THE ECONOMICS OF THE LNG VALUE CHAIN….

LNG: Siting a Twin Ports Liquefaction Plant

University of Wisconsin-Superior, Yellowjacket Student Union, Great Room
1605 Catlin Ave, Superior WI 54880---Tuesday, May 21, 2013

Taylor-Wharton

Taylor Wharton – not just any company….

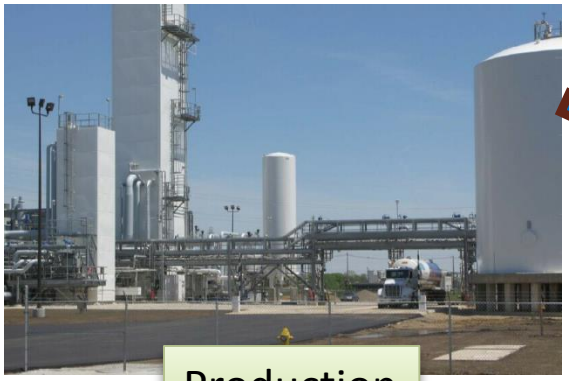
- Built first liquid oxygen rail cars in 1937
- Built the first liquid cylinder in the late ‘50’s
- Invented the first cryogenic refrigerator for biological samples in 1957.
- In the late ‘50’s invented production SI while working with NASA.
- Developed and built LNG fueling systems in the 60’s.
- Built the first 110,000 gallon shop built vacuum insulated tank in the US in the early ‘90’s
- Offering the first SD tanks in the US – 264,000+ gallons. And we’ll take orders for larger ones!

Some things you didn’t know…

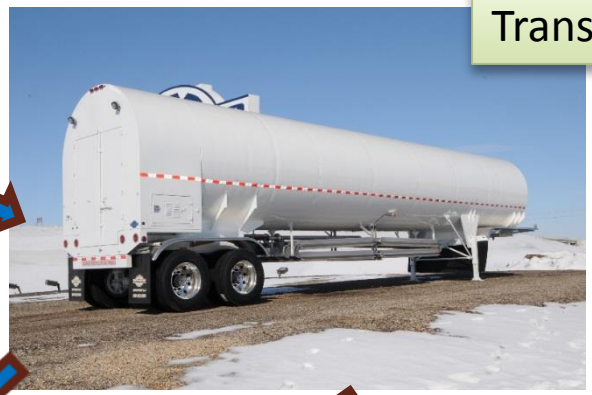
- We’re the oldest manufacturing company in the US.
- Anecdotally - we made cannon balls for George Washington….

- Our cryogenic systems…
  - Safely hold and store the Ebola virus…
  - Transfer liquid hydrogen to rocket tanks…
  - Provide you with life saving oxygen in the hospital.
  - Freeze your food
  - Fizz your soft drink

The value chain we're going to talk about today…..

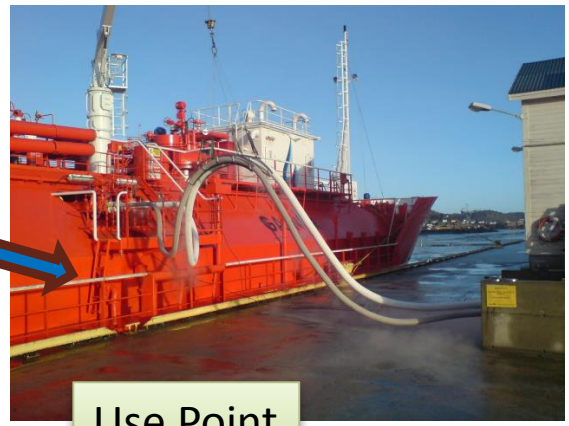


Production



Transport

Storage



Use Point

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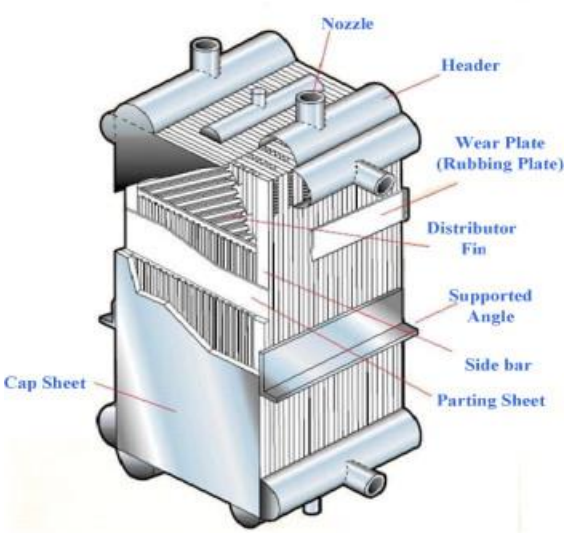
- Major components to an LNG liquefier are the compressor, the heat exchanger and the cleanup.
- Circulating cold fluid through heat exchanger cools down and eventually liquefies the natural gas stream.
- For greatest energy efficiency, the fluid temperature should be close to the methane temperature as it cools and liquefies. Lots of compressor energy needed to cool the fluid, and it needn't be colder than just enough to cool the natural gas at each step of the way.
- Two key metrics – capital costs and operating costs. CAPEX and OPEX.
- And the largest single item on the OPEX side is the specific power consumption –i.e. how many kilowatts to make a certain amount of LNG.

Brazed Aluminum Heat Exchanger



http://dx.doi.org/10.1016/j.applthermaleng.2007.03.032

Coiled Tubing Heat Exchanger

http://resources.linde.com/international/web/linde/like35lindecom.nsf/0/0B7A61ED38095909C125729E0053E803/$file/Completion_Heat_Exchangerdown.jpg

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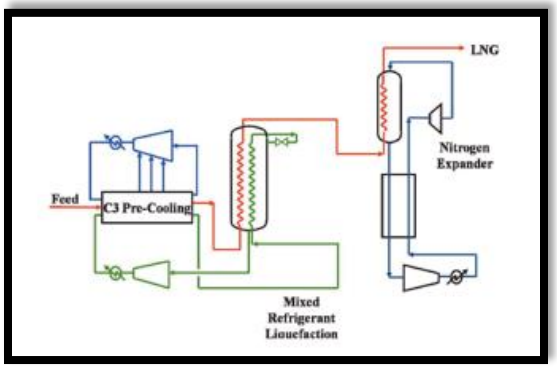
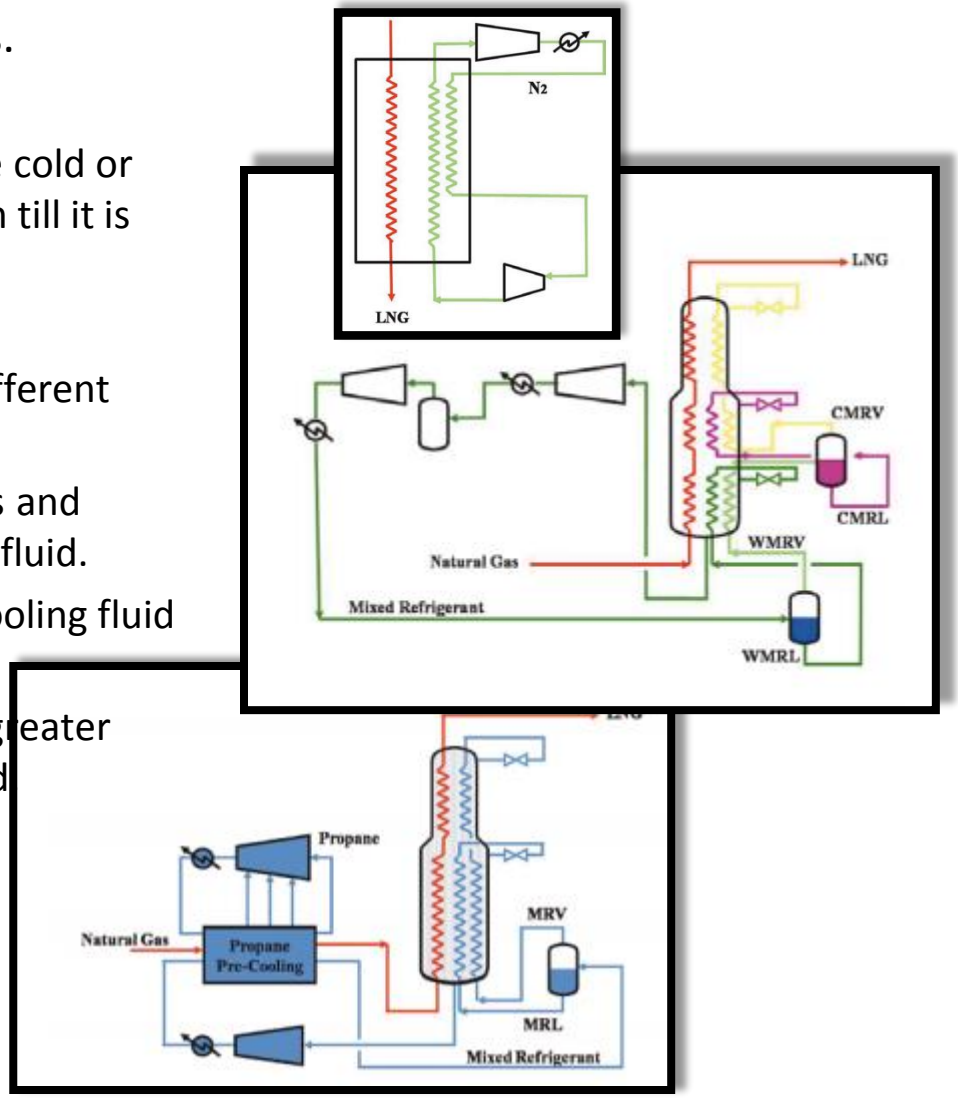
Liquefiers have different process cycles.

- The simplest is the nitrogen cycle, where cold or liquid nitrogen chills a natural gas stream till it is liquid.
  - Not very efficient.
- Cascade system – multiple streams of different fluids at various temperatures.
  - Expensive, as multiple compressors and interchangers are needed for each fluid.
- Mixed Refrigerants are blended into a cooling fluid that has matches methane's needs.
  - More highly skilled operators and greater complexity to make up correct fluid





Source: http://www.airproducts.com/~/media/Files/PDF/industries/lng-selecting-suitable-process-technology-liquefaction-natural-gas.pdf

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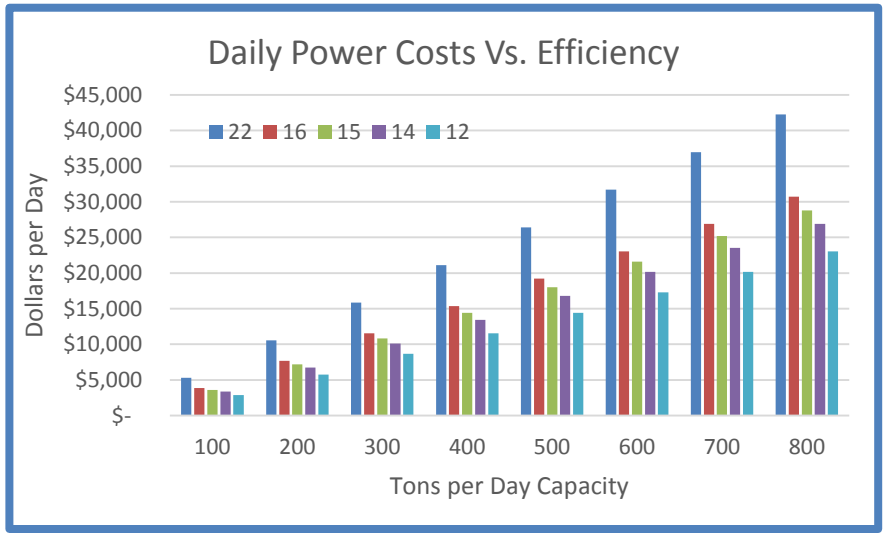
Kilowatts per Ton Per day Capacity

- N2 Expansion 22
- Single Mixed Refrigerant 16
- Propane Mixed Refrigerant 13
- Cascade 12
- Turn Town NA

Converting Kw/ton to dollars per day…

- So, assuming a N2 Expansion Cycle, and a 100 Tons per day, at a power cost of $0.10 per Kwh.
- Or a cascade cycle for the same capacity

Kw/TPD	24 Hrs/Day		hrs/Day		kw hrs/ton												
22	kw x day / TON	x	24	hrs / day	=	528	kw hrs / ton	x	100	Tons / day	=	52,800	kw hr / day	x	0.10	$ / Kw hr	=	$ 5,280	$ / day
Kw/TPD	24 Hrs/Day		hrs/Day		kw hrs/ton												
12	kw x day / TON	x	24	hrs / day	=	288	kw hrs / ton	x	100	Tons / day	=	28,800	kw hr / day	x	0.10	$ / Kw hr	=	$ 2,880	$ / day



- Efficiency comes at a price however
  - Greater Capital Costs
  - Higher Labor costs
- Efficient plants are more complex
  - Requires higher skill labor
  - More spares
  - More space
- The take home is that it generally pays to have the most efficient plant, even if it is more expensive.

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Plant Pricing

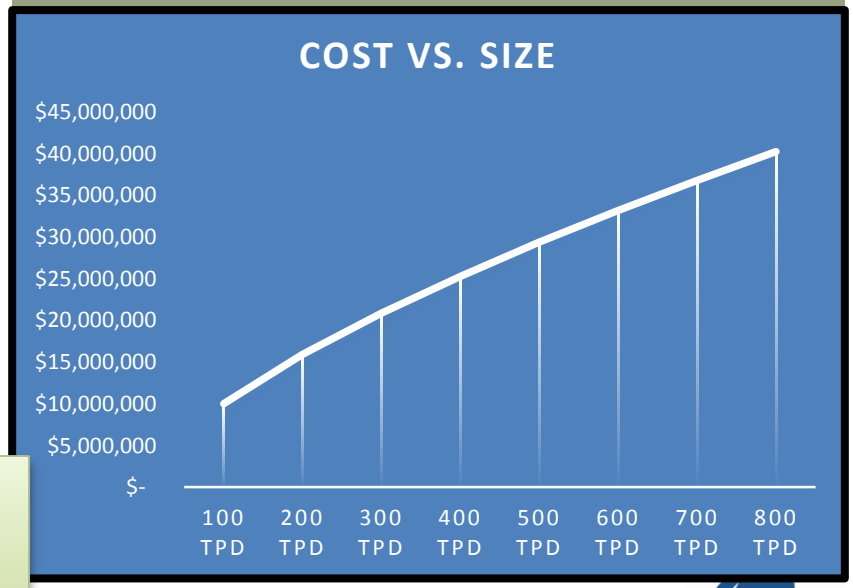
- Pricing a liquefier depends on many factors.
  - Gas supply pressure
  - Gas composition
  - Ambient temperatures
  - Height above sea level.
  - Storage pressure.
  - Purity required.
  - Turndown.
  - Power costs
- For example
  - It takes less energy to manufacture LNG stored at three atmospheres than at one.
  - Cleanup systems to remove water and carbon dioxide can add up to a significant part of the cost of the plant.
  - A liquefier will liquefy all components of the gas – so if you need to take out propane and ethane that requires additional distillation columns.

For budgeting

$$\text{Cost}_{\text{Size 2}} = \text{Cost}_{\text{Size 1}}(\text{Cost}_{\text{Size 2}}/\text{Cost}_{\text{Size 1}})^{.67}$$

- This is a common generic relationship for incremental cost vs. incremental size.
  - Generally a factor of 0.67 is accepted.

Starting with a 100 TPD plant selling for 10,000,000 Dollars…



I used 10 million dollars for a 100 TPD plant. This is just an illustrative example, and is not a quoted price

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But wait – there's more costs

In addition to the plant and cleanup systems to produce LNG, also needed are:

- Storage tanks – generally 5 to 10 days of production….
- Possibly storage for byproducts if ethane and propane are separated.
- Truck and/or rail loading systems
- Possible ship bunkering systems
- Power plant or substation
- Offices and workshops
- Possible refrigerant mixing systems.
- Permitting
  - Hazops, environmental studies, etc. etc.
- Spares
- Installation,

- This generally equals 100 to 125% of the cost of the plant.

• Equipment to source from Taylor Wharton.

- Equipment to source from Taylor Wharton:
  - Storage tanks – generally 5 to 10 days of production….
  - ~~Possibly storage for byproducts if ethane and propane are separated~~.
  - Truck and/or rail loading systems
  - Ship bunkering systems
  - ~~Power plant or substation~~
  - ~~Offices and workshops~~
  - ~~Possible refrigerant mixing systems.~~
  - ~~Permitting~~
    - ~~Hazops, environmental studies, etc. etc.~~
  - ~~Spares~~
  - Installation (TW Equipment only)
  - Transport tanks – road, rail, sea.
  - End user systems..
    - Ship tanks
    - Vaporizing Stations
    - Fuel tanks
    - Bunkering systems or stations

BUT WAIT – THAT'S ONLY HALF OF IT….

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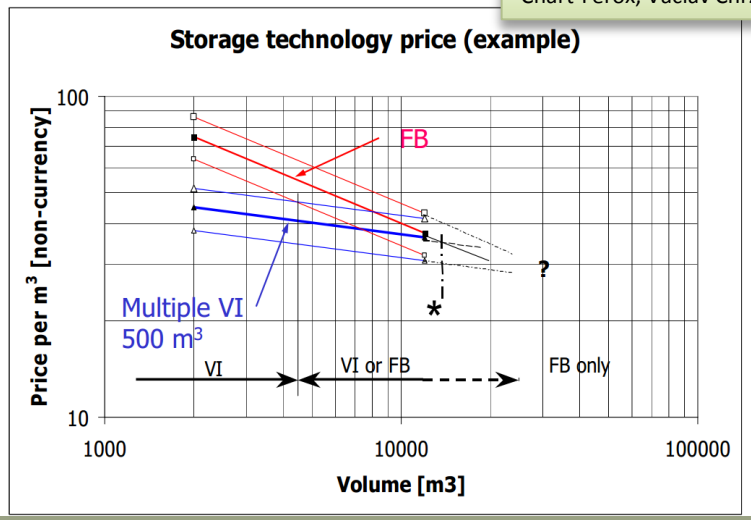
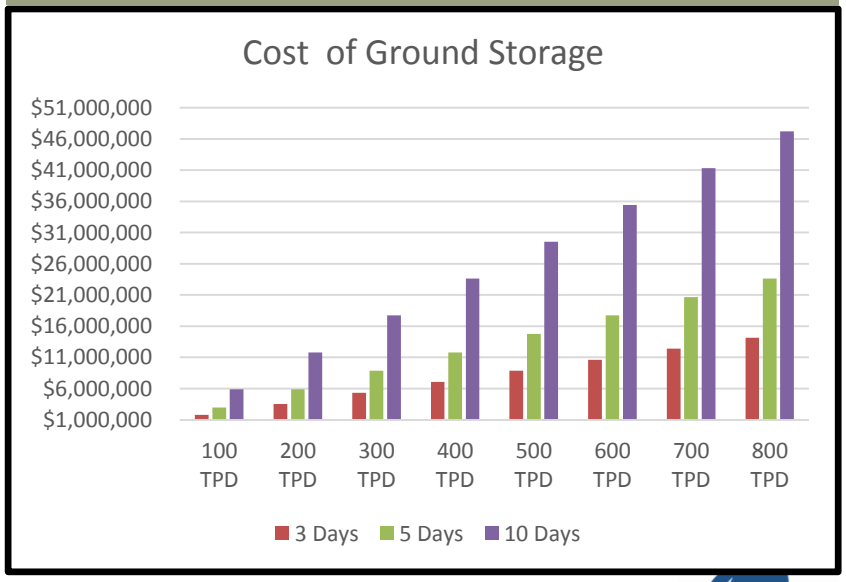
World's first 11,000 gallon vacuum insulated tank leaving our factory

Economic Comparison

Chart-Ferox, Vaclav Chrz.



- Up to a certain storage volume, it is cheaper to use shop built tanks than a flat bottom, site erected tank.
- Have the advantage of being able to hold liquid under pressure – thus no rollover or weathering.
- Can grow with need – additional tanks can be added as required.
- Can store lower cost saturated liquid production.
- …though transportation can be a challenge.



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RELATIVE TANK SIZES

265,000 gallon (1,003,100 L)

162' (49m)

Ø 20' (6m)

Largest LNG tank delivered over water to site.

110,000 gallon (416,400 L)

Smaller & inland liquefiers use these size tanks

30,000 gallon (113,600 L)

Largest tanks that can be transported over land to sites

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- The cost of transporting LNG is the same as transporting any other product.
- Insulations based on Taylor Wharton's insulation developments in the 50's allow for extended travel:
  - Trailers : > 1,000 hours
  - ISO's: > 1,440 hours
  - Railcars > 1,680 hours.
- Loading is relatively rapid:
  - 50 minutes with a cold unit
  - 300+ minutes with a warm unit.
- Unloading usually takes about an hour, with another hour of hose and pump cool-down and connection operations.
- HAZMAT operators are required.
- Cargo and travel must be planned to prevent venting and product loss.
- In most cases, pump transfer results in the lowest transfer losses.
- Special care must be taken when circulating with a cold but empty transport. Warm up of the remaining liquid heel can cause unplanned pressure rise.

Trailers can carry about 10,600 gallons in the US

EDL Road Train in Australia

Railcars can carry about 30,000 gallons in the US

Chart Ind. LNG Railcar

ISO's can carry around 10,000 gallons in the US.

Wessington Rugged service LNG ISO.

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Natural gas at 350 PSI, 24/7, off pipeline

- A tank farm system to drive a turbine genset 24/7.
- Multiple tanks allow growth with demand
- And they allow maintenance without taking the whole system down.

Storage for natural gas for boilers.

- A tank farm for storage, designed for growth.

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- LNG storage and vaporizing system, with spill containment.

- Notice the pressure transfer trailer offload skid.
- This is a low pressure gas application.
- Dual vaporizers allow switching for deriming for 24/7 operation.

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Trailer, ISO, and Rail car filling.

- Trailers are loaded with relatively cold liquid – you cant cheat the heat. Any heat gain must be considered in the shelf life of LNG.
- This is a lossless operation.
  - Warm trailer are vented back into the storage tank and its vapor recovery system during filling.
  - Cold trailers are simply top filled.
- Custody transfer is usually done by weight. The trucks are standing on a truck scale that provides info for a computerized fill process.
- Filling takes significantly less than an hour. The exact speed depends on the storage tank's sendout pumps.

4 Trailer Loading bay at Distrigas' Everett terminal

Two bay loading system at AES, Dominican Republic

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TW roofmount tanks being skidded by FAB Industries (now AGILITY) for buses

Fuel tank at Hardstaff, in the UK

- We have manufactured vehicle tanks being used on buses, trucks, and mining vehicles.
- We have ongoing research and development to increase the storage capacity of tanks to the theoretical maximum of available space.
- We are particularly focuses on increasing the reliability of vehicle tanks in the harshest environments of mines and off-road vehicles.

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- The shipboard system can be bunkered in several ways…
  - Ship to ship
  - Trailer to ship
  - Ground to ship.
- Trailer to ship bunkering is limited by the capacity of pump that fits onto a trailer – generally maxing out at 300 GPM.
- Ship to ship and ground to ship bunkering is generally limited by line size and distances causing increasing pressure drop.
- For longer distances, increasing pipe diameters increases:
  - Costs
  - Cool down time and cool down losses.
  - Design challenges due to thermal shrinkage from the 300+ degree temperature drop.

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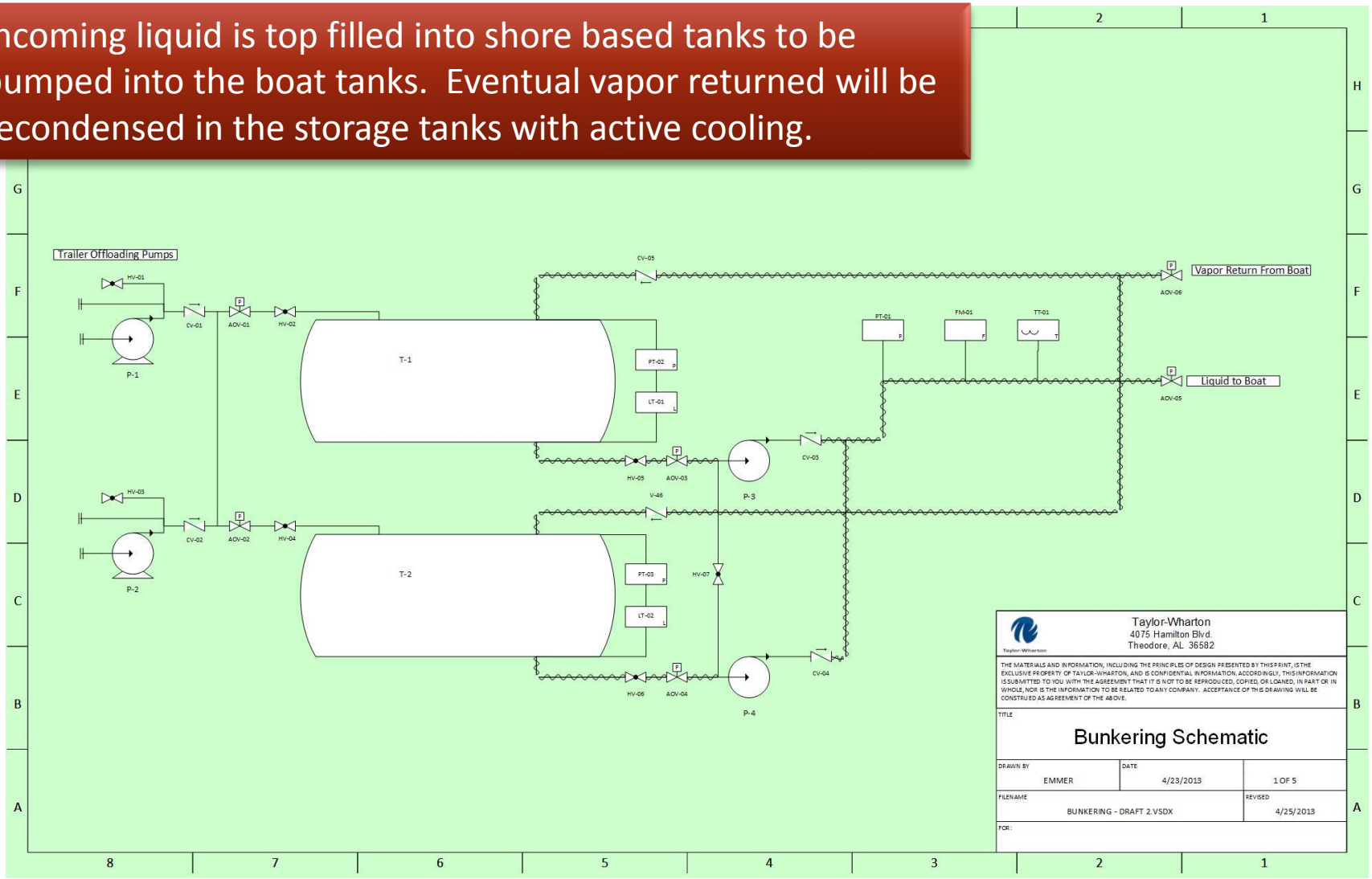
Incoming liquid is top filled into shore based tanks to be pumped into the boat tanks. Eventual vapor returned will be recondensed in the storage tanks with active cooling.



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- Taylor Wharton and our team members can provide innovative cutting edge technologies to solve the challenges that modern LNG applications require.
- We can design, manufacture, and install all equipment between the liquefier spigot to the end us application point.
- We can provide this equipment built to a variety of codes and requirements in the US, Europe, and China.

Thank You

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- http://dx.doi.org/10.1016/j.applthermaleng.2007.03.032 **Optimal design approach for the plate-fin heat exchangers using neural networks cooperated with genetic algorithms**
- **http://www.airproducts.com/~/media/Files/PDF/industries/lng-selecting-suitable-process-technology-liquefaction-natural-gas.pdf Selecting a suitable process.**
- http://resources.linde.com/international/web/linde/like35lindecom.nsf/0/0B7A61ED38095909C125729E0053E803/$file/Completion_Heat_Exchangerdown.jpg Spiral heat exchanger manufacture – Linde AG
- http://www.gasener.com/images/FLAT_BOTTOM_OR_VACUUM_INSULATED_TANKS.pdf FLAT BOTTOM OR VACUUM INSULATED TANKS? VACLAV CHRZ, JIRI KRIVAN, PETR ZARUBA, JIRI ZEMAN Chart-Ferox, a.s.

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