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DOE Hydrogen Program

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

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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 – June 12
  - 50% Complete
  - May need to request time extension

Budget

- Total project funding **(Phase I & II)**
  - DOE share $3M
  - Contractor share $2.73M
- Funding received in FY11 - $470K
- Planned Funding for FY12 - $372K

Barriers

- Barriers addressed
  - Gaseous Hydrogen Storage and Tube Trailer Delivery Costs
  - System Weight and Volume
  - Efficiency
- 2010/2015 Targets
  - $500/kg of H2 stored by FY2010, $300/kg by FY2015
  - Volumetric capacity 0.03 kg/liter by FY2010, >0.035 kg/liter by FY 2015
  - Tube trailer delivery capacity 700 kg by 2010, 1,100 kg by 2017
- 2015/2020 Targets (DRAFT)
  - $500/kg of H2 stored by FY2010, $300/kg by FY2015
  - Volumetric capacity 0.03 kg/liter by FY2010, >0.035 kg/liter by FY 2015
  - Tube trailer delivery capacity 700 kg by FY2015 and 940 kg by FY2020

Partners

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

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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).**

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 current ISO assembly, with four tanks installed, met the $500 per kg hydrogen objective in 2010, but due to current carbon fiber price results in greater than 20% increase in cost. Costs of operating and staffing a facility require forecast of significant volumes to meet goals.
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

Objectives-Technical Targets 2015/2020

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 current ISO assembly, with four tanks installed, met the $500 per kg hydrogen objective in 2010, but due to current carbon fiber price results in greater than 20% increase in cost. Costs of operating and staffing a facility require forecast of significant volumes to meet goals.
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 FY2015 and 940 kg by FY2020	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 Titan 5 (5 tube trailer) is estimated to contain approximately 726 kg of hydrogen. At 90% hauling efficiency, delivery of approximately 653 kg of hydrogen Titan 5 + additional 6 tanks is estimated to contain approximately 775 kg of hydrogen. At 90% hauling efficiency, delivery of approximately 698 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

Task 6.0 Investigate Increased Capacity

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

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Technical Accomplishments/ Progress/Results

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- **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

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Technical Accomplishments/ Progress/Results

DOE Hydrogen Program

Completed the design, manufacture and assembly of ISO container (standard dimensions) capable of storing ~616 kg H_2 @ 3600 psi.

- ✓ Pressure vessel targeted at 3600 as infrastructure already in place to utilize
- ✓ 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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Trade Studies of 350 bar System

DOE Hydrogen Program

- 350 bar TITAN™ 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™
  - $500 to $452 per kg H_2 with 2010 assumptions
- 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
- However …

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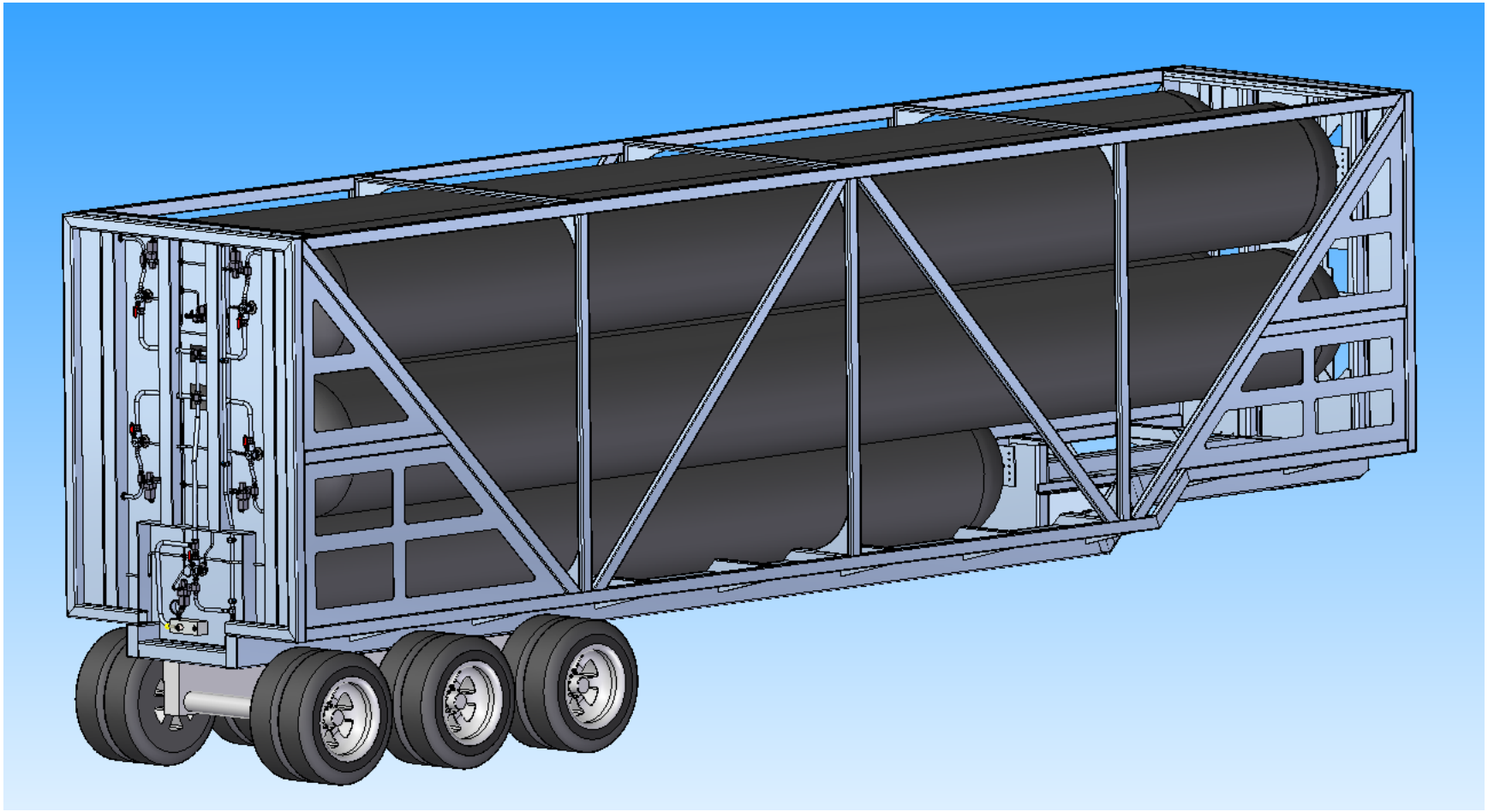
Business Issues of 350 bar System

DOE Hydrogen Program

- Lack of Market Definition
  - Working Pressure 350 bar or 500 bar?
  - Market size impossible to forecast at this time
- Testing Costs
  - Cost of 350 bar based on estimates from testing laboratories is $3.5 million
  - Total cost of $5 million is likely
  - $1 million of DOE funding possible
  - $2.5 to $4 million qualification cost to LC
  - 500 bar testing would be even more expensive
    - Testing infrastructure is not capable
    - Facilitation would be costly
- 350 bar Qualification on no longer being pursued.

Titan 5



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Titan 5 Integrated Trailer

DOE Hydrogen Program

- Design and prototyping of a trailer capable of holding 5 large cylinders.
- 18% increase in volume capacity compared to 4 cylinder module.
- Capable of holding 726 kg of hydrogen and delivering 653 kg at 90% efficiency.

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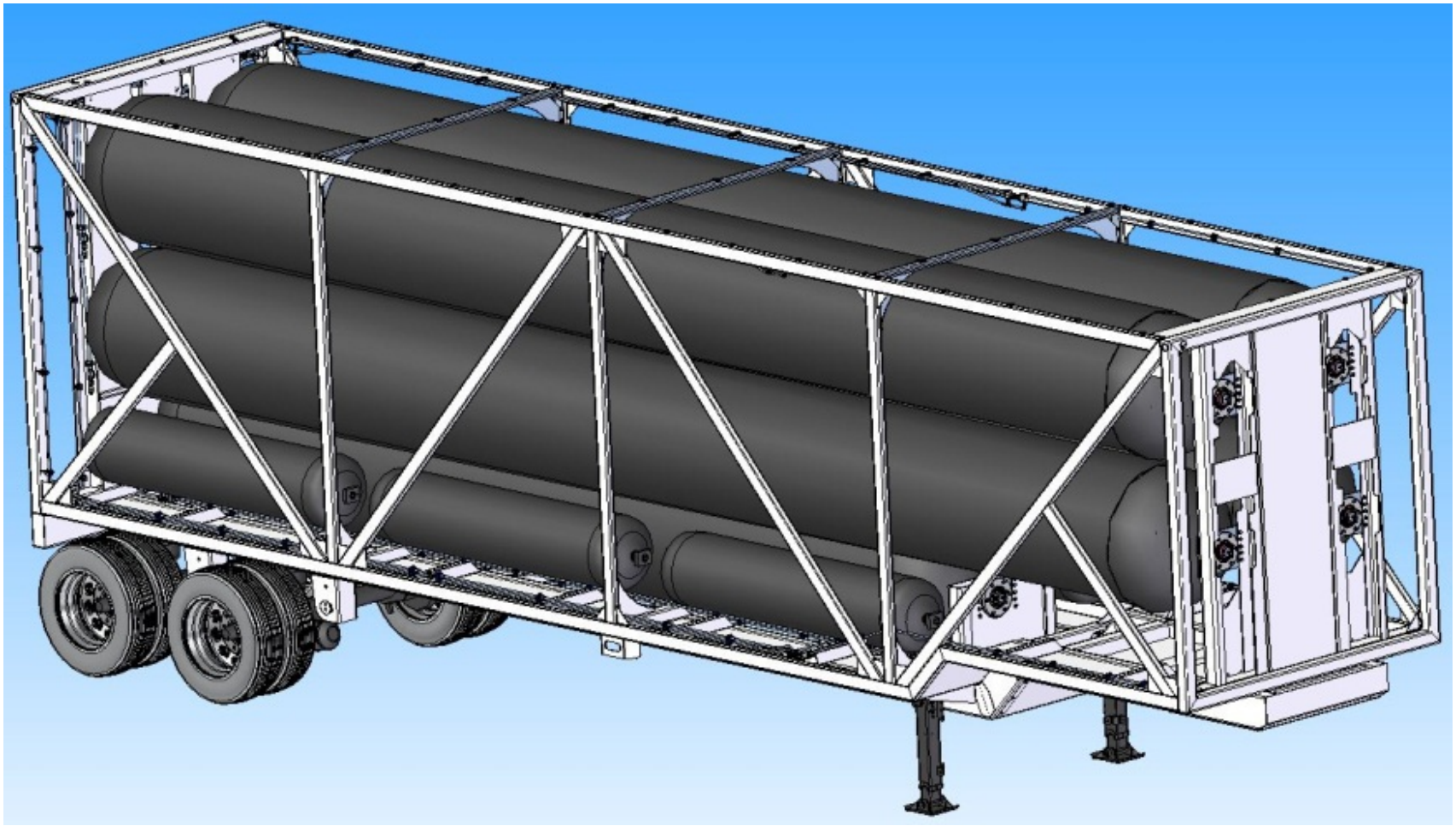
Titan 5 “Magnum”



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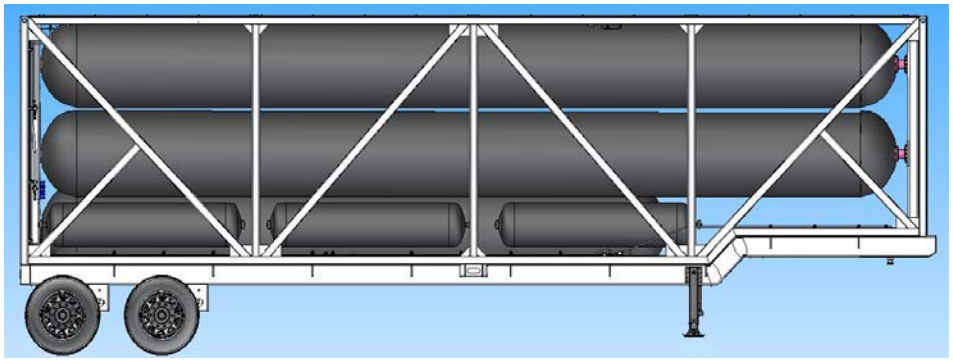
Titan 5 Additional Capacity

DOE Hydrogen Program

- Design and delivery of a trailer capable of holding 5 large cylinders plus additional 6 tanks located in lower portion of the trailer (3 on either side).
- 26% increase in volume capacity compared to 4 cylinder module.
- Capable of holding 775 kg of hydrogen and delivering approximately 698 kg at 90% efficiency.



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Collaborations

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- 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.

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Proposed Future Work 2012

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- LC has been encouraged to use funds to continue to advance project goals at 250 bar
- Increase Capacity per Trailer Load
- Decrease Acquisition and Operating Costs
  - Fire protection system
    - Increased safety and reliability
  - Materials R&D
    - Laboratory equipment
    - Effects of CHG on polymers
- Qualify System Components for CHG
  - Fire protection system components
  - Valves and manifolds

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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 6 tanks) – contains 775 kg of hydrogen, 698 kg deliverable at 90% efficiency.
Tube trailer operating pressure goal is <10,000 psi by FY2012	Current module configuration is 3600 psi

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