



Underground LH2 Off-Board Hydrogen Storage Technology

- > **U.S. Department of Energy
2005 Hydrogen Program Review**

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Project ID # STP57

Overview

> Timeline

- Task 1
 - > Start: May 2005
 - > End: Feb 2006
- Task 2
 - > Start: Mar 2006
 - > End: Apr 2008

> Budget

- Total project funding
 - > DOE: \$968,000
 - > Cost share: \$245,000
- FY05: \$90,000

> Barriers addressed

- Reduce the cost and footprint of hydrogen storage at refueling stations
 - > Barrier F: Hydrogen Delivery Infrastructure Storage Costs
 - > Barrier H: Storage Tank Materials and Costs

> Partners

- NexGen Fueling Division of Chart Industries
- BOC Gases

Project Objectives

- > Better understand the technical and economic factors related to bulk hydrogen transportation, storage, and dispensing for vehicle applications
- > Operating costs and efficiencies of various hydrogen storage methods
- > Capability of fueling system to store and effectively deliver H₂ to vehicles
- > Understand the safety of the fuel storage and delivery system

Technical Approach

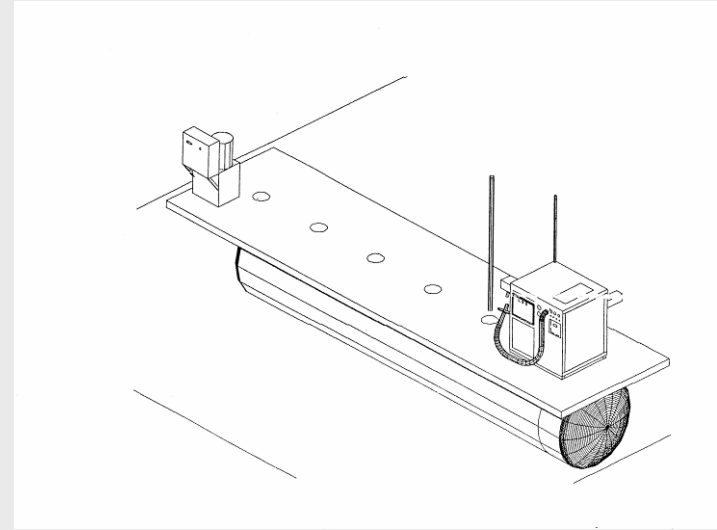
- > Two tasks
 1. Design analysis and economic modeling
 2. Demonstration to validate analysis and modeling
- > Issues to be investigated
 - Economics
 - Safety
 - Ground freezing
 - Effects of soil pressure
 - Effects of tank leakage
 - Tank integrity monitoring
 - LH2 withdrawal

Benefits of Direct Burial

- > Decreased land usage/footprint
- > Eliminates some potential hazards
 - Vandalism
 - Fire
 - Vehicle impact
- > Inherent spill containment
- > Direct burial is preferred over vaulted configuration for additional safety
 - Eliminates confined space issues

Prior GTI/GRI Underground LNG Tank Project

- > Previous work done in mid-90s on underground LNG tank burial
- > Analytical investigation coupled with real-world empirical testing
- > Helped lead to greater acceptance of this practice



New LNG Vehicle Fueling Site With Buried Cryogenic Tanks

- > Orange County Transit Authority (OCTA)



Project Work Plan

- > Task 1: LH2 off-board storage technology analysis
 - 1.1 Design analysis of H2 off-board storage technologies
- > Go / no go decision
- > Task 2: Off-board LH2 in-ground tank testing and evaluation
 - 2.1 Analytical investigation of buried LH2 tanks
 - 2.2 Experimental facility and test of underground releases
 - 2.3 Equipment and soil instrumentation
 - 2.4 Soil preparation
 - 2.5 LH2 tank tests

LH2 Off-Board Storage Technology Analysis (Task 1)

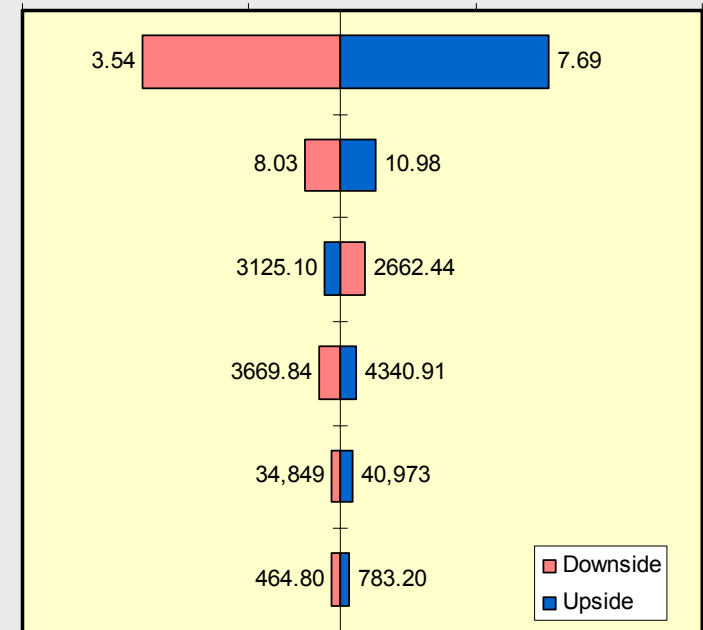
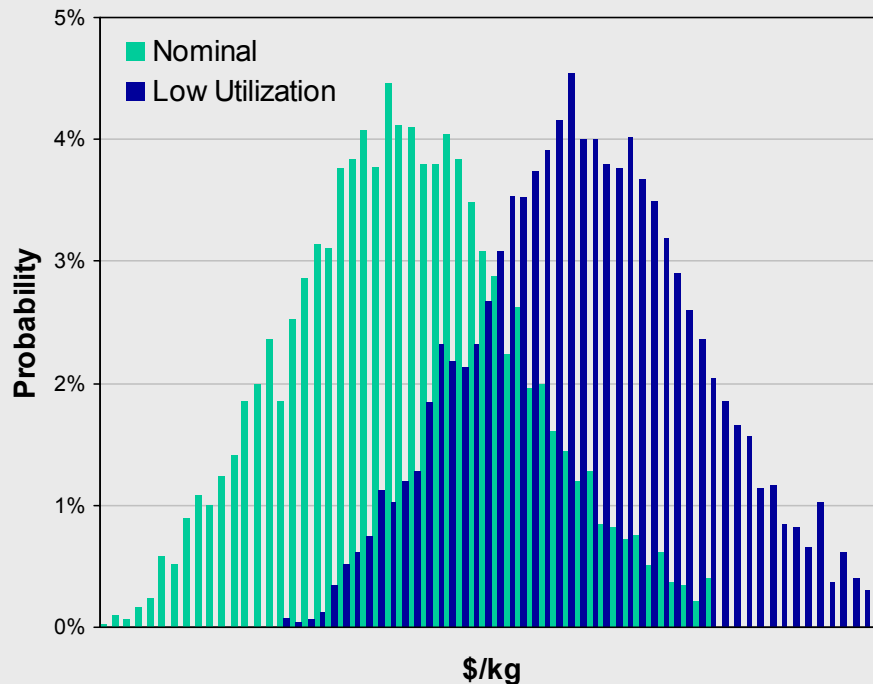
- > Design analysis for:
 - Above- and below-ground compressed H2 storage
 - Above- and below-ground LH2 storage
- > Economic analysis to include:
 - Capital cost
 - Operating cost
 - Operational issues
 - Safety elements
- > Site issues analysis to include:
 - Site requirements (system footprint, storage capacity, heat gain/boil-off, etc.)
 - Code and standards, permitting issues

Capital and Operational Cost Evaluation (Task 1.1.1)

- > Life-cycle cost model for each case (GH2, LH2 above and below ground)
 - Capital costs
 - > Site infrastructure, land, equipment, permitting
 - Operation and maintenance costs
 - > Energy, maintenance, product loss (venting), safety
 - Task will consult and coordinate with H2A and DOE/Nexant efforts

GTI's Life-cycle Cost Model

- > Includes time- and hours-of-operation-dependent costs and allowances for incentives, salvage value, and income tax effects
- > Probabilistic (Monte Carlo) and sensitivity analysis capabilities



Buried LH2 Tank Site Issues Evaluation (Task 1.1.2)

- > Site requirements
 - System footprint, H2 storage capacity, heat gain and boil-off rates, piping and fitting requirements and maintainability
 - Codes for vapor dispersion and thermal radiation zones, buffer zones, spill containment and other safety regulations
- > Code and standards issues
 - Contact and participation with appropriate organizations (ICC, NFPA, etc.)
- > Evaluate local permitting issues for Task 2 (burial of LH2 tank)

Codes and Standards

- > Underground LH2 storage allowed in ICC International Fire Code
 - §2209 Hydrogen Motor Fuel-dispensing and Generation Facilities
 - §3204 Cryogenic Fluid Storage
- > NFPA 50B does NOT allow underground storage
 - NFPA 55 will combine NFPA 50, 50A, and 50B and will allow underground storage
- > NFPA 52 (draft) will allow underground storage
- > Code changes commonly take two to three years for adoption by localities
 - Early outreach to local authorities

ICC IFC Requirements

- > §2209 contains general H2 fueling station requirements, including
 - Equipment approval/listing, location on property, dispensing, safety precautions (including venting)
- > §3204 contains underground LH2 tank requirements, including
 - Separation from other in-ground structures, fill and cover (1' earth, 4" concrete), vacuum jacket corrosion and load protection, vacuum monitoring, etc.

Go / No-Go Decision

- > At the conclusion of Task 1 (ten months) a go / no-go decision will be based on:
 - Economic viability of LH2 compared to alternatives (LH2 costs \leq alternatives)

LH2 In-Ground Storage Tank Testing and Evaluation (Task 2)

- > Task 2: Off-board LH2 in-ground tank testing and evaluation
 - 2.1 Analytical investigation of buried LH2 tanks
 - > Heat transfer modeling
 - 2.2 Experimental facility and test of underground LH2 tanks
 - > Test hydrogen dispersion profiles
 - > Evaluate methods of hydrogen leak detection
 - 2.3 Equipment and soil instrumentation
 - 2.4 Soil preparation
 - 2.5 LH2 tank tests
 - > Baseline tank heat loss test
 - > Soil moisture effect test
 - > Supplemental soil heating effects test
 - > Analytical evaluation of LH2 tank vacuum loss

Analytical Investigation of Buried LH2 Tanks (Task 2.1)

- > Analyze potential freezing of the soil layer adjacent to the buried LH2 tank
 - Model heat transfer from the soil to the LH2 tank (transient finite element analyses)
 - > Different soil compositions
 - > Depth of tank burial
 - > Ambient temperature
 - The model will be verified / updated in Task 2.5 based on field measurements
 - Quantify heat flux rate
 - > Consider supplemental heating

Experimental Facility and Test of Underground Releases of LH2 (Task 2.2)

- > Construct a scaled test facility
 - Bury a vacuum jacketed pipe to enable the release of LH2 into several test conditions
 - > Different soil compositions
 - > Dry and moist soil
 - > Several depths of release
- > Evaluate issues related to underground LH2 release
 - Test hydrogen dispersion profiles
 - Evaluate methods of hydrogen leak detection

Equipment and Soil Instrumentation (Task 2.3)

- > Temperature instrumentation of LH2 tank at several location of exterior and within vapor space of inner tank
- > Temperature instrumentation of soil space around tank consistent with analysis of Task 2.1
- > Moisture sensors at selected soil locations
- > Strain gauges at selected tank and piping locations

Soil Preparation (Task 2.4)

- > Two types of soil:
 - Clay fill
 - Sandy fill
- > Each end of buried tank will be backfilled with each type of soil
- > Apparatus for inserting moisture into the soil to be implemented

LH2 Tank Tests (Task 2.5)

- > Baseline tank heat loss test (Task 2.5.1)
 - Determine relief setting and monitor soil and tank conditions for 90 to 120 days
- > Soil moisture effect test (Task 2.5.2)
 - Reheat soil to initial conditions of prior task
 - Approach saturated soil moisture level and monitor soil and tank conditions for 90 to 120 days

LH2 Tank Tests (Task 2.5)

- > Tank shell heater effects test (Task 2.5.3)
 - Reheat soil to initial conditions of prior task
 - Maintain soil temperature via heating coils on tank exterior
 - Monitor soil and tank conditions for 90 to 120 days
- > Evaluation of LH2 tank vacuum loss (Task 2.5.4)
 - Analytical evaluation of updated model
 - Possible test with actual tank

Project Management and Reporting (All Tasks)

- > Project management
 - Overall technical, fiscal, and administrative management of the proposed project
 - Preparation of deliverables, reporting of project progress at review meetings
 - Presentation of the research results
- > Reporting
 - Status reports (quarterly and annual)
 - Oral presentation
 - Annual participation in DOE meeting, DOE Program Review and USCAR review

Gas Technology Institute

- > Independent non-profit R&D organization
- > Focus on energy and environmental issues
 - Natural gas and hydrogen emphasis
- > Over 40 years experience with hydrogen and 20 years with gaseous vehicle fueling stations



GTI's Main Research Facility



Energy & Environmental Technology Center



Cryogenic Equipment Testing

Chart Industries and NexGen

- > Chart Industries is a leading supplier for the industrial gas and hydrocarbon processing markets.
 - Cryogenic equipment used to purify, liquefy, store, and transport gases such as helium, hydrogen, nitrogen, oxygen, and natural gas for further use in industrial, commercial, and scientific applications.
 - NexGen Fueling Division meets the needs of natural gas and hydrogen vehicle markets. They supplied over 98% of on-board LNG fuel tanks for transit buses and heavy-duty trucks.

