. An outer container to keep the insulation in place…

- **Tank Design NEEDS**

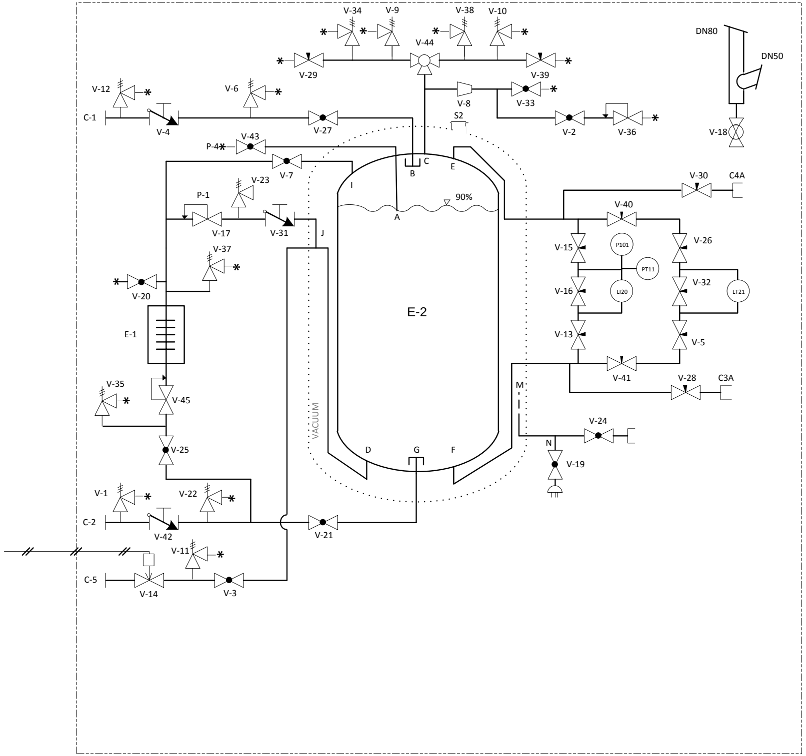
1. Designed to the proper Codes and regulations
2. To be strong enough to hold the liquid at some defined pressure.
3. Supports be strong enough to be transported from the factory to the destination.
4. In addition to be strong enough for any service conditions.
    1. Seismic, wind force, road forces, wave forces, vibration, heat, corrosion.
5. Thermally efficient design to keep the liquid cold as long as possible.
6. Proper safety features for normal operation.
7. Design for maintainability.
8. Application requirements, such as pump, high flow , etc. (

We once built a 15,000 gallon hydrogen tank designed to be emptied in five minutes or less.)

Some of the Basics

- Fill lines
  - Top and bottom fill lines if pressure needs to be constant during fill.
    - Top filling lowers pressure
    - Bottom filling raises pressure.
- Vent lines
  - Relief system
  - Vent system
- Pressure Control System
  - Regulators and vaporizers
- Instrumentation
- Product Withdrawal
  - As gas
  - As Liquid
- Gas safe vent system
- Possible re-cooling system.

Typical Piping Schematic



NER – the Boil Off Rate

- Thermal performance is usually stated in % per day of evaporated product at atmospheric pressure.
- Typical NER's on larger vacuum insulated tanks is on the order of 0.15 to 0.07 % of capacity per day.
- Thus a normal 15,000 gallon LNG tank will evaporate about 15 gallons of LNG per day due to thermal inefficiencies.
- Larger tanks will have lower heat leak as the volume increases faster than the surface area.

Holding Time

- A moving tank has a better non-venting holding time than a stationary tank.
- If the tank is not moving, the liquid will stratify – cold liquid will sink and warm liquid will rise. The pressure in a stratified tank is set by the warmest liquid on the top.
  - Typically, a larger cryogenic tank will rise in pressure around 3 to 5 PSI per day.
- A road tanker, that is moving and has liquid mixing, rises at around 1.5 PSI per day. They can have a OWTT of over 1,000 hours.

Filling tanks

- Consider that the field erected tanks commonly used in LNG storage are not pressure vessels, and any vapor formed needs to be handled and controlled.
- Shop built tanks – are pressure vessels – and are filled with a single hose from the top with cold liquid.
- This cold liquid recondenses any vapor in the vapor space and the pressure in the tank drops correspondingly.
- There is no practical limit to the top-fill rate, other than that it must become slower as the tank becomes fuller, in order not to overfill.
- Since the tanks are pressure vessels, no vapor needs to be handled – at worst, the liquid is stored at a slightly higher pressure/temperature.
- Large horizontal tanks – like the 250,000 gallon units we build – have a long spray bar to distribute cold liquid evenly along the length during filling.

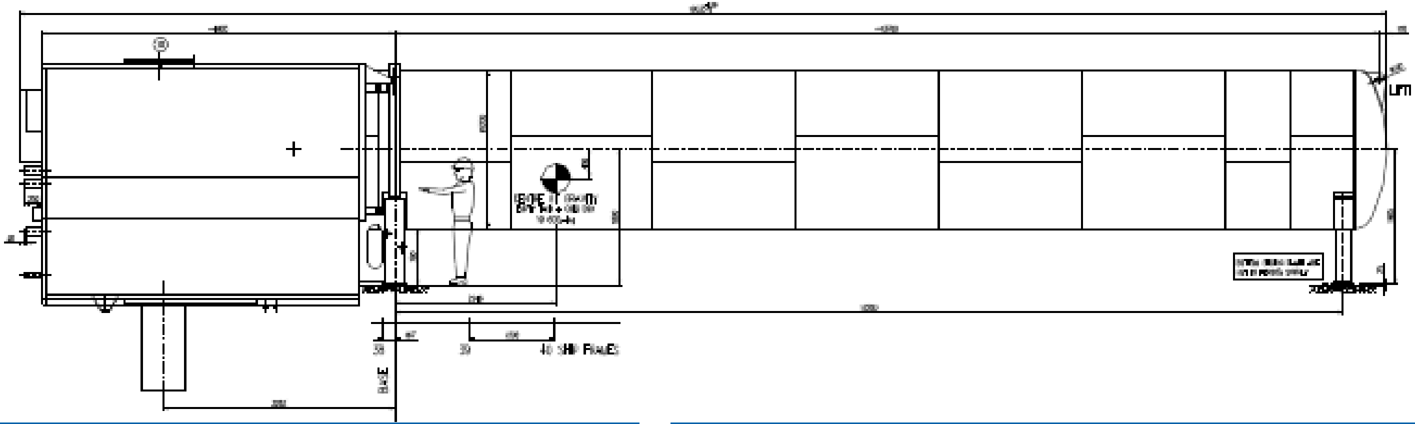
Tank Construction (2)

Some Key thoughts…

- Lines that are connected to the liquid side of the tank need to have vapor locks to prevent excessive heat transfer into the liquid.
- Pressurizing systems need to be sized for maximum withdrawal rates. And liquid flows into pressure building circuits by gravity only, so line sizing and routing is a challenge.
- Liquid to pump essentially flows by gravity. Traps in pump feed lines limit this flow.
- There is a lot of heat generated by pumps. Oversizing a pump is counterproductive.
- Stainless steel contracts about 1/32nds of an inch per foot when it cools. Improper design can rip things apart.
- Liquid trapped between two valves can generate much higher pressure than the burst pressure of a pipe. Proper cryogenic design always includes a thermal relief device between two lquid valves.
- Moving or sloshing will homogenize the liquid and remove any false pressure, stratification, or subcool.

In Practice

- We're designing and building the entire fuel system for the first high speed turbine driven ferry.
  http://www.incat.com.au/069VesselBrochure/index.html



• Key Points

- LNG Has no odor.
- Warm natural gas always rises.
- Need to ensure that no unwanted gas in unexpected areas, since there is no odor, nor is odor a reliable means of detection.
- Need to protect non-cryogenic steel piping in contact with LNG.

• Mitigation….

- Need to have gas detection.
- Need to have means to dilute natural gas concentrations
- Need to have protection in case of fire – inside or outside.
- All stainless construction acts as containment, and is impervious to spills or cold cracking.
- All key connections fail closed.
- Piping is either vacuum insulated, or purged double walled piping.

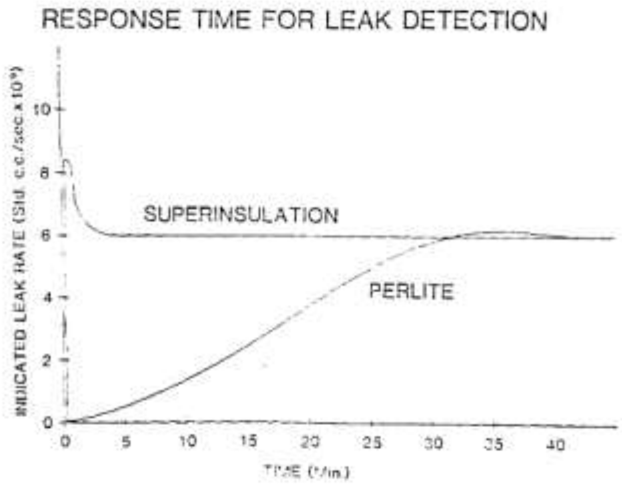
Component selection is limited. Not that many companies manufacture DNV certified valves, for example.

And the ones that do charge accordingly.

The piping is enclosed in a fire proof (or at least resistant, purged control room

The safety record of double walled cryogenic tanks has been exceptional. And LNG is just another cryogenic liquid. Some say it is safer than Liquid Oxygen.

- Typically, ASME pressure vessels that are in a vacuum – i.e. a non-corrosive environment - are used a minimum of 30 years. We sometimes refurbish piping of tanks built in the 60's
- In order of priority, vacuum or performance is affected because:
    1. The vacuum gauge is removed or exchanged improperly causing a slow vacuum leak.
    2. Insulation has settled. This happens with perlite, not with SI.
    3. An outer leak on the jacket, due to thermal cycling or contact with cryogen.
    4. A leak on the annular piping, due to thermal cycling.
    5. A inner tank leak.
- Leaks are very easy to find on super insulated tank.
- And all leaks are easy to fix once they are found.



Non-Jacketed Tanks

- There is no effect, since there is no vacuum to loose.
- But there is a lot of insulation between inner and outer tank.

Vacuum jacketed Tanks

- Rapid loss of efficiency as annular space pressures approach 1 atm.
- Heat leak is in proportion to insulation thickness.
- Since vacuum insulation (perlite or SI) is so effective, only a small distance of insulation is needed.
- When vacuum is lost the insulation reverts back to that of a thin non-jacketed tank.

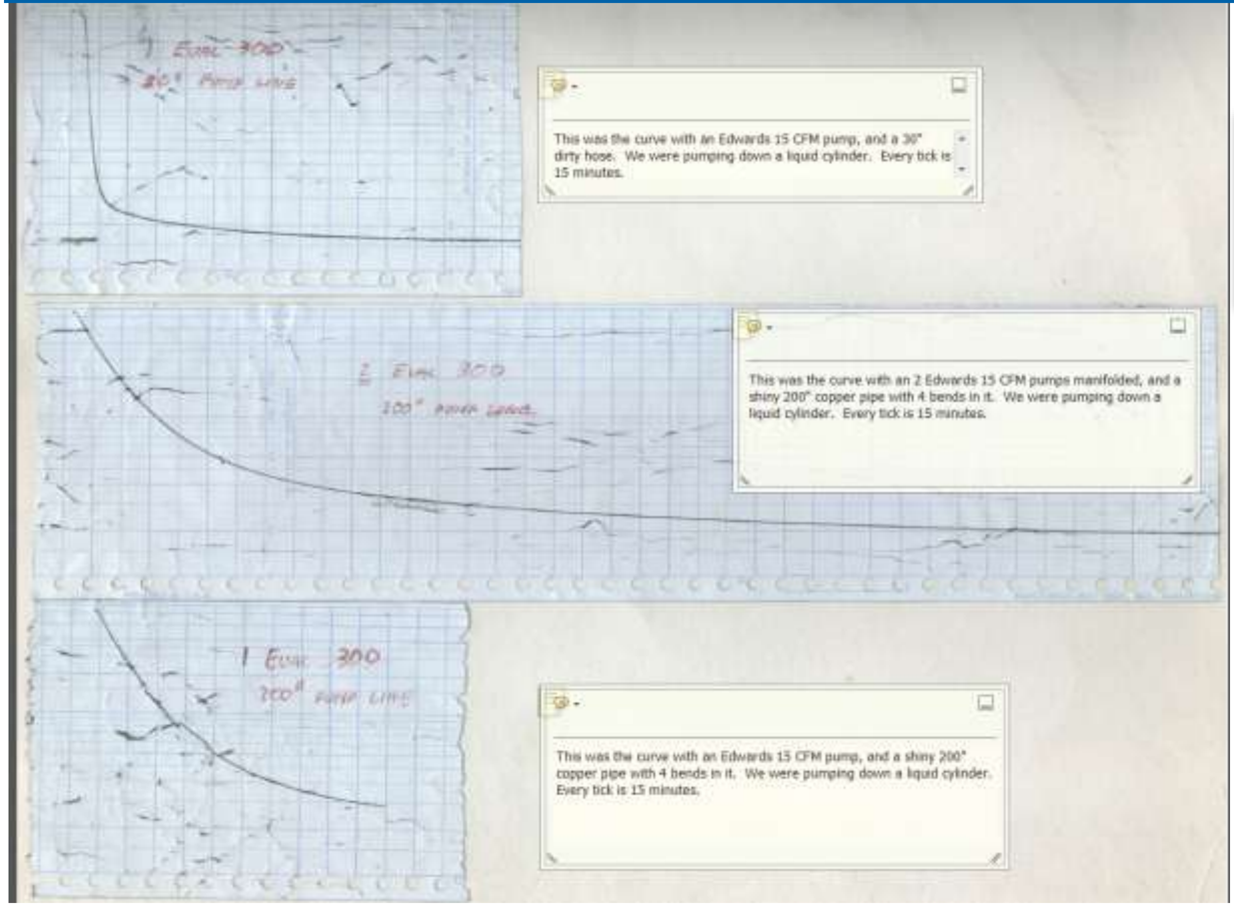
• To restore vacuum

Restoring vacuum on a jacketed tank is easy.

1. Use Helium to determine location of leak if it is too small to be seen or heard.
    1. Fast with SI Tanks
    2. A bit more laborious and slower with perlite.
2. Fix leak
3. Replace getters
4. Reactivate absorbents with heat and vacuum.

• Equipment

- Good for finding leaks down to 10-8 cc of helium/sec.
- That number is almost meaninglessly small. Moisture can temporarily plug that hole.
- And a small pump, up close, has faster pumping speeds than a big one far away.
- Getting molecules out at high vacuum is like having a drunk find a small door in the dark…



And you didn't believe me about small pumps....