Composite Tube Trailer Design/Manufacturing Needs

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Overview

- Lincoln Composites has, with support from DOE, built composite tube trailers and can, therefore, address issues with:
  - Design
  - Materials
  - Manufacturing
  - Testing
  - Approvals

Objectives

- Meet market needs for cost effective, light weight, bulk transport of CNG and CH2
  - Requires composite cylinders for light weight (cargo is volume limited, not weight limited)
  - Requires cost effective fibers (high strength/$)
  - Requires reasonable safety factors
  - Requires appropriate manufacturing and testing
- Safety must be maintained

Design

- Baseline design is Type 4 construction
  - Full composite reinforcement
  - Plastic liner
  - End bosses molded into dome
- Same design as used on 100,000+ CNG fuel containers (minimizes risk)
- Contained in frame per ISO 1496-3

Materials

- Baseline fiber is Toray T-700
  - High strength/cost
  - Alternate fibers have been identified/qualified
- Epoxy resin
  - Environmentally stable
  - Low temperature cure
- HDPE liner
- Metal boss
- Steel frame

Manufacturing

- Welded liner assembly
- Filament wound construction
- Oven cured
- Proof tested
- Same process as used on 100,000+ CNG fuel containers (minimizes risk)

Testing

- **Successful completion of all qualification tests for a 3600 pressure vessel**

  ✓**Hydrostatic Burst Test**
  ✓**Ambient Pressure Cycle Test**
  ✓**LBB (Leak Before Burst) Test**
  ✓**Penetration (Gunfire)**
  ✓**Environmental Test**
  ✓**Flaw Tolerance Test**
  ✓**High Temperature Creep Test**
  ✓**Accelerated Stress Rupture Test**
  ✓**Extreme Temperature Cycle Test**
  ✓**Natural Gas Cycle Test with Blowdown**

Testing is consistent with requirements of established standards

DOE Hydrogen Program

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Approvals

DOE Hydrogen Program

- No existing standard applies to large composite tube/trailer
- Developed specification in conjunction with American Bureau of Shipping (ABS)
- ABS approved design, worked with Lincoln Composites to gain regulatory approvals
  - Currently approved in 5 countries
  - Approval being sought in US, Canada, and other countries

DOE Technical Targets

DOE Hydrogen Program

Hydrogen delivery targets	ISO container with four 3600 psi tanks
\$500/kg of hydrogen stored by FY2010, \$300/kg by FY2015	The current ISO assembly, with four tanks installed, can store about 600 kg of compressed hydrogen gas at 3600 psi with a safety factor of 2.35. It is estimated that the cost will be \$675-\$750 per kg of hydrogen depending on market demand.
Volumetric capacity 0.03 kg/liter by FY2010, >0.035 kg/liter by FY 2015	The baseline tank has a capacity of 150 kg hydrogen in a volume of ~8500 liters, achieving a performance of ~0.018 kg/liter. This performance measure can be increased 33% to 0.024 kg/liter by increasing the service pressure to 5000 psi and 95% to 0.035 kg/liter by increasing the service pressure **to 8300** psi.
Tube trailer delivery capacity 700 kg by FY2010 and 1,100 kg by FY2017	The current ISO assembly, with four tanks installed, will contain about 600 kg of hydrogen. This can be increased 33% to about 800 kg by increasing the service pressure to 5000 psi and 44% to about 1150 kg by increasing the service pressure **to 8300** psi.

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Technical Progress

DOE Hydrogen Program

Completed the design, manufacture and assembly of ISO container (standard dimensions) capable of storing ~600 kg H_2 @ 3600 psi.

- ✓ **Designed to meet industry standard transporting dimensions**
- ✓ **Completed stress analysis on frame**
- ✓ **Performed DFMEA**
- ✓ **Performed HazID analysis**
- ✓ **Developed pressure relief system for fire protection**

Completed Testing of ISO Container

- ✓ **Dimensional**
- ✓ **Stacking**
- ✓ **Lifting – Top and bottom**
- ✓ **Inertia Test**
- ✓ **Impact Test**
- ✓ **Bonfire**

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Areas for Improvement

- Composite reinforcement is the most significant cost in the system
  - Lower cost of carbon fiber ($/strength)
  - Identify material with lower net cost ($/strength)
  - Identify lower cost resin system (raw material & manufacture)
  - Reduce carbon fiber safety factor (from 2.35 to 2.25 or 2.0)
    - Additional stress rupture testing to confirm acceptability
    - Combine stress rupture testing with cycling, impact damage to assess real-life conditions
    - Consider in-situ monitoring and/or NDE
- Reduce cost of manufacture
  - Sell more! (reduces overhead, but must balance supply with need)
  - Improve throughput (faster winding, cure, assembly)

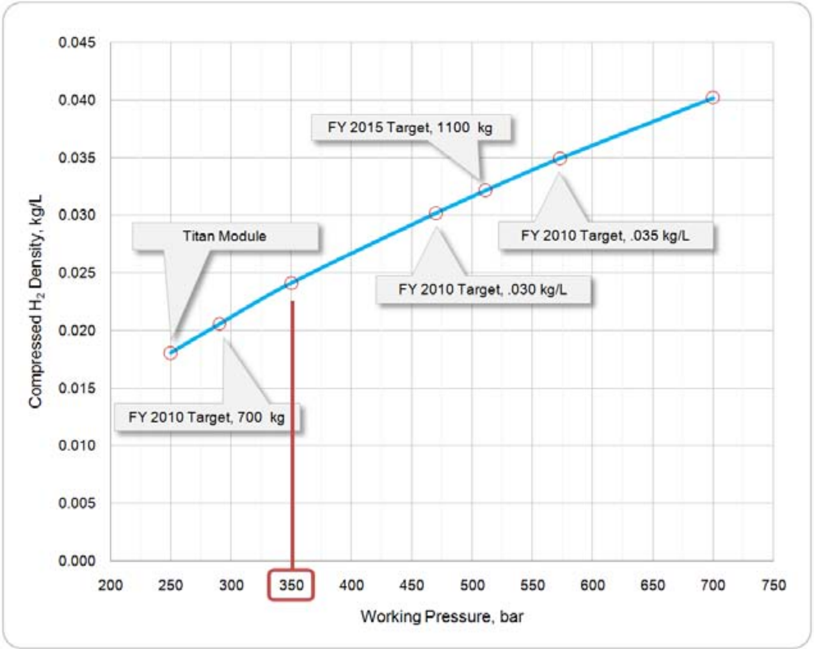
Areas for Improvement

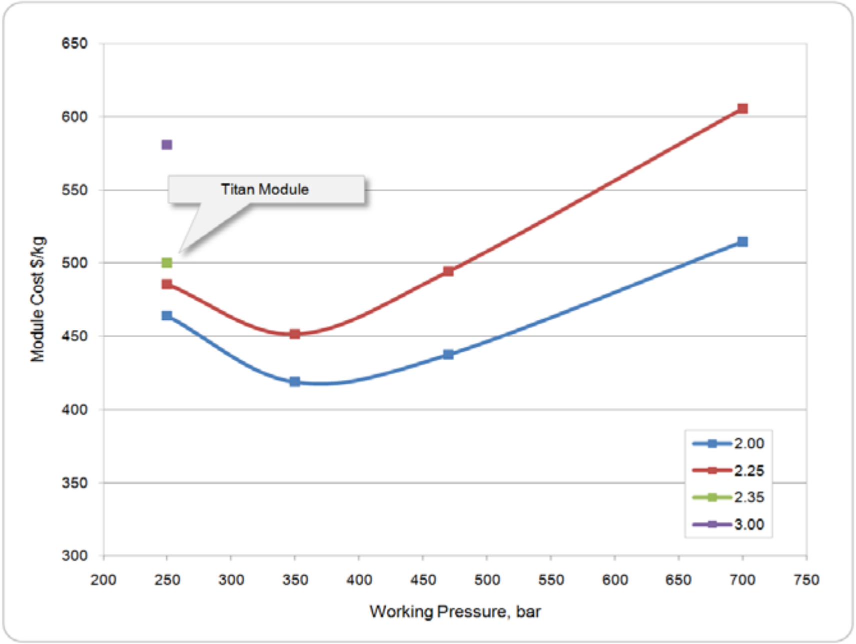
- Increase pressure to increase H_2 contents
  - Qualification testing is expensive
  - Test facilities are limited
  - Need to fully assess initial vs. operational costs
- Facilitate regulatory approvals
  - Some countries are slower to approve, or have barriers
    - e.g. ADR requires higher FS
  - No standards or regulations directly apply
    - Working with ISO, ASME, et al to develop
  - Need support from DOE, customers, regulators

Areas for Improvement

- Increase diameter to use single tank?
  - New liner manufacturing process required
  - High cost and risk involved
  - Reduces cost for plumbing, assembly
  - Increases space utilization (63% vs. 60%)
  - Redesign frame
- Develop special purpose (integrated) running gear/frame, with lower ground clearance and reduced interface, to permit more tanks (e.g. 5 or 6 of current size within height limit, instead of 4 tanks mounted 2x2)

Working Pressure Trade Study





- Increasing H_2 Density by Raising Working Pressure
- 33 % Increase in Capacity at 15°C
  - .024 kg/L at 350 bar
  - .018 kg/L at 250 bar

- Practical Limit is 350 bar
  - Higher pressures exacerbates thick-wall effects and reduced strength translation
  - Availability of Plumbing Hardware
  - Availability of H_2 Compressors
  - *Operation costs may offset initial costs, allow higher pressure limit*

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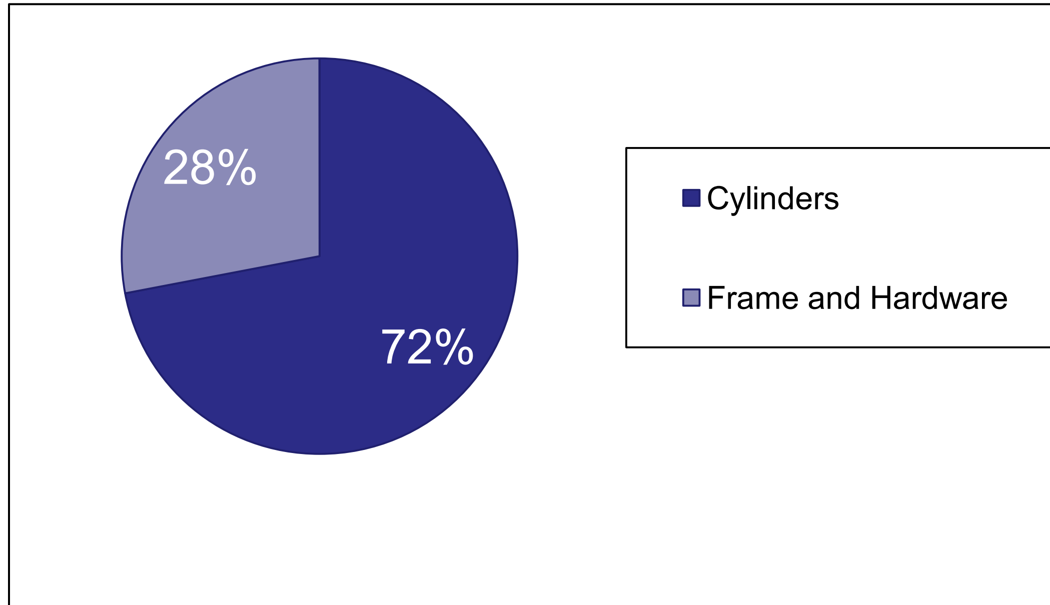
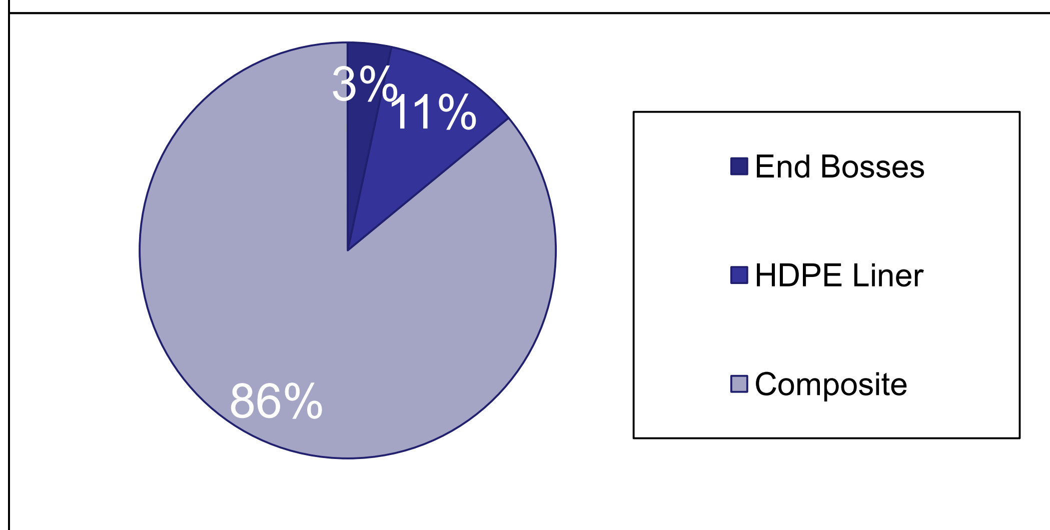
Module/Cylinder Cost Study

DOE Hydrogen Program

- Currently Meet $500 per kg H_2
  - 72 % of Cost is Cylinders
  - 86 % of Cylinder Costs is Composite





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Summary

- Lincoln Composites has developed and produced composite tube trailers that are currently in service
- These tube trailers are a cost effective solution, based on established technology and a solid safety record, but there are opportunities to reduce cost and weight, and increase H_2 mass
- Areas for improvement have been identified