LINCOLN COMPOSITES

Fuel Tank Manufacturing, Testing, Field Performance, and Certification

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LC Pressure Vessel Background

- Over 45 years experience
- 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

LC Fuel Tank History

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 950 bar

Proven History

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

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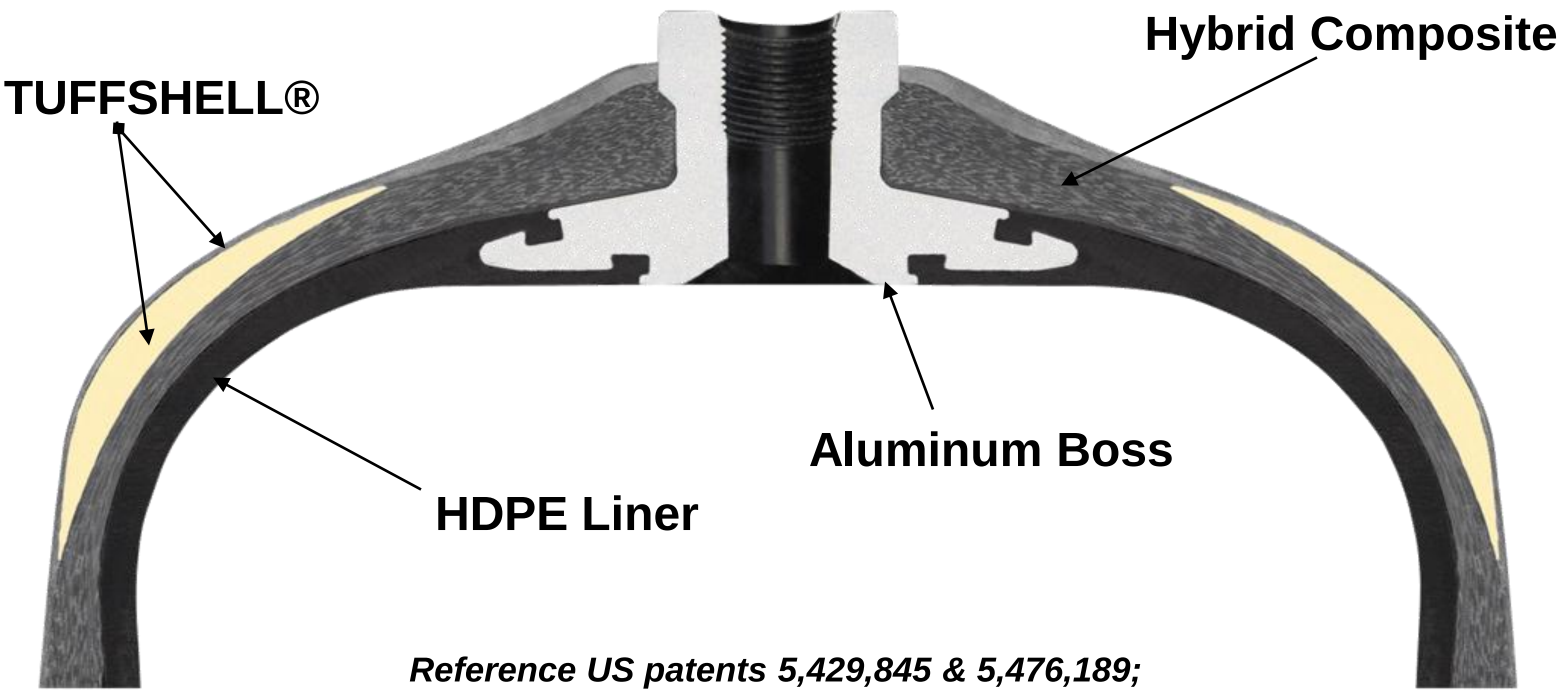
TUFFSHELL™ Tank Details



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

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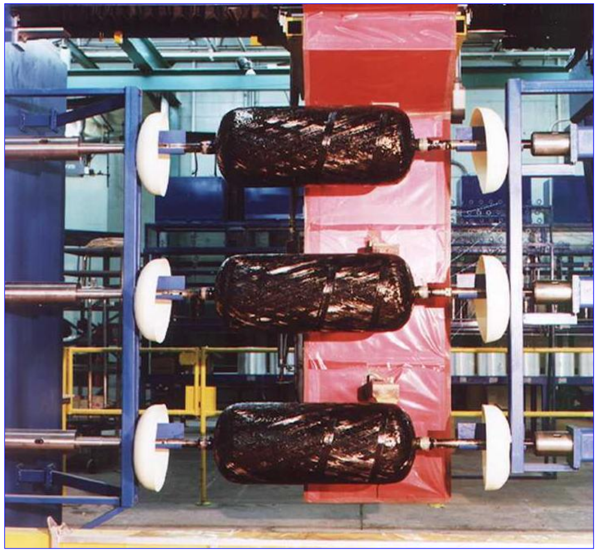
Manufacturing Process

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



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Tanks for cars

Tank Packs for Trucks

Tank Packs for Buses

High Pressure Gas Transport

- Weight savings of 70-80% compared to steel cylinders
- Higher operating pressure is possible with Type 4 tank
- Improved corrosion resistance, gas compatibility, cyclic fatigue

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 8500 liters
- Qualification completed and ABS Certification received in 4th Quarter 2009
- Approved modules are in the field
- CNG and H2
- Supported by US DOE
- 600 kg H2 at 250 bar
- 800 kg H2 at 350 bar

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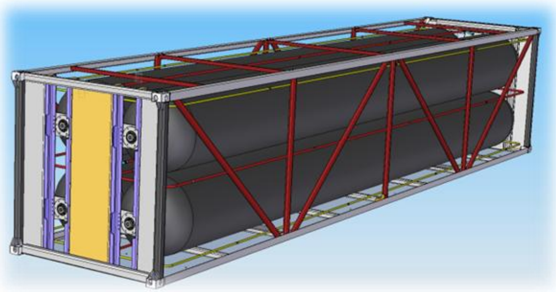
Stationary Cascades



Qualification Testing

Strength and Life Cycle

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

Environmental

- Environmental fluid exposure
- Extreme temperature cycling
- Bonfire

Damage Tolerance

- Penetration (gunfire)
- Flaw tolerance
- Drop

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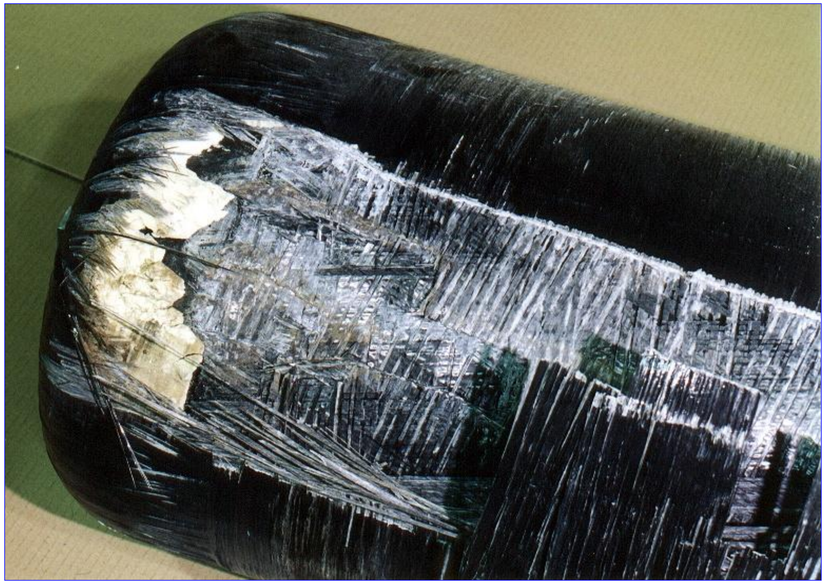
Field Incidents – Bridge Hit

- 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

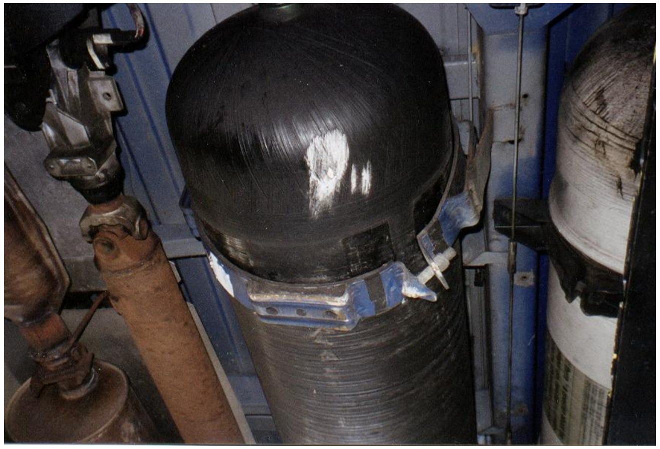
Field Incidents – Bridge Hit



- 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

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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

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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

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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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Cylinder Certification

- Cylinders have been qualified to a number of different standards for different applications:
  - Vehicle fuel containers
  - Transportable cylinders and tubes
  - Stationary pressure vessels
- Each application also falls under a regulatory authority
- Authorities vary from country to country
- Independent agencies are often involved in qualification testing and approvals

Vehicle Fuel Containers

- Standards include:
  ANSI/CSA NGV2
  ISO 11439
  SAE J2579
  CSA B51 Part 2
  ISO/TS 15869
- Regulations include:
  DOT-NHTSA FMVSS 304
  ECE R110
  TC 301.2
- Issues:
  - World-wide acceptance of consistent standards and regulations for CNG
  - Hydrogen standards and regulations are under development
  - Significant technical issues are being debated prior to development of global technical regulations for hydrogen fuel containers

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Transportable Cylinders and Tubes

- Standards include:

  ISO 11119-3 | EN 12245
  ISO 9809 | ISO 7866
  ISO 11120 | Fuel container standards
  Draft composite standards in development
  Agency standards

ISO 11119-3	EN 12245
ISO 9809	ISO 7866
ISO 11120	Fuel container standards

Draft composite standards in development
Agency standards

- Regulations include:

  DOT-PHMSA 49 CFR, Special Permits
  ADR/RID TPED

- Issues
  - Transportation standards and regulations have been the slowest to adopt new technologies and approaches
  - UN COE (Orange Book) has a goal of globally harmonized standards, but national and regional regulations inhibit progress
  - Size and pressure are limited in some standards and regulations, but Special Permits and Approvals may be an option

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Stationary Pressure Vessels

- Standards include:

  ASME BPV Code CSA B51 Part 3
- Regulations include:

  US/State Building Codes ADR PED
- Issues:
  - ASME Section VIII Div. 3 and ASME Section X have been updated for high pressure hydrogen storage
  - Vehicle fuel container standards have been accepted
  - Special Permits are common
  - Approvals are required in every jurisdiction used in US

In-Service Inspection

- Hydrostatic test has been the tradition
- NDE methods are gaining favor
  - Ultrasonic
  - Acoustic emission
- Visual inspection is widely accepted for fuel containers
- In-situ NDE may offer benefits, but must be cost effective
- Inspection of transportation and stationary vessels is generally required legally
- Inspection of fuel containers is often voluntary

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Summary

- Composite cylinders have been in use over 50 years
- Cylinders are used for a number of different applications:
  - Vehicle fuel containers
  - Transportable cylinders and tubes
  - Stationary pressure vessels
- Pressure vessels and cylinders are highly regulated
- Approval process is complicated overall