



# Development of a Turnkey H<sub>2</sub> 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 H<sub>2</sub> Fueling Station based on reforming of natural gas
    - To build on the learnings from the Las Vegas H<sub>2</sub> Fueling Energy Station program.
    - Optimize the system. Advance the technology. Lower the cost of delivered H<sub>2</sub>.
  - 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)

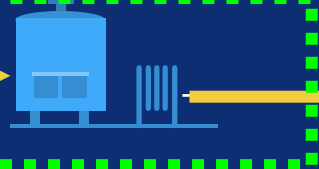
# H2 Fueling Station at Penn State

## Feedstocks

## Fueling Station

## Vehicles

Liquid H2 Supply



H2 Generator

Compression

H<sub>2</sub>

Storage



H<sub>2</sub>

Blend

PTI, CATA,  
Penn State



# Budget

- 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. H<sub>2</sub> Refueling Infrastructure (cost of H<sub>2</sub>; interface for fast-fill)
  - D. Maintenance & Training Facilities (train personnel for H<sub>2</sub>)
  - 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 H<sub>2</sub> 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

- **H<sub>2</sub> Production** (Table 3.1.2 of HFCIT Program Report), Task #3.
  - **Price of H<sub>2</sub> 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

# Three Phase Industry-DOE Project



U.S. DEPT.  
OF ENERGY



PENNSTATE



## 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 3: System Deployment

- Scale-up & detailed engineering
- Fabricate & install at Penn State
- Operate and Test – Vehicles Filled
- 6 Month Operations

## Phase 2: Subsystem Development

- Develop Subsystems and Test Components
- Advance **every** aspect of station
- Begin station aesthetics work

Oct 2001

May 2002

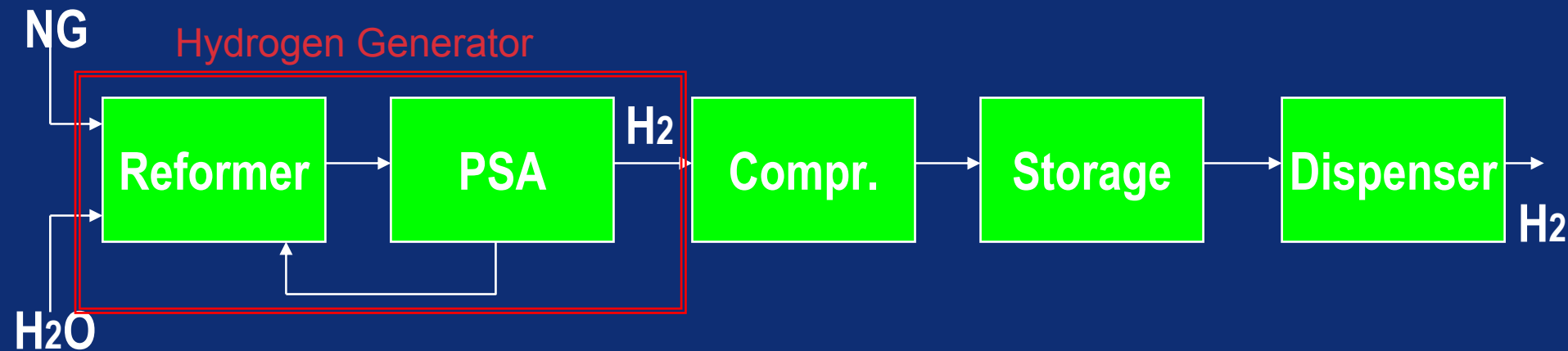
Fall 2003

Oct '04  
LHy  
Tank &  
Fueling  
Station  
Installed

Oct '05  
Generator  
Installed  
&  
On-Line

Operation

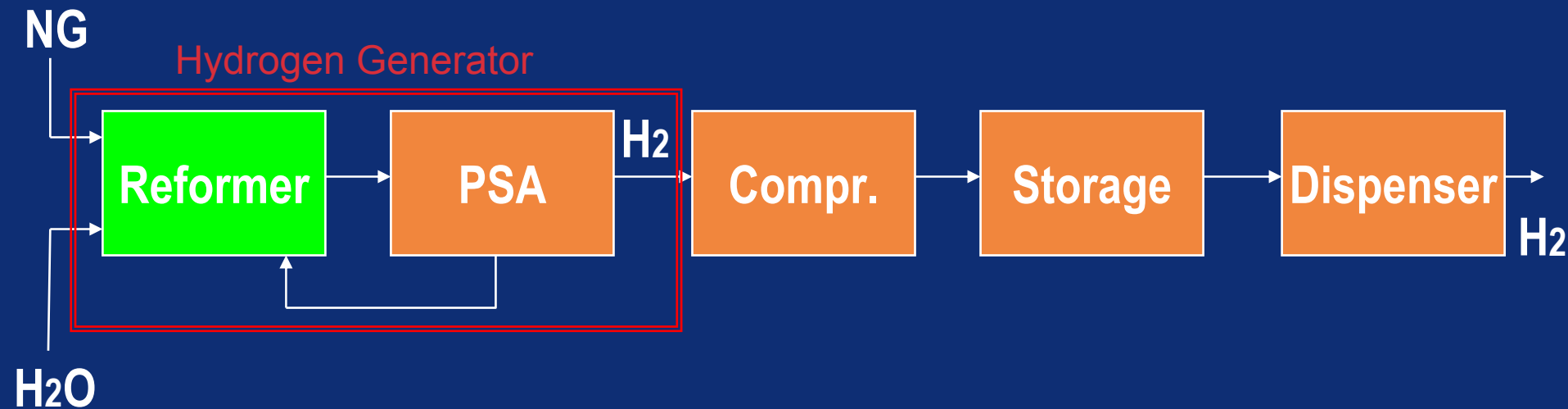
# Approach Sub-System R&D



- **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

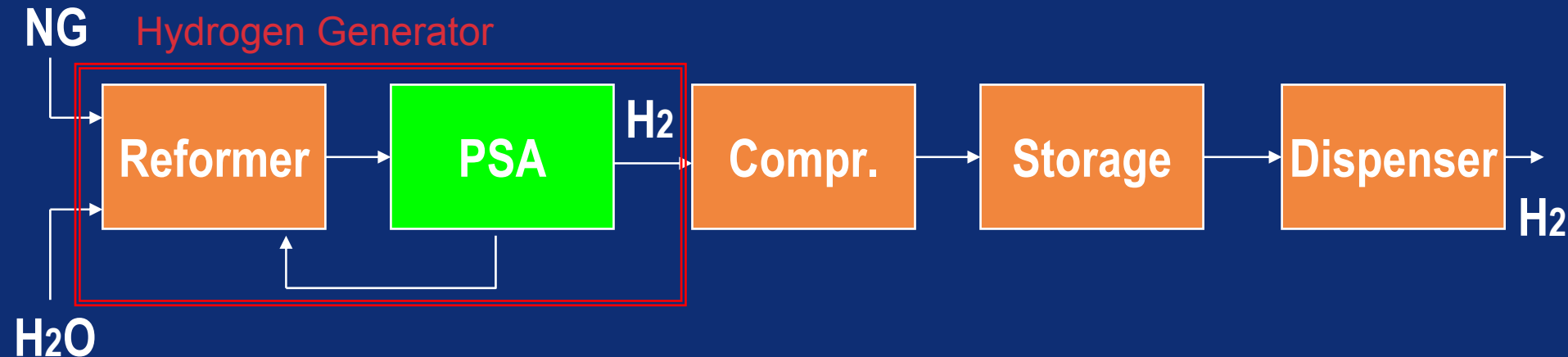
- **Phase 1 – Advanced SMR chosen by comprehensive technical and cost evaluation**
  - Evaluated SMR, POX, ATR, CPOX
  - Received 10 quotations for commercial or near-commercial systems
  - Advanced Technology SMR's are more cost competitive than the other evaluated technologies for small scale reforming applications used in hydrogen fueling stations
- **Operation and testing of Las Vegas H<sub>2</sub> 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

# H<sub>2</sub> Generator Development

- **Improvement in All Areas:**

- Desulfurization
- Shift
- Syngas Compression
- PSA
- Heat Exchange Train
- Boiler, Pump
- Utilities
  - Water Treatment
  - N<sub>2</sub> 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 (H<sub>2</sub> recovery) of PSA

# Purifier (PSA) Development

## ● PSA Technology Chosen

- High H<sub>2</sub> Recovery at <1 ppm CO in H<sub>2</sub>
- Low capital cost
- Maintainable

## ● Innovation in Multiple Areas and Functions

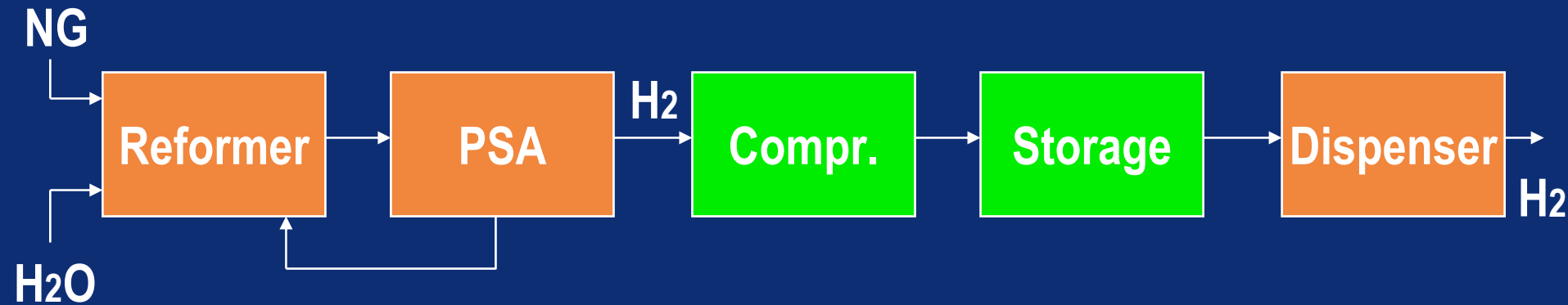
- Exotic adsorbents developed for higher recovery
- Cycle optimization to reap benefits of new adsorbents
- Valve development for rapid cycles
- Process/Material/Mechanical integration
- Low cost manufacturing / systems assembly (DFMA)
- Lab and operating plant data collected

# PSA Summary

- **Engineering Work Completed**
  - System components specified
  - Mechanical design & manufacturing improvements implemented
  - DFMA, DfX, Flow CI Tools Used
  - System running at APCI H<sub>2</sub> 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

## ● H<sub>2</sub> Compression

- Economic Study
  - Reciprocating, diaphragm, novel concepts
    - Spawned new DOE/APCI program – Novel H<sub>2</sub> Compression
  - DFMA for packaging & aesthetic impact
- Diaphragm compressor chosen – driven by capital cost & maintenance benefits



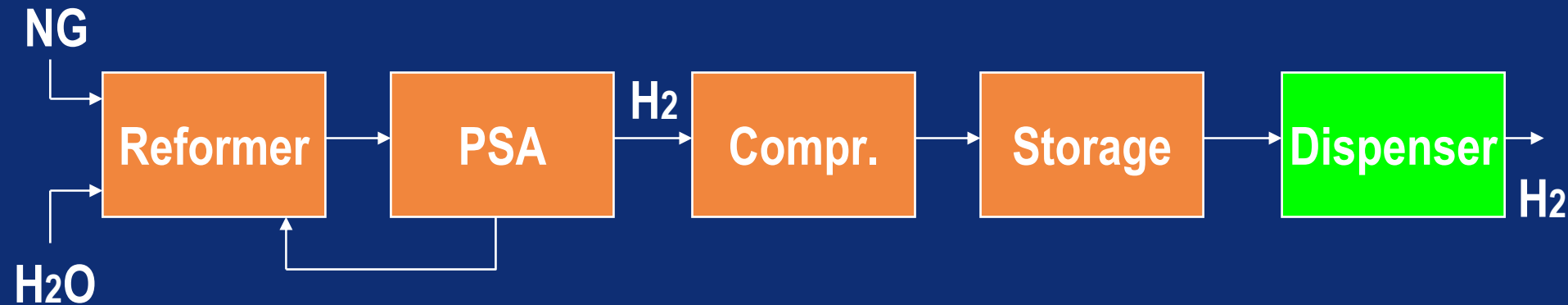
# Compression and Storage



# 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

# Dispenser Development



## 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:

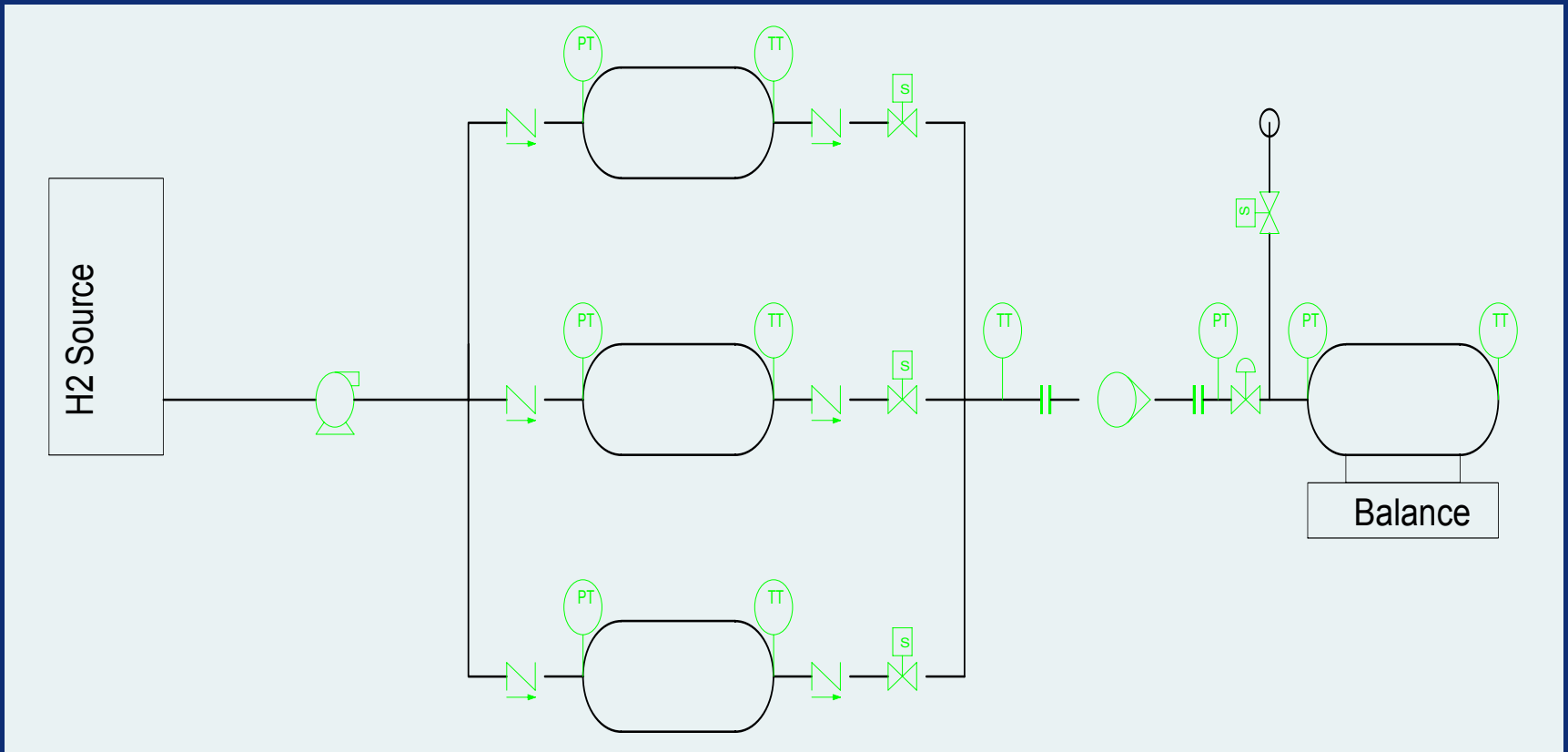


# Dispenser Development

- **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)



- LHy supply system, H2 compression, H2 storage, H2 dispenser and Blend dispenser installed Oct. 2004.



# 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 H<sub>2</sub> production per generator
    - To mass production of stations (100 units)
  - \$2.72/kg H<sub>2</sub> Price at Dispenser is feasible based on this program's technology\*
    - Meets DOE 2005 Target of \$3.00/kg H<sub>2</sub>
    - Pathway Re-Validated that a Stand-Alone H<sub>2</sub> 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 – 1<sup>st</sup> 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](http://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 H<sub>2</sub> plants.
    - > 12,000 H<sub>2</sub> 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 H<sub>2</sub> handling and maintenance of H<sub>2</sub>-related equipment