# LNG on the Rails – Precursor to LH2 on the Rails?

# Cryogenics on the Rails

LNG Fuel Tenders for fueling Locomotives:


Tank Cars for hauling Liquid Hydrogen, Ethylene and Ar/O2/N2 LNG by rail:

# Tenders and Tank Cars

Chart Lifecycle, Inc.

## Progress Made / History

- Chart Active in Several Past and Present Tender and Transport Projects
  - 1961-present:  AAR-204W and DOT-113 Tank Cars
    - Liquid Ethylene (flammable) in DOT-113 tank cars
    - Argon, Oxygen, Nitrogen (non-flammable) in AAR-204W and 113 cars
    - (1960s / 70s) Liquid Hydrogen – 20 cars; Praxair (UCC) and Nasa
  - 1994: Union Pacific LNG Fuel Tender
  - 2012-2013: Canadian National LNG Fuel Tender
  - 2012-2017: Burlington Northern LNG Fuel Tenders
  - 2014: Chart 28,000 gallon tank car style tender
  - 2014: Transport Canada approves LNG by rail – tank car and ISO
  - 2015-present:  Chart ISO container style LNG Fuel Tenders in service
  - 2015: Alaska RR receives SP to carry LNG by rail in ISO containers
  - 2016: Alaska RR runs demonstration loads of LNG by rail
    AAR Petition for Rulemaking - LNG in DOT-113C120W tank cars
  - 2017: Extensive Use of tenders at FECR
    AAR NGFT Standards Published
  - 2018-2019: FECR LNG fuel tenders continue
    US DOT approval process moving forward (HM-264) for LNG TC

# LNG on the Rails – Ready to Go!

Chart Lifecycle, Inc.

28,000 Gallon (106 m³) Tank Car Style LNG Fuel Tender


11,000 Gallon (41.6 m³) ISO Container Style LNG Fuel Tender

# Railroads are moving to LNG


Florida East Coast Railway locomotives from GE with LNG tender

- Chart LNG Fuel Tenders
  - *Provide clean burning, domestically produced natural gas to one or two freight locomotives*
  - *displacing up to 80% of the diesel fuel required to power the locomotive.*
- Chart LNG and Cryogenic Tank Cars


- WHY LNG as a Fuel:
  - *Lower cost than Diesel*
  - *Cleaner burning*
  - *Abundantly Available*

- WHY LH2 as a Fuel:
  - *Very clean – zero emissions*
  - *Lower cost than diesel – someday ?*
  - *Abundantly Available*
    *…. In water*
    *…. In natural gas*
    *…. As a by product….*

# Chart Cryogenic Tank Cars

Chart Lifecycle, Inc.

## Progress Made / History

- Chart Active in Several Past and Present Cryogenic Tank Car Projects
  - 1961-present:  AAR-204W and DOT-113 Tank Cars

←34,500 Gallon (130.6 M3) DOT-113C120W Tank Cars for LNG, Liquid Ethylene or Liquid Ethane; LH2?

DOT-113A90W Tank Cars for Liquid Argon, Liquid Oxygen and Liquid Nitrogen →

# Chart Cryogenic Tank Cars


Chart teamed up with VTG, a leading rail logistic company, to develop cryogenic tank cars for the European network

Chart Vacuum Technology® provides the best insulation system to protect product loss and is at the core of why Chart is recognised as the premier supplier of cryogenic equipment solutions

# Chart LNG Fuel Tenders

CHART
Chart Lifecycle, Inc.


1990's Burlington Northern


1994 Union Pacific

2012-13 Canadian National

# Chart LNG Fuel Tenders

Chart Lifecycle, Inc.

# Chart LNG Fuel Tenders

Chart Lifecycle, Inc.

**Basic Operation:**

- Mechanical and Electrical Connections between Locomotive and Tender
  - Locomotive sends a ‘Gas Request’
  - Glycol supply and return within acceptable parameters
  - Pressurizing the gas supply system – for pump transfer, pressure transfer or ‘economizer’ transfer
  - “Tender Ready” signal is given and gas can be supplied to one or both locomotives

# Chart LNG Fuel Tenders

Chart Lifecycle, Inc.

**Basic Operation (continued):**

- PLC system monitors pressures, temperatures, locomotive signals
- Safety systems shut down the tender when required
- HMI allows visualization and adjustment of operating parameters
- PLC can be connected to remote telemetry for 'back room' monitoring of tender status and performance

# Chart LNG Fuel Tenders

Chart Lifecycle, Inc.


# Chart LNG Fuel Tender Challenges

Chart Lifecycle, Inc.

**Structural challenges:**

- Purpose Built Rail Wagon (similar in shape and appearance to a well car, but much, much more robust)
  - Excellent performance to date
  - Crashworthiness:
    - 45 MPH head on collision
    - 40 mph, 80,000 lb truck side impact
- Piping components; vacuum penetrations to tank
  - Several loss of vacuum incidents
    - But no direct loss of gas; no safety relief valve openings
  - Extended stem cryogenic valve leaks / failures
  - Pressure, temperature, flow component failures
  - ‘breakaway‘ device failures
  - Piping cracks
- Telemetry alerts operating personnel to abnormal conditions
- Trained personnel address the issue prior to any significant gas loss

# Chart LNG Fuel Tender Challenges

**Operational challenges:**

- Pumps – not so simple to ramp up and down on demand with cryogenic liquids
- Pressure building – low supply pressures; sloshing liquid; small lines
- Durability of PLCs; VFDs
- Operational coordination between tender and locomotive

# Chart LNG Fuel Tender Challenges

Chart Lifecycle, Inc.

**Other challenges:**

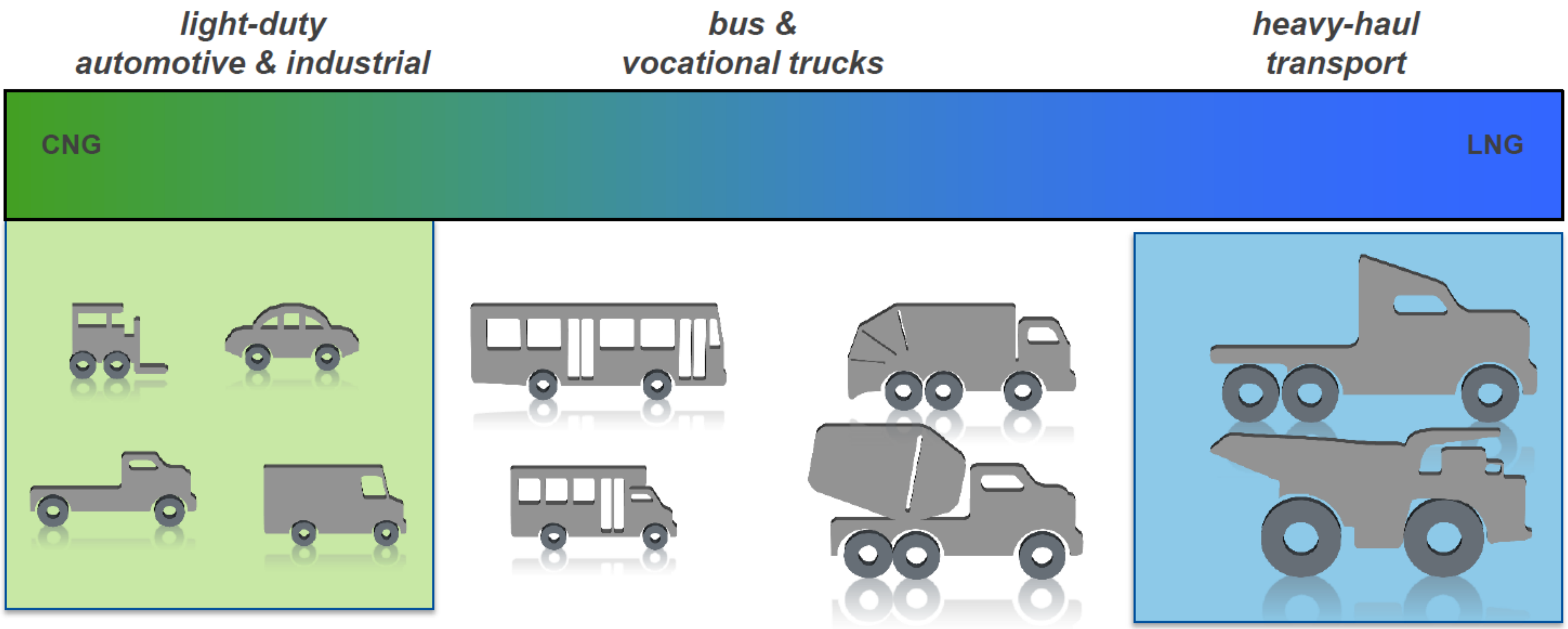
- Lack of familiarity with cryogenic fuels
  - LNG handles differently than diesel
  - LH2 can be even more different
    - Colder; wider flammability range; small molecule
    - Less dense; more buoyant; invisible flame

- New, additional safety training and emergency response personnel and equipment required.

**Table II: Physical and Combustion Property Values for Hydrogen and Methane.**

| Quantity | Hydrogen | Methane |
|---|---|---|
| Molecular Weight | 2.016 | 16.043 |
| Density of Gas at NTP, kg/m³ | 0.08376 | 0.65119 |
| Temperature to Achieve NTP Neutral Buoyancy in Air (1.204 kg/m³), K | 22.07 | 164.3 |
| Normal Boiling Point (NBP), K | 20 | 111 |
| Liquid Density at NBP, g/L | 71 | 422 |
| Enthalpy of Vaporization at NBP, kJ/mole | 0.92 | 8.5 |
| Lower Heating Value, MJ/kg | 119.96 | 50.02 |
| Limits of Flammability in Air, vol% | 4 – 75 | 5.3 - 15 |
| Explosive Limits in Air, vol% | 18.3 – 59.0 | 6.3 – 13.5 |
| Minimum Spontaneous Ignition Pressure, bar | ~ 41 | ~ 100 |
| Stoichiometric Composition in Air, vol% | 29.53 | 9.48 |
| Minimum Ignition Energy, J | 0.02 | 0.29 |
| Flame Temperature in Air, K | 2318 | 2148 |
| Autoignition Temperature, K | 858 | 813 |
| Burning Velocity in NTP Air, m/s | 2.6 – 3.2 | 0.37 – 0.45 |
| Diffusivity in Air, cm²/s | 0.63 | 0.2 |

# LNG & CNG Vehicle Fueling

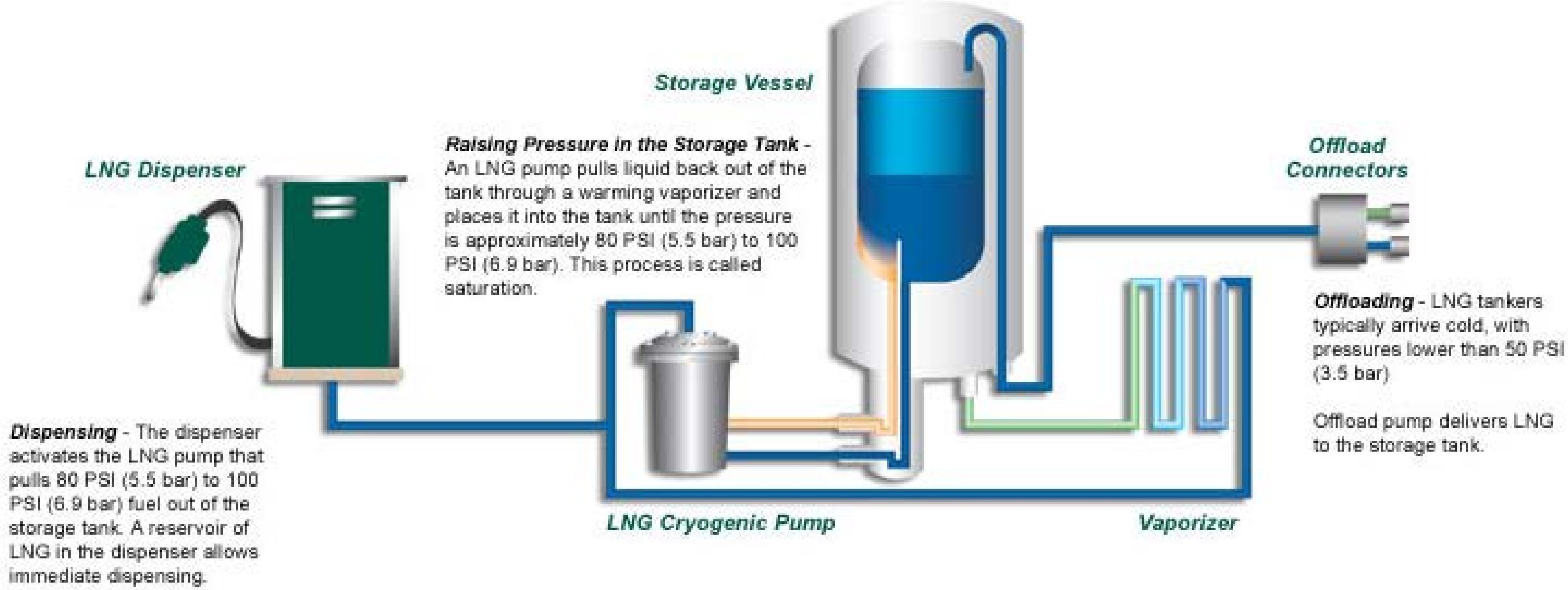


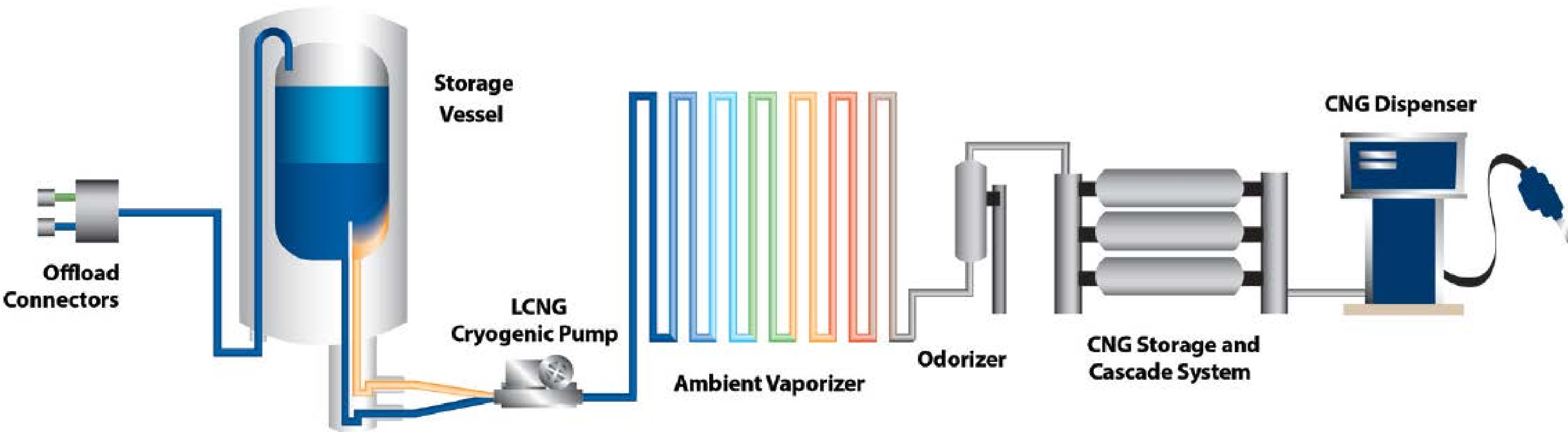
# LNG & CNG Vehicle Fueling

## LNG compared to CNG – Heavy Duty Applications

- Highest energy density
  - Less space & weight required
  - Longer driving range
- Faster filling speeds
- Easily scalable infrastructure
- Lower maintenance/ongoing costs
  - Longer tank life expectancy
- Lower electricity costs at fuel stations

# LCNG Option


Storage Vessel
Raising Pressure in the Storage Tank - An LNG pump pulls liquid back out of the tank through a warming vaporizer and places it into the tank until the pressure is approximately 80 PSI (5.5 bar) to 100 PSI (6.9 bar). This process is called saturation.
LNG Dispenser
Offload Connectors
Offloading - LNG tankers typically arrive cold, with pressures lower than 50 PSI (3.5 bar)
Offload pump delivers LNG to the storage tank.
Dispensing - The dispenser activates the LNG pump that pulls 80 PSI (5.5 bar) to 100 PSI (6.9 bar) fuel out of the storage tank. A reservoir of LNG in the dispenser allows immediate dispensing.
LNG Cryogenic Pump
Vaporizer


Storage Vessel
CNG Dispenser
Offload Connectors
LCNG Cryogenic Pump
Ambient Vaporizer
Odorizer
CNG Storage and Cascade System

# Comparing to Hydrogen

- Most Natural Gas fueling is done via pumping
- Most Hydrogen fueling today is done via pressure transfer
    - Bulk transfer of $GH_2$ and $LH_2$
    - On-road $H_2$ stations have pumps/compressor(s) that slowly fill high-pressure buffer tanks, but flow through dispenser is PT
    - Current pumps/compressors are too slow for direct fueling
    - Challenges with speed of fill and gas temperature
- Physical properties of $H_2$ make it difficult to pump
    - “Easier” to pump $LH_2$ vs. $GH_2$
    - But fewer $LH_2$ pump options than $GH_2$ compression options

# Comparing to Hydrogen

Hydrogen rail fueling possibilities:

- $LH_2$ tenders
  - Use bulk trailers or tanks to fuel – Pump or PT
- $GH_2$ tenders
  - Use tube trailers – PT
  - Or possibility of a “L-$GH_2$” fuel station? – Pump

Thank you for your attention.

If you have further questions or comments, please contact us directly:

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Higher NER with Hydrogen vs. LNG

Liquid air formation on uninsulated Liquid Hydrogen lines