LINCOLN COMPOSITES

Tank Manufacturing, Testing, Deployment, and Field Performance

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LINCOLN COMPOSITES
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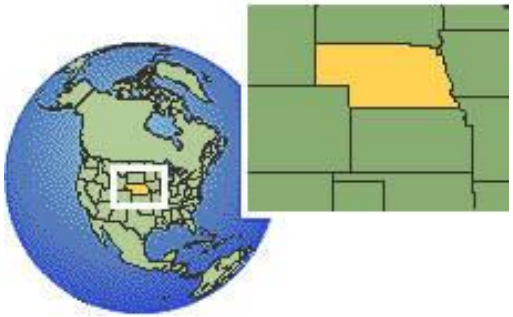
Lincoln Composites, Inc.

- Founded in 1963 in Lincoln, Nebraska
- Previously part of:
  - Brunswick Corporation–Defense Division (1963–1995)
  - Technical Products Group, Inc. (1995–1997)
  - Advanced Technical Products, Inc. (1997–2002)
  - General Dynamics Armament and Technical Products (GDATP) (2002–2005)
- Became Lincoln Composites, Inc. following purchase of GDATP commercial operations by Hexagon Composites Group of Norway on January 21, 2005



BRUNSWICK COMPOSITES

ATP LINCOLN COMPOSITES

GENERAL DYNAMICS
Armament and Technical Products

HEXAGON COMPOSITES

LC Pressure Vessel Background

- Aerospace
  - Skylab Oxygen Tanks
  - Sikorsky S-76 Floatation
  - Space Shuttle He, N2, O2
  - Titan Trans-Stage
  - Shuttle Launch Dispenser PV
  - Titan Centaur
- Defense
  - F-16 & X-29 EPU
  - Pershing Missile
  - F-111 Crew Module
  - UH-60 and EH-101 PV
  - Navy Life Raft Inflation
  - F-18 External Fuel Tank
- Rocket Motor Cases
  - Polaris
  - Minuteman
  - MX/Peacekeeper
  - IUS/Orbus
  - Trident D-5
  - Pac-3

- Commercial
  - NGV Fuel Containers
  - Hydraulic Accumulators
  - Hydrogen Fuel Containers
  - Stationary Cascades
  - Boeing 767 Escape Slide PV
  - Tube Trailers

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LC Pressure Vessel Background

- Over 80 configurations
- Liner types: aluminum, Inconel, titanium, carbon steel, stainless steel, rubber, plastic
- Fiber types: glass, aramid, carbon
- Type 2, Type 3, and Type 4 construction
- Over 180,000 pressure vessels in service
- Volumes from 65 cc to 8500 L
- Operating pressures from 35 bar to 1725 bar
- Burst pressures up to 3450 bar
- First ASME Section X pressure vessel

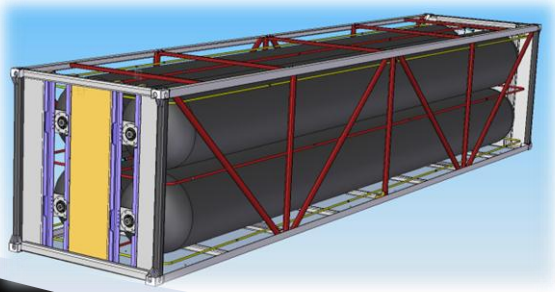
Lincoln Composites' Markets

- Compressed Energy Storage
  - Natural Gas Vehicles
  - Fuel Cell Vehicles
  - Accumulators
    - Industrial
    - Vehicle
  - Stationary (Fill Stations)
- Compressed Energy Transport
  - Road
  - Rail
  - Sea

natural gas

H_2

Low Emission
Hydraulic Hybrid



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NGV Fuel Tank History

ISO 9001

DNV

REGISTERED

TUFFSHELL®

Beginnings

- Development initiated in 1990
- 1st Type 4 Tank Certified to ANSI/AGA NGV2

Certifications

- NGV2
- FMVSS 304
- CSA B-51
- ISO 11439
- KHK
- ECE R110
- TUV

Parameters

- CNG Operating Pressures of 207 & 248 bar
- CH2 Operating Pressures from 250 to 700 bar

Proven History

- 17 Years of Service History
- Approximately 100,000 tanks in service

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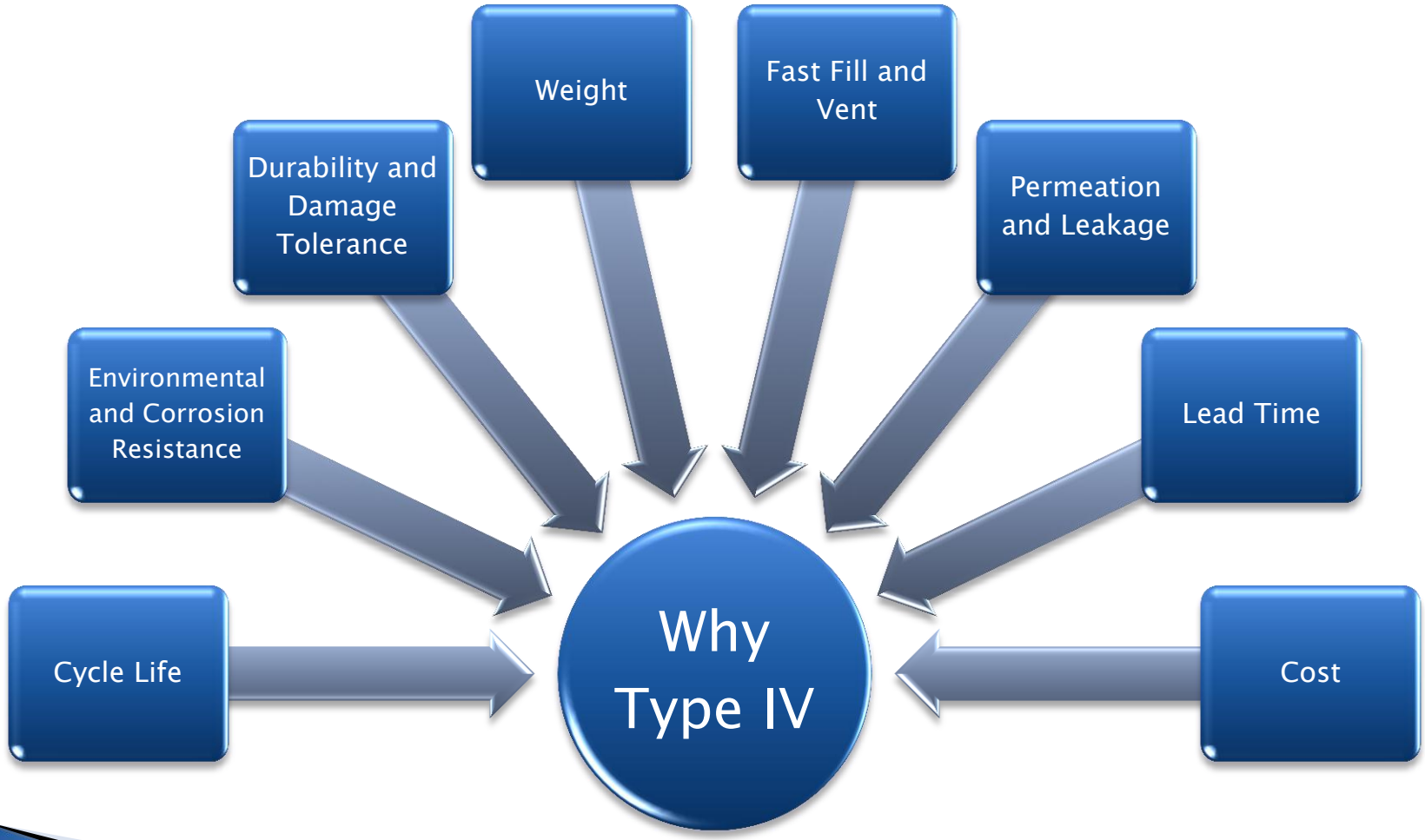
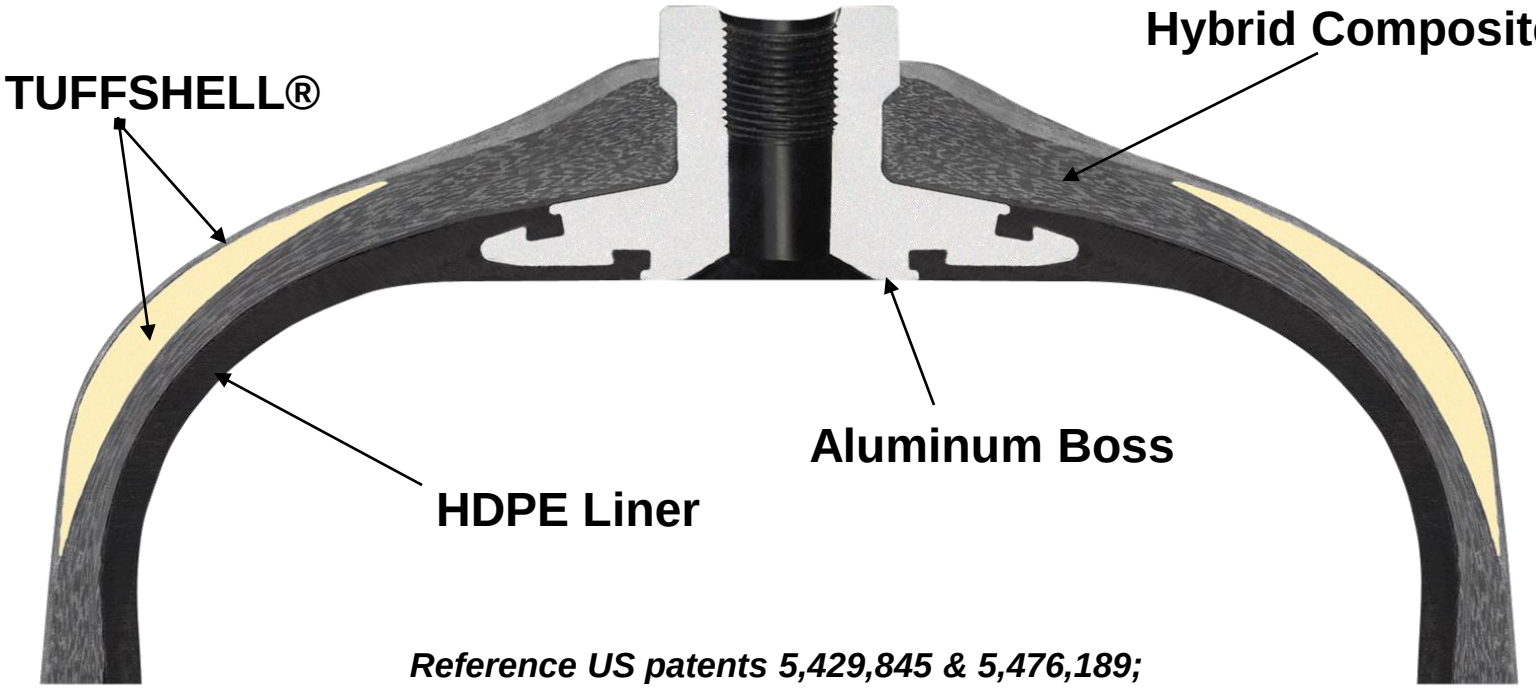
Type 4 versus Type 1, 2, 3



TUFFSHELL™ Tank Details



Reference US patents 5,429,845 & 5,476,189; and International Patents

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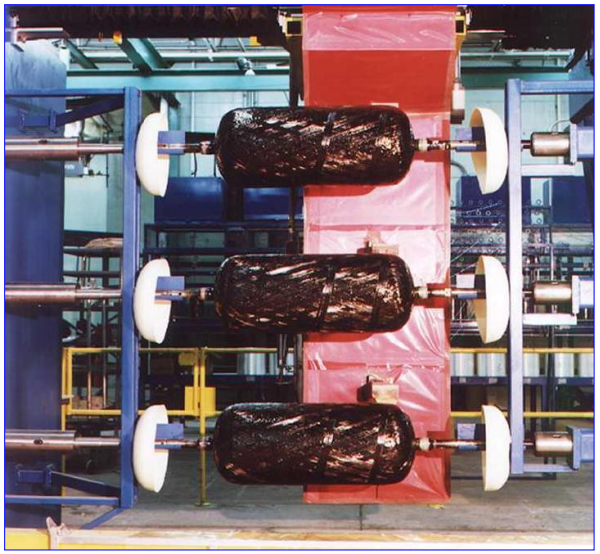
Manufacturing Process

- Manufacture liner components
- Assemble liner
- Wind composite
- Cure composite
- Proof test
- Leak test
- Final inspection



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CNG Tank Packs for Buses

- Complete Roof-top Systems for buses
  - 1 or 2 Packs per bus
  - Wide range of standard configurations are available

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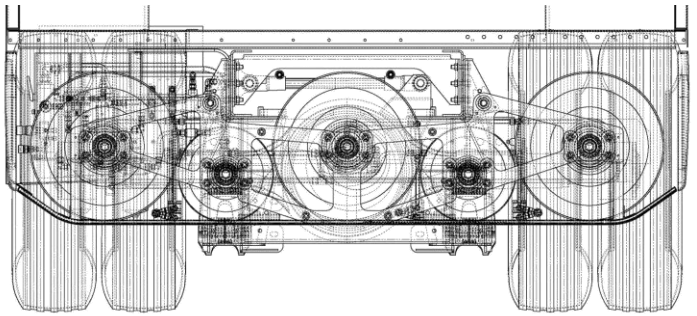
CNG Tank Packs for Trucks

- Tank Pack Systems for “behind the cab” mounting.
- Tank Pack Systems for frame rail mounting.



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CNG Tanks for cars/trucks

- Trunk mounting or underbody mounting

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TUFFSHELL™ CHG Experience

- Two Neoplan Buses in Germany use four (4) roof-mounted tanks per bus (Certified by TÜV @ 250 bar)
- Delivered 350 and 500 bar cylinders to Honda for stationary fill application (HES)
- DOE contract through Johns Hopkins University for a H_2 integrated storage system (HISS)
- Delivered (>300 tanks) 700 Bar cylinders for fuel cell lift trucks
- Delivered 700 bar tanks to GTI and Shell for stationary H_2 cascade
- Delivered 500 and 950 bar tanks with PED approval

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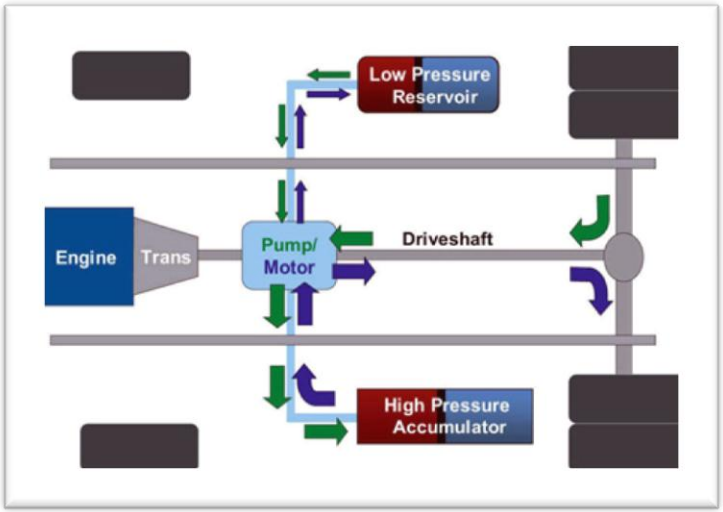
High Pressure Accumulators
(Hydraulic Launch Assist)

- Energy Recovery drive system offers significant fuel savings and increased efficiency
  - System replaces current transmissions with a hydro-mechanical drive system that recovers energy during vehicle braking
  - Energy is stored in the accumulators during braking, then used to accelerate the vehicle
  - Reduces fuel consumption in high start-and-stop applications like public buses, delivery and refuse vehicles
- LC's Type 4 tank technology is enabling
  - High cycle life (>1M cycles)
  - More than 80% lighter than a metal accumulator
- Supplier to Southwest Research Institute since 1996
- Working with a world leader in hydraulic components and systems



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High Pressure Accumulators
(Offshore Oil Platforms)

- Offshore accumulators for TLP tensioning systems
- Composite Accumulator Bottle (CAB) design is based on All-Composite NGV tank
- Designed and qualified three (3) CAB designs to ASME X
- Weight is approximately 1/3 of steel accumulator
- More than 550 bottles have been manufactured and installed on TLP's

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High Pressure Gas Transport

- LC tanks have significant advantages over Steel
  - Weight savings of 70-80% compared to steel cylinders
  - Purchase cost is “competitive” with steel
  - Lower weight, higher capacity = lower operating cost
  - Higher operating pressure is possible with Type 4 tank
  - Improved corrosion resistance, gas compatibility, cyclic fatigue

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Large Tank Development

- ***LINCOLN COMPOSITES*** has developed the TITAN™ Tank for gas bulk hauling
  - Diameter is 1.1 meters
  - Length is 11.6 meters
  - Operating Pressure is 250 bar
  - Water Volume of 8400 liters
- Qualification completed and ABS Certification received in 4th Quarter 2009
- CNG and H2
- Supported by US DOE

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Qualification Testing

Strength and Life Cycle

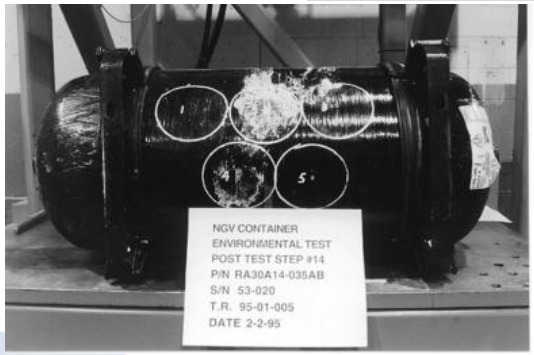
- Burst
- Ambient cycling
- Leak before break
- Accelerated stress rupture
- Natural gas/hydrogen cycling
- Boss torque

Damage Tolerance

- Penetration (gunfire)
- Flaw tolerance
- Drop
- Impact

Environmental

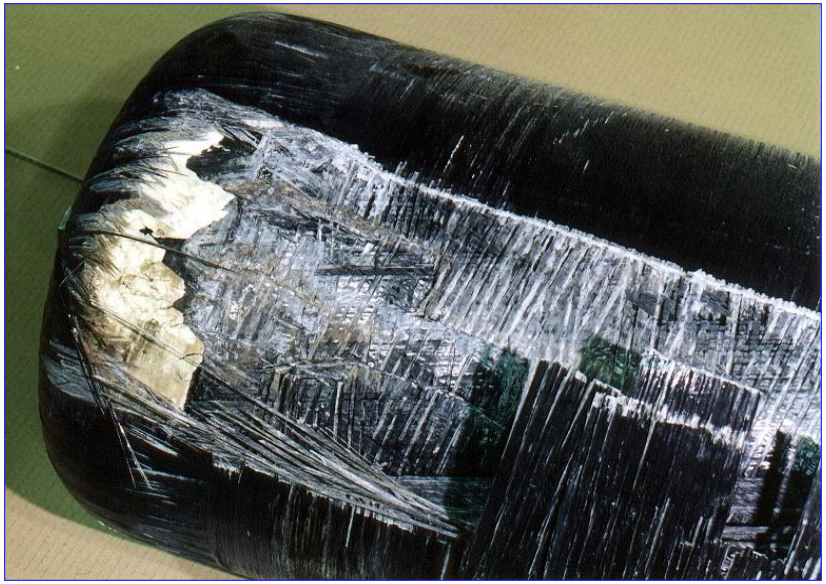
- Environmental fluid exposure
- Extreme temperature cycling
- Bonfire



Field Incidents – Bridge Hit

- A Bridge impact was one of the most significant incidents
  - Vehicle speed was approximately 75 km/hr (45 mph)
  - Tank pressure was about 200 bar (3000 psi)
  - Interference was 15 cm (6 inches)
  - Vehicle traveled approximately 30 m (100 ft) past bridge

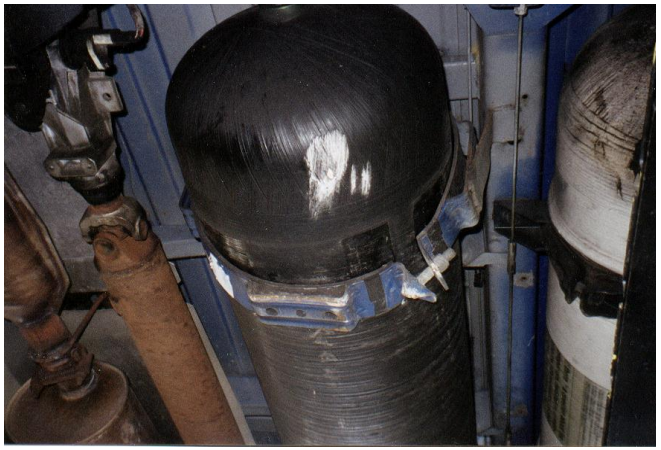
Field Incidents – Bridge Hit



- Burst pressure was 597 bar (8660 psi)
  - Front tank was most severely damaged
  - Requirement is 559 bar (8100 psi) minimum for lot acceptance
  - Lot sample burst test was 627 bar (9100 psi)

Field Incidents – Impact and Drop

- Curb hit, visible damage to dome, tank still met burst requirement



- Tank dropped from, dragged by, and run over by heavy duty vehicle, tank still met burst requirement

Field Incidents – Impacts

- Tank impacted by metal shelf support, did not rupture

- Bus hijacked, collided with another heavy vehicle, ran through fence and into parked cars, no reported damage to tanks

Field Incidents – Fire

- Fire in bus engine compartment, hot enough to melt ceramic elements in catalytic converter, PRD activated and all tanks vented safely

- Fire engulfed bus, PRDs activated and all tanks vented safely

Field Incidents – Collision

- Tank mounted in trunk
- Impacted by fully loaded gasoline transport
- No leakage or rupture
- According to the fleet manager, the accident investigator stated that the strength provided by the CNG fuel tank probably saved the driver's life

Field Ruptures

- Two LC tanks have ruptured in service
- Rupture in parked passenger vehicle
  - Fire burned inside vehicle for about 20 minutes before tank rupture
  - Vehicle system installation issue
  - PRD was isolated, did not see heat from fire
- Rupture in delivery vehicle during refueling
  - Tank was not mounted properly
  - Indications of severe abrasion
  - No indication of inspections
  - In service about 14 ½ years
- No performance difference expected for Type 3 tanks in same conditions

Permeation Issues

- Polymer materials absorb and permeate gases
- HDPE liners can meet permeation requirements for H2 and CNG gases.
- Gas is released as pressure is decreased
- Proper choice of design, materials, and process can prevent problems with release of gas from liner
- Normal usage rate avoids blistering problems
- Maintaining normal minimum pressure avoids most collapse problems
- LC has demonstrated ability to fully collapse liner, then re-expand with no loss of function

Fill and Discharge Issues

- Issues have been raised about ability to fully fill Type 4 tanks
- Testing 1-to-1 with Type 3 tank showed no difference in filling with CNG
- Filling can be managed effectively with proper filling equipment and filling algorithms
- LC has done cold fast fill and blowdown testing to demonstrate capabilities
- Cold filling should be within guidelines for normal operation – do not fill with cryogens

Fatigue Life of HDPE Liner

- LC HDPE liners have superior fatigue life
- No know instances of fatigue problems in service
- LC uses injection molded domes, extruded cylinder, butt-fusion weld
- LC tank has been cycled up to 1,000,000 without leakage

End of Life Performance

- Some LC tanks have reached end of 15-year life
- No indication of problems with permeation or strength loss
- LC cylinders were tested after 9 years of service (323,348 miles = 520,380 km)
  - Five tanks passed visual inspection, proof and leak test
  - One tank cycled 45,000 times, then proof and leak, then burst, passing all tests, no evidence of strength loss
  - One tank dissected, no evidence of deterioration, liner tensile test, cold impact test, and t_g test showed no signs of deterioration
  - One tank permeation tested, passed NGV2 requirements, no evidence of deterioration

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Summary

- Lincoln Composites has been manufacturing composite pressure vessels, including Type 4, for over 45 years
- Lincoln Composites chose to manufacture Type 4 tanks for CNG and H2 because of their benefits
- The Lincoln Composites Type 4 tanks have been safe and reliable in service
- It is necessary to use proper designs, materials, and processes, and to qualify tanks to proper standards, to ensure safe and reliable service
  - If tanks are found to have field problems, standards may need to be updated or additional tests conducted

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