Underground LH2 Off-Board Hydrogen Storage Technology

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

Mark E. Richards
Gas Technology Institute
25 May 2005

Project ID # STP57

This presentation does not contain any proprietary or confidential information

Overview

- Timeline
  - Task 1
    - Start: May 2005
    - End: Feb 2006
  - Task 2
    - Start: Mar 2006
    - End: Apr 2008
- 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
- Budget
  - Total project funding
    - DOE: $968,000
    - Cost share: $245,000
  - FY05: $90,000
- 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

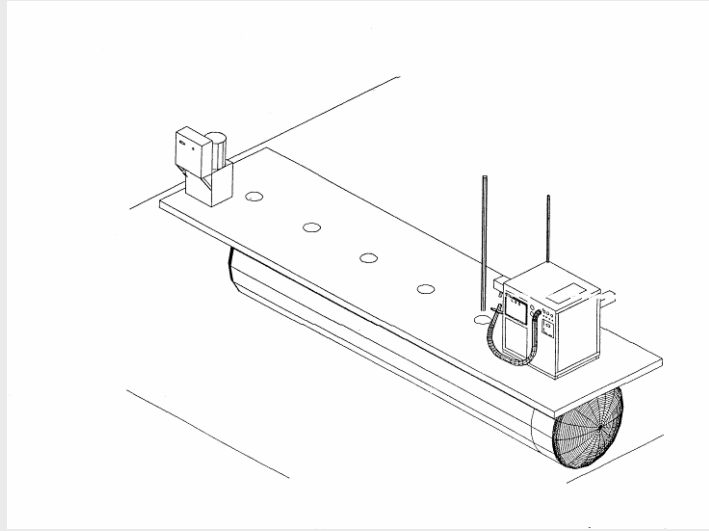
- Two tasks
  1. Design analysis and economic modeling
  2. Demonstration to validate analysis and modeling
- Issues to be investigated
  - Economics
  - Safety
  - Ground freezing
  - Effects of soil pressure
  - Effects of tank leakage
  - Tank integrity monitoring
  - LH2 withdrawal

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)

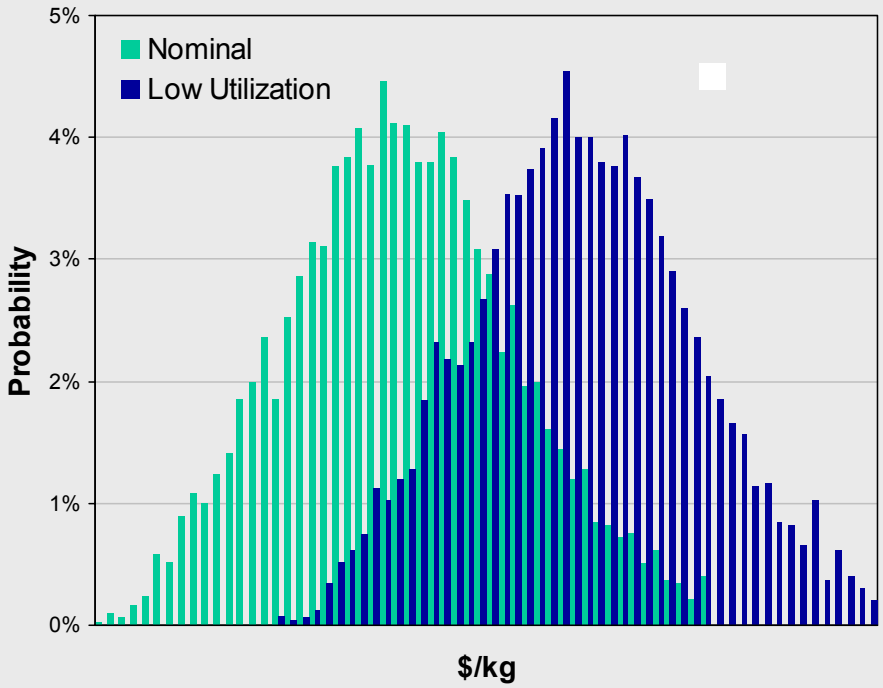
- Design analysis for:
  - Above- and below-ground compressed H2 storage
  - Above- and below-ground LH2 storage
- Economic analysis to include:
  - Capital cost
  - Operating cost
  - Operational issues
  - Safety elements
- Site issues analysis to include:
  - Site requirements (system footprint, storage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

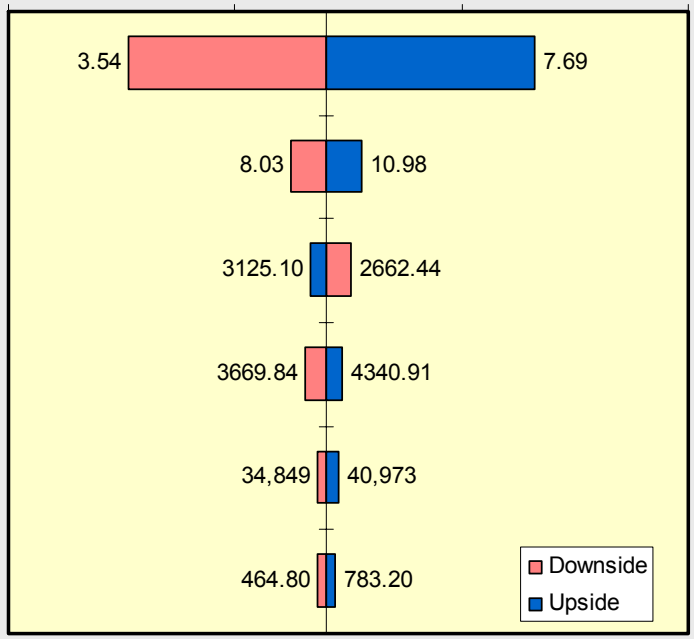
Capital and Operational Cost Evaluation (Task 1.1.1)

- 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 ≤ 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.