Development of a Turnkey H₂ Refueling Station

Project ID # PD4

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This presentation does not contain any proprietary or confidential information.
Program Objectives

- To demonstrate the economic and technical viability of a stand-alone, fully integrated H₂ Fueling Station based on reforming of natural gas
  - To build on the learnings from the Las Vegas H₂ Fueling Energy Station program.
  - Optimize the system. Advance the technology. Lower the cost of delivered H₂.

- To demonstrate the operation of the fueling station at Penn State University
  - To obtain adequate operational data to provide the basis for future commercial fueling stations

- To maintain safety as the top priority in the fueling station design and operation

Goals for Past Year:
- Complete Phase 2 – Subsystem Development (Accomplished)
- Execute Phase 3 – Subsystem Deployment (Underway)
H₂ Fueling Station at Penn State

**Feedstocks**
- Liquid H₂ Supply
- NG

**Fueling Station**
- Compression
- Storage
- H₂ Generator

**Vehicles**
- PTI, CATA, Penn State
  - H₂
  - Blend

**Processes**
- Ref.
- PSA
Total Project Budget:
- $8.929 MM

Cost Sharing:
- DOE - $5.169MM
- APCI and Partners – balance.

FY2005 Funding
- $2,083,508 Total
  - DOE = $1,187,560
  - APCI = $ 895,948

Forecast is on-budget completion of program
Goals & Targets

● DOE Technical Barriers
  ➢ Technical Validation (Section 3.5.4.2 of HFCIT Program Report), Task #3.
    • B. Storage (fast fill)
    • C. H₂ Refueling Infrastructure (cost of H₂; interface for fast-fill)
    • D. Maintenance & Training Facilities (train personnel for H₂)
    • E. Codes & Standards (lack of adopted codes & standards)

● Goal per RFP – Subtopic 5C
  ➢ “To design, develop, and demonstrate a small-scale reformer and refueling system that can produce H₂ at a cost that is within 5% of the cost, on a miles-equivalent basis, of commercially available premium gasoline.”
  ➢ >40 kg/d. $2.00 - $2.50 / kg (miles equiv basis). Utilize concepts of mass production.
  ➢ Phase 1 Study showed pathway to achieve goal.

● DOE Targets
  ➢ H₂ Production (Table 3.1.2 of HFCIT Program Report), Task #3.
    • Price of H₂ into Vehicle:
      – $3.00 / kg in 2005.
    • Efficiency:
      – PSA: 82% in 2005 (not mentioned in Jan 2005 Table)
      – Overall: 68% in 2005 (changed to 65% in Jan 2005 Table)
  ➢ Program is expected to validate these targets
Phase 1: Conceptual Design & Economic Evaluation
- Formulated & costed subsystem conceptual designs
- We believe we can demonstrate the roadmap to providing H2 fuel equivalent to gasoline prices
  - Completed, on-schedule.

Phase 2: Subsystem Development
- Develop Subsystems and Test Components
- Advance every aspect of station
- Begin station aesthetics work

Phase 3: System Deployment
- Scale-up & detailed engineering
- Fabricate & install at Penn State
- Operate and Test – Vehicles Filled
- 6 Month Operations
Approach Sub-System R&D

- Comprehensive Development Program
  - Work organized by sub-system
  - Combination of simulation, lab R&D, Real-world component testing, collaboration with vendors, and engineering design work
  - Significant progress towards DOE Targets and Barriers
**Hydrogen Generator**

Goals:
1. Advance the most cost effective natural gas reforming technology for fueling station applications.
2. Improve efficiency, reliability, capital cost, aesthetics, and footprint.
Hydrogen Generator

- Advanced SMR chosen by comprehensive technical and cost evaluation
  - Evaluated SMR, POX, ATR, CPOX
  - Received 10 quotations for commercial or near-commercial systems
  - Advanced Technology SMR’s are more cost competitive than the other evaluated technologies for small scale reforming applications used in hydrogen fueling stations
Hydrogen Generator

● Phase 1 – Advanced SMR chosen by comprehensive technical and cost evaluation
  ➢ Evaluated SMR, POX, ATR, CPOX
  ➢ Received 10 quotations for commercial or near-commercial systems
  ➢ Advanced Technology SMR’s are more cost competitive than the other evaluated technologies for small scale reforming applications used in hydrogen fueling stations

● Operation and testing of Las Vegas H₂ Energy Station
  ➢ Nothing better than real-world operating data
  ➢ Incorporating lessons learned

● Engineering Development Complete
  ➢ Optimization of desulfurization, reformer, and shift catalysts
  ➢ Improved heat recovery system
  ➢ Improved efficiency
  ➢ Improved capital costs
H₂ Generator Development

- **Improvement in All Areas:**
  - Desulfurization
  - Shift
  - Syngas Compression
  - PSA
  - Heat Exchange Train
  - Boiler, Pump
  - Utilities
    - Water Treatment
    - N₂ Purging
  - Controls
  - Packaging
  - Layout
  - Aesthetics
Purifier Development

Goals:
1. Reduce capital and operating costs of PSA system
2. Reduce footprint (volume) of PSA system
3. Increase efficiency (H2 recovery) of PSA
Purifier (PSA) Development

- PSA Technology Chosen
  - High H₂ Recovery at <1 ppm CO in H₂
  - Low capital cost
  - Maintainable

- Innovation in Multiple Areas and Functions
  - Exotic adsorbents developed for higher recovery
  - Cycle optimization to reap benefits of new adsorbents
  - Valve development for rapid cycles
  - Process/Material/Mechanical integration
  - Low cost manufacturing / systems assembly (DFMA)
  - Lab and operating plant data collected
PSA Summary

- **Engineering Work Completed**
  - System components specified
  - Mechanical design & manufacturing improvements implemented
  - DFMA, DfX, Flow CI Tools Used
  - System running at APCI H₂ Production Facility (>1.5 yrs)

- **Goals Met**
  - Achieved 2 – 4x reduction in cost of PSA when compared with commercially available units
  - New PSA Unit Much smaller than commercially available units
  - Efficiency Meets DOE 2005 Target of 82%
Compression & Storage

Goals:
1. Improve footprint, aesthetics, and cost of compression and storage.
Compression & Storage

- Investigated Storage Materials
  - Steel
  - Composites
  - Hydrides
  - Steel chosen as most cost effective for both 350 and 700 barg fueling

- H₂ Compression
  - Economic Study
    - Reciprocating, diaphragm, novel concepts
      - Spawned new DOE/APCI program – Novel H₂ Compression
    - DFMA for packaging & aesthetic impact
  - Diaphragm compressor chosen – driven by capital cost & maintenance benefits
Compression and Storage
Compression/Storage Sub-System Attributes

- High reliability, automated operation
- Totally integrated compression and cascaded fueling module
- Integrates to storage system that can be matched in size to varying fleet requirements
- Designed to operate from any large hydrogen source – electrolysis, reformer, tube trailer, liquid tank, or pipeline
- Reduced installation complexity and cost
Goals:
1. Use Sacramento and Las Vegas as starting point. Make dispenser less “industrial” and more aesthetic. Continue validation of control program.
2. Improve metering alternatives and test plan. Implement test plan.
3. Reduce cost.
Dispenser Development

- **Component Selection Completed – Dispenser Built**
  - Good for classified area – Class 1 Div 1.
  - High Pressure - Components selected for 14,000 – 20,000 psig

- **Design for Manufacturability and Aesthetics**
  - Continuous Improvement Tools – DFMA, Flow, DfX, Mistakeproofing
  - Involved fabricator in DFMA
  - Significant cost reduction and parts list reduction
External Design

From:
External Design

To:
Dispenser Development

- **Control Program (with communications)**
  - Proven accurate to within limits of instrumentation
  - To date, over 12,000 successful fills in the field – real cars
  - Ongoing lab testing (outdoors) at APCI to continue to improve

- **Some customers and/or regulations may demand a separate “custody transfer” paymeter**

- **Flow Meter Testing & Development**
  - Test skid built and in service. Test program underway.
  - 10 Meters Investigated
  - 3 Chosen for Test. All 3 Tested to Date.
Flow Meter

- Test program:

- Options: Coriolis, single and twin turbine meters
Dispenser Development

● Metering (continued)

➢ Flow Meter Testing & Development
  • Test skid built and in service. Test program underway.
  • 10 Meters Investigated
  • 3 Chosen for Test. All 3 Tested to Date.
    – Several meters achieve acceptable steady-state flow accuracy
    – However, best measured batch accuracy to date is +/- 5% over entire range of fill pressure & flowrate
      • Improvement from original +/- 30%
      • None performs to acceptable accuracy
      • Testing and vendor development continues
    – Interfacing with NIST to help write certification rules
Dispenser Progress

- Customer Feedback used to Improve Aesthetics & User Interface

- DFMA, Hazop, DFX, Flow, CI Tools

- Cost Reduction
  - Factor of >2 reduction from starting point

- Fast-Fill with Vehicle Communications
  - Accurate by calculation: +/- 0.2%
  - Much improved metering during project.
  - Metering work needs to continue in this area for the entire industry
Siting - Before

APCI, Penn State, and PTI Chose Site
- Choice: At current CNG vehicle filling site
- East end of PSU campus, by Beaver Stadium
  - Meets needs of PTI – for test track
  - Near ECEC where fuel cell research is done (Dr. Wang)
After (during)

Validation of DOE 2005 Targets

- **Las Vegas**
  - Validated <$5.00/kg

- **Penn State**
  - Capital cost reduction, maint. cost improvement, efficiency boost

- **Efficiency**
  - Integrated Station with Advanced SMR, Novel PSA, and Optimized Process
  - Meets DOE 2005 Target of 68% Overall Efficiency (LHV)

- **Refueling Station Costs**
  - Studied effect of scaling:
    - To larger H₂ production per generator
    - To mass production of stations (100 units)
  - $2.72/kg H₂ Price at Dispenser is feasible based on this program’s technology*
    - Meets DOE 2005 Target of $3.00/kg H₂
    - Pathway Re-Validated that a Stand-Alone H₂ Station can be Technically and Economically Feasible

* DOE HFCIT May 2004 Assumptions: 690 kg/day, 11% capital factor, >100 units annually, $4/MMBTU(HHV) NG, 90% utilization
Future Work

- **Operation of Station with LHy Supply**
  - Continue data collection in field
  - Support vehicle hydrogen demand

- **H2 Generator (reformer based)**
  - Integration of H2 Generator Sub-systems
  - Installation / Start-Up in October 2005

- **Vehicles**
  - Continue to collaborate with PSU, CATA, and State of PA on vehicle plan and funding for plan
  - **PSU**
    - OPP: 1 H2/CNG blend van. Converted by Collier Technology
    - PTI – HyLion FCV. Converted EV1.
  - **CATA Buses – 1st Bus Operational Late Spring 2005**
    - H2/CNG Blend
  - Additional funding for more buses expected.
Response to Reviewers’ Questions

- **Next Generation Station**
  - Build on learnings of Las Vegas Station
  - Advance technology – improve efficiency
  - Address all aspects of H₂ refueling facility design
  - Reduce cost of H₂ delivered

- **Technical Advancements**
  - PSA System Efficiency Increased
  - H₂ Generator Efficiency Increased
  - Dispenser Metering Advanced
  - System Integration Optimized
  - Results in Reduced Cost of Dispensed H₂
  - Meets DOE Targets

- **Vehicles “Not Part of Work Scope” is Unacceptable**
  - Significant effort was spent with PSU and State of PA
    - Proposal Approved by PA DEP for funding vehicle conversions and stations operating costs
      - by PSU H₂ Institute, PSU PTI, CATA, Air Products
  - Contract changed to include CNG/H₂ blend dispenser and to match the timing of station start-up with vehicle availability
Thank you
tell me more
www.airproducts.com/H2energy
Publications / Presentations

- DOE Annual Review Meeting – 2002-2004
- DOE Regional Meeting in Annapolis, MD - 2004
- NHA Annual Meeting – March 2005
- SAE Annual Meeting – 2004
Hydrogen Safety

- The most significant hydrogen hazard associated with this project is:

  - This is a comprehensive project which includes the operating demonstration of an integrated hydrogen generation, hydrogen refueling, and CNG/hydrogen refueling station. As such, several potentially hazardous situations are possible and are covered in Air Products’ safety and design reviews. The detailed HAZOP identifies the hazards and the safety measures taken to mitigate them.
Hydrogen Safety - Approach

Our approach to safety issues is comprehensive and is based upon a tremendous experience base:

Safety
- APCI has >40 years experience in safe design, construction, & operation of H2 plants.
  - > 12,000 H2 fuel fills complete to date (>75-120 per week now)
  - Leader in Management of Change, Near Miss Reporting, and Quantified Risk Assessment Procedures
- PHR: Phase 1
- HAZOP: Phases 2 & 3
- All applicable industry codes are followed
- APCI participates in SAE, ICC, ISO, HFPA, IETC, and EIHP2 committees.

Site Selection and Personnel Training
- Site concurrent with existing CNG filling station
- Personnel will be trained in H2 handling and maintenance of H2-related equipment