HEXAGON LINCOLN

DOE Hydrogen Program

Development of High Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery

Don Baldwin, Principal Investigator
Norm Newhouse, Presenter
Hexagon Lincoln

May 15, 2013

Project ID#
PD021

This presentation does not contain any proprietary, confidential, or otherwise restricted information

OVERVIEW

DOE Hydrogen Program

Timeline

- Phase I July 08 – June 09
  - 100% Complete
- Phase II June 09 – April 13

Barriers

- Barriers addressed

  E. Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

  I. Other Fueling Site/Terminal Operations

Budget

- Total project funding **(Phase I & II)**
  - DOE share $3M
  - Contractor share $2.73M
- Funding received in FY12 - $489K

Partners

- Discussions with ABS on vessel qualification
- Discussions with US DOT

HEXAGON LINCOLN

RELEVANCE

DOE Hydrogen Program

- Relevance: to reduce the cost of a near-term means of transporting gaseous H_2 from the production or city gate site to the station.
- Design and develop the most effective bulk hauling and storage solution for hydrogen in terms of cost, safety, weight, and volumetric efficiency. This will be done by developing and manufacturing a tank and corresponding ISO frame that can be used for the storage of hydrogen in a stationary or hauling application. Complete 4Q 2009.
- Based on current knowledge of tube trailer design, carry out preliminary design and qualify a 3600 psi tank and ISO frame that will hold 510000 in^3 (~8500L) water volume. Complete 4Q 2009.
- Complete trade studies needed to increase vessel capacity by increasing pressure to 5000 psi (ultimately exceeds the DOE's FY01 capacity target by >15%). Complete 1Q 2011.
- Complete the enhancement of the 250 bar system with respect to capacity (> 700 kg/liter) and safety (fire protection). Complete 4Q 2012.

HEXAGON LINCOLN

OBJECTIVES-TECHNICAL TARGETS 2010/2015*

DOE Hydrogen Program

Hydrogen delivery targets	ISO container with four 3600 psi tanks (FY 2009 Work Scope)
$500/kg of hydrogen stored by FY2010, $300/kg by FY2015	The TITAN Module, with four tanks installed, met the $500 per kg hydrogen objective in 2010. However, since 2010 increases in market prices for materials of construction (specifically carbon fiber and specialty forgings) have forced us to increase our current pricing to about $800/kg (1Q 2013). [We have strong domestic and international sales of our high-capacity modules and trailers at this price level for CNG.]
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.
Tube trailer delivery capacity 700 kg by FY2010 and 1,140 kg by FY2017	The current ISO assembly, with four tanks installed, will contain approximately 616 kg of hydrogen. At 90% hauling efficiency, delivery of 555 kg of hydrogen

* Based on the Fuel Cell Technologies Office 2007 MYRD&D

HEXAGON LINCOLN

OBJECTIVES-TECHNICAL TARGETS 2015/2020

DOE Hydrogen Program

Hydrogen delivery targets	ISO container with four 3600 psi tanks (FY 2009 Work Scope)
$730/kg of hydrogen delivered by FY2015, $575/kg by FY2015	The TITAN Module, with four tanks installed, met the $500 per kg hydrogen objective in 2010. However, since 2010 increases in market prices for materials of construction (specifically carbon fiber and specialty forgings) have forced us to increase our current pricing to about $800/kg (1Q 2013). [We have strong domestic and international sales of our high-capacity modules and trailers at this price level for CNG.]
Delivery Pressure 400 bar by FY2015, 520 bar by FY2020	The current delivery pressure is 250 bar. Design and trade studies have been performed which indicate that a delivery pressure of 350 bar is optimal for TITAN modules/trailers. Higher pressures are achievable but would require extensive redesign and retooling of the manufacturing infrastructure. Any further validation and homologation activity must be preceded by industry consensus on delivery pressure and better definition of the business opportunity
Tube trailer delivery capacity 700 kg by FY2015 and 940 kg by FY2020	The Titan module system, (four large tanks) contains approximately 616 kg of hydrogen. At 90% hauling efficiency, delivery of 555 kg of hydrogen The Titan 5 (5 large tank trailer) contains approximately 726 kg of hydrogen. At 90% hauling efficiency, delivery of approximately 653 kg of hydrogen The Titan 5 Magnum, (5 large tanks and 9 small tanks) contains approximately 800 kg of hydrogen. At 90% hauling efficiency, delivery of approximately 720 kg of hydrogen.

APPROACH/MILESTONES

DOE Hydrogen Program

Task 1.0 Develop and Qualify a 3600 psi Tank

- design and qualify a tank that will hold approximately 8500 liters of water at 3600 psi
- Primary focus will be on manufacturing methods of a tank this size
- **Completed 4Q 2009**

Task 2.0 Develop and Qualify an ISO Frame

- ISO container assembly will be able to hold four tanks with a combined capacity of 600 kg of hydrogen
- **Completed 3Q 2009**

Task 3.0 5000 psi Trade Study

- A higher pressure tank will be required to meet DOE goals
- Initial review suggest a 5000 psi tank will be the most cost effective
- **Completed 1Q 2011**

Task 4.0 Develop and Qualify a 5000 psi Tank

- This task is no longer being pursued.
- Lack of market definition in regards to working pressure 5000 or 7250 psi and forecasting of market size.
- High testing costs ~$5 million to fully qualify.

Task 5.0 Cost Reduction Studies

- Methods to reduce cost and increase safety of the system will be investigated.
  - Decrease costs by increasing safety and reliability of current fire protection system
  - Laboratory equipment to help in the understanding of hydrogen and the effect on polymer liners
- **Completed 4Q 2012**

Task 6.0 Investigate Increased Capacity

- Design and prototype a Titan5 trailer that will increase storage capacity per truck load.
- **Completed 1Q 2012**
- Design a modification of the Titan5 to include additional capacity via smaller tanks in empty space within existing trailer design.
- **Completed 4Q 2012**

HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

- Completed the design, manufacture and assembly of ISO format container (standard dimensions) capable of storing ~616 kg H2 @ 3600 psi.
  - Successful completion of all qualification tests for a 3600 pressure vessel per ABS Document No. ABSHOU557163
  - Completed Testing of Container per CSC 49 CFR Part 451
  - DOT Special Permit 14951 issued 22 February 2012

HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

HEXAGON LINCOLN TITAN™ Module System

Compressed Hydrogen Gas

Capacity

250 bar – 616 kg (554 kg delivered)
350 bar – 809 kg (728 kg delivered)
540 bar – 1155 kg (1040 kg delivered)

Gross Vehicle Weight (with prime mover)

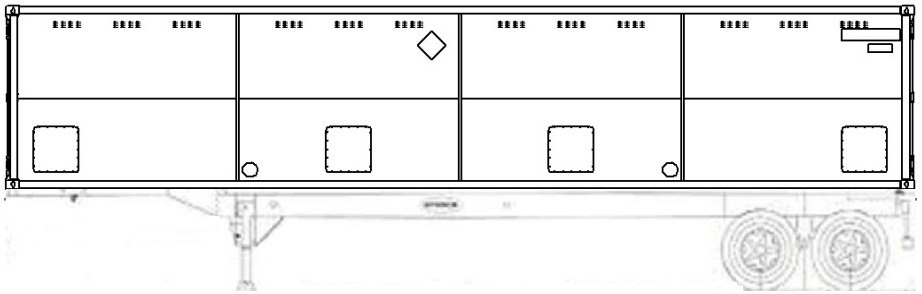
250 bar – 28 450 kg
350 bar – 30 820 kg
540 bar – 39 440 kg

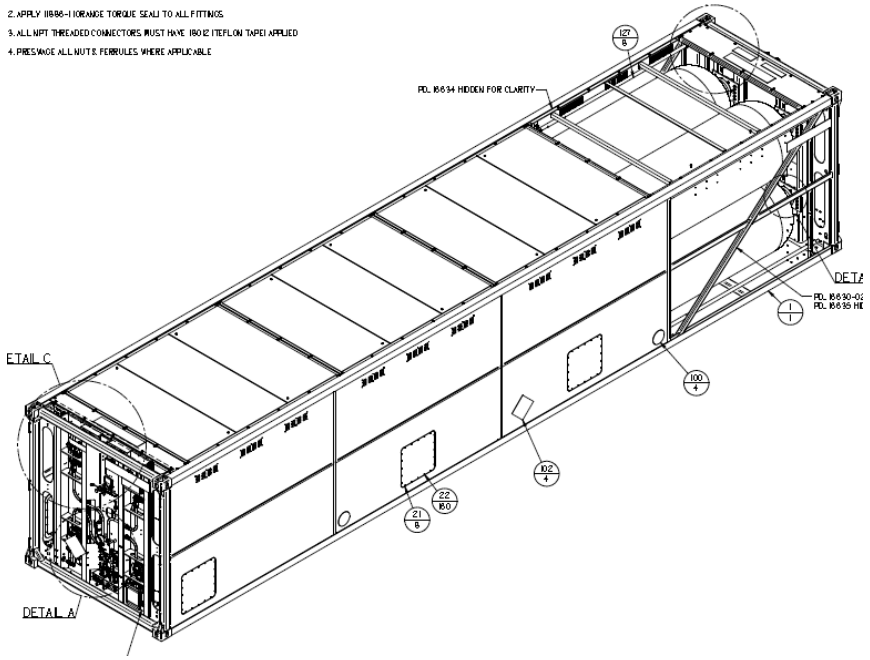
Purchase Cost

250 bar – $510,000 ($828/kg)
350 bar – $633,750 ($783/kg)
540 bar – $1,100,000 ($952/kg)

Compressed Natural Gas

Capacity (250 bar at 15 C) – 7412 kg
GVW (With prime mover) – 35 250 kg
Purchase Cost (+/- 5%) - $510,000





HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

- Completed the design, manufacture and assembly of integrated trailer system capable of storing ~800 kg H_2 @ 3600 psi.
  - Maximum width and height allowed on Interstate Highway System
  - Gross Vehicle Weight within limits for Interstate up to 350 bar

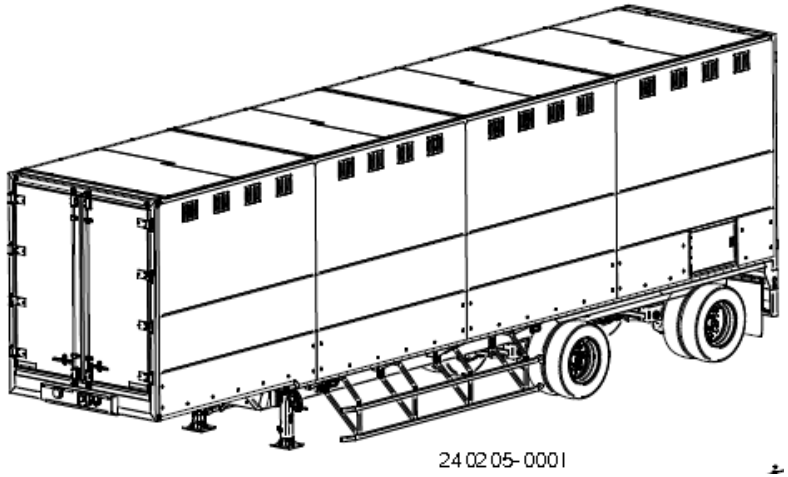
HEXAGON
LINCOLN

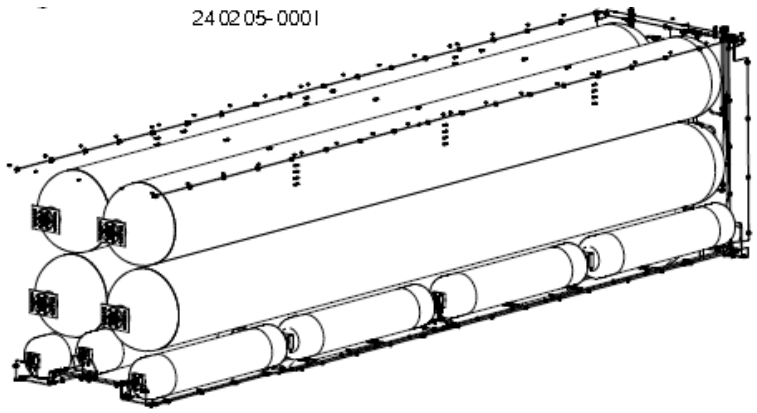
TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

HEXAGON LINCOLN TITAN™ V Magnum Trailer System

- Compressed Hydrogen Gas
  - Capacity
    - 250 bar – 800 kg (720 kg delivered)
    - 350 bar – 1050 kg (907 kg delivered)
    - 540 bar – 1500 kg (1350 kg delivered)
  - Gross Vehicle Weight (with prime mover)
    - 250 bar – 31 000 kg
    - 350 bar – 34 200 kg
    - 540 bar – 45 700 kg
  - Purchase Cost
    - 250 bar – $595,000 ($744/kg)
    - 350 bar – $745,000 ($710/kg)
    - 540 bar – $1,295,000 ($863/kg)
- Compressed Natural Gas
  - Capacity (250 bar at 15 C) – 9649 kg
  - GVW (With prime mover) – 39 830 kg
  - Purchase Cost (+/- 5%) - $595,000





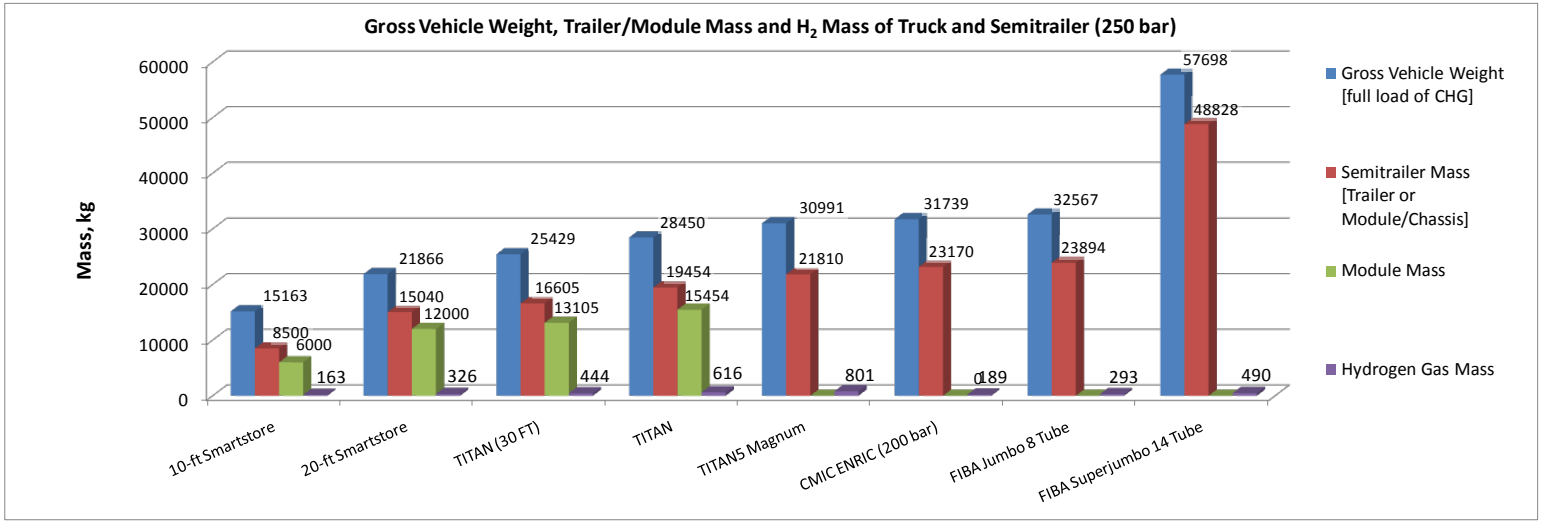
HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

OPERATIONAL PARAMETERS FOR BULK HAULING EQUIPMENT

- More Hydrogen Capacity and Lower GVW Reduces Operating Expenses
- 350 bar TITAN™ and TITAN V Magnum™ Would be a Logical Next Step
  - 2.25 SR Design Fits ISO Frame and Trailer Widths
  - .018 to .024 kg H_2 per Liter
  - 616 to 816 kg H_2 Capacity for TITAN™, 801 to 1051 kg H_2 Capacity for TITAN V Magnum™
  - 5% reduction in $ per kg H_2 [capital expenditure for rolling stock only]
  - Practical Limit in Industry is 350 bar
    - Higher pressures exacerbates thick-wall effects and reduced strength translation
    - Availability of Plumbing Hardware
    - Availability of H_2 Compressors
- Need Definition of Market Size and Operating Parameters [i.e.; 350 bar vs 540 bar] before a Business Case Can be Made for Investment in Qualification at a Higher Pressure

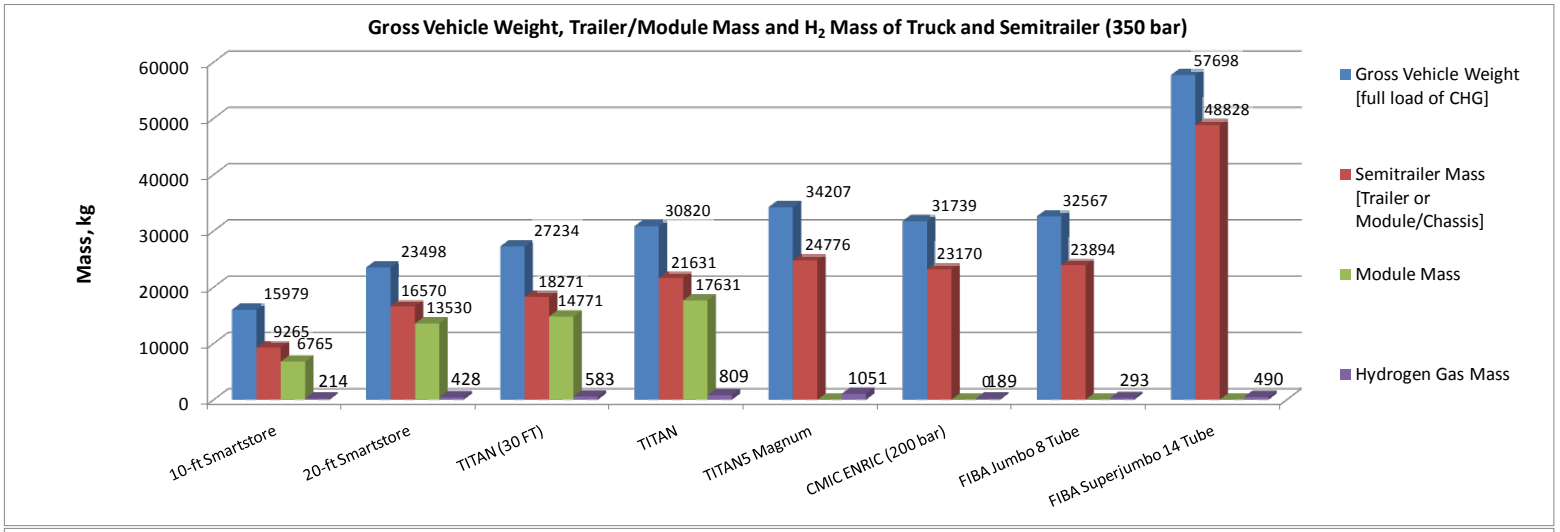


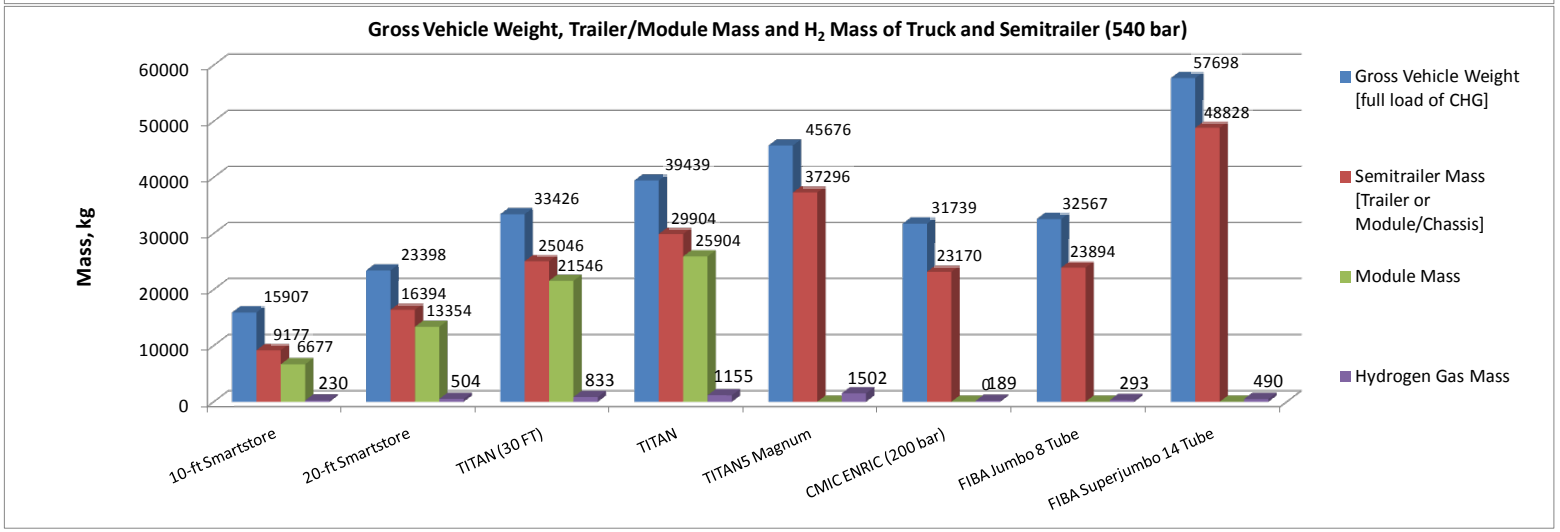
HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program

OPERATIONAL PARAMETERS FOR BULK HAULING EQUIPMENT

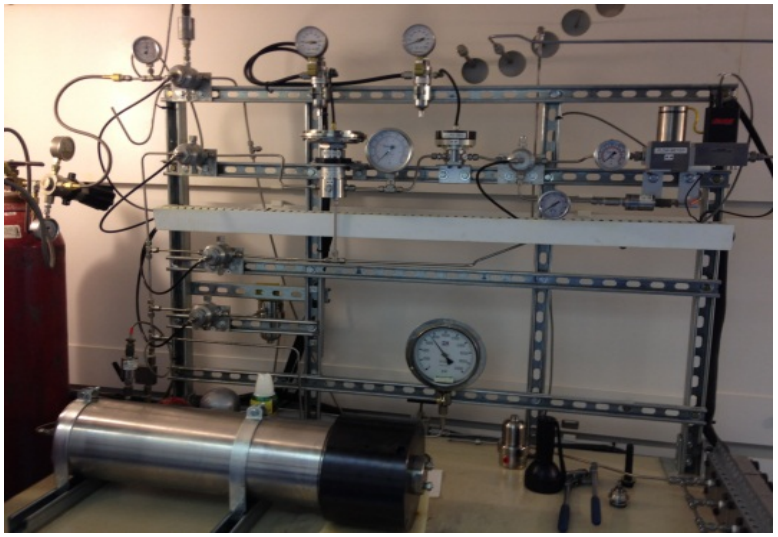




HEXAGON LINCOLN

TECHNICAL ACCOMPLISHMENTS/PROGRESS/RESULTS

DOE Hydrogen Program



- Completed the build of laboratory area that enables Hexagon Lincoln to begin looking at the effect of hydrogen on polymers that are and could potentially be used as liner materials
  - Capable of using 100% hydrogen up to 700 bar
  - Automated pressure cycling
  - Variable depressurization rates
    - Minimum - 30 psi/minute
    - Maximum - 160,000 psi/minute

HEXAGON LINCOLN

COLLABORATIONS

DOE Hydrogen Program

- American Bureau of Shipping on qualification of existing and potential changes to composition of current pressure vessels.
- Lincoln Composites has received Special Permit from the U.S. DOT authorizing the manufacture, making, sale and use of the Titan bulk hauling 4 cylinder module in February 2012.

HEXAGON LINCOLN

SUMMARY

DOE Hydrogen Program

- Hydrogen delivery and storage are key to the roll out of PEMFC technology
- Low cost, near-term delivery pathways such as tube trailer transport will enable early adoption of these technologies
- Developing a bulk storage unit that can be transported on an ISO frame is a critical part of this strategy

Technical Targets*	
DOE Goals	**Estimated Results**
$500/kg of hydrogen stored by FY2010, $300/kg by FY2015	3600 psi - $500 per kg of H2
Volumetric capacity 0.03 kg/liter by FY2010, >0.035 kg/liter by FY 2015	Current 3600 psi tank – 0.018 kg/liter
Tube trailer delivery capacity 700 kg by FY2010 and 1,100 kg by FY2017	3600 psi (4-tube ISO container) - contains 616 kg of hydrogen, 555 kg deliverable at 90% efficiency.
Tube trailer delivery capacity 700 kg by FY2015 and 940 kg by FY2020 (DRAFT)	3600 psi (4-tube ISO container) - contains 616 kg of hydrogen, 555 kg deliverable at 90% efficiency. 3600 psi (5-tube trailer) – contains 726 kg of hydrogen, 653 kg deliverable at 90% efficiency. 3600 psi (5-tube trailer with additional 9 tanks) – contains 800kg of hydrogen, 720 kg deliverable at 90% efficiency.
Tube trailer operating pressure goal is <10,000 psi by FY2012	Current module configuration is 3600 psi

* Based on the Fuel Cell Technologies Office 2007 MYRD&D

HEXAGON LINCOLN