Development of a Turnkey H_2 Refueling Station

Project ID # TV5

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U.S. D.O.E. – Hydrogen Program Annual Review
May 18, 2006

Program Objectives

- To demonstrate the economic and technical viability of a stand-alone, fully integrated H_2 Fueling Station based on reforming of natural gas
  - To build on the learnings from the Las Vegas H_2 Fueling Energy Station program.
  - Optimize the system. Advance the technology. Lower the cost of delivered H_2.

- 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

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- Goals for Past Year:
  - Execute Phase 3 – Subsystem Deployment (Completed)
  - System Operation – Underway, ongoing.

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Goals & Targets

- DOE Technical Barriers
  - Technical Validation (Section 3.5.4.2 of HFCIT Program Report), Task #3.
    - B. Storage (fast fill)
    - C. H_2 Refueling Infrastructure (cost of H_2; interface for fast-fill)
    - D. Maintenance & Training Facilities (train personnel for H_2)
    - 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.
  - Using 2.2 – 2.6 "EER", goal was: \$4.40 - \$6.50 / kg into vehicle
  - Phase 1 Study showed pathway to achieve goal.

- DOE Targets
  - **H_2 Production** (Table 3.1.2 of HFCIT Program Report), Task #3.
    - **Price of H_2 into Vehicle:**
      - \$3.00 / kg. (now \$3.00/gge at \$0.05/kwh power and \$5.00/MMBTU NG)
    - **Efficiency:**
      - Overall: 65%.
  - Program is expected to validate these targets
  - Reviewed by DOE Tech Team…. "Deep Dive" Meeting… Feb 2006

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Three Phase Industry-DOE Project

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

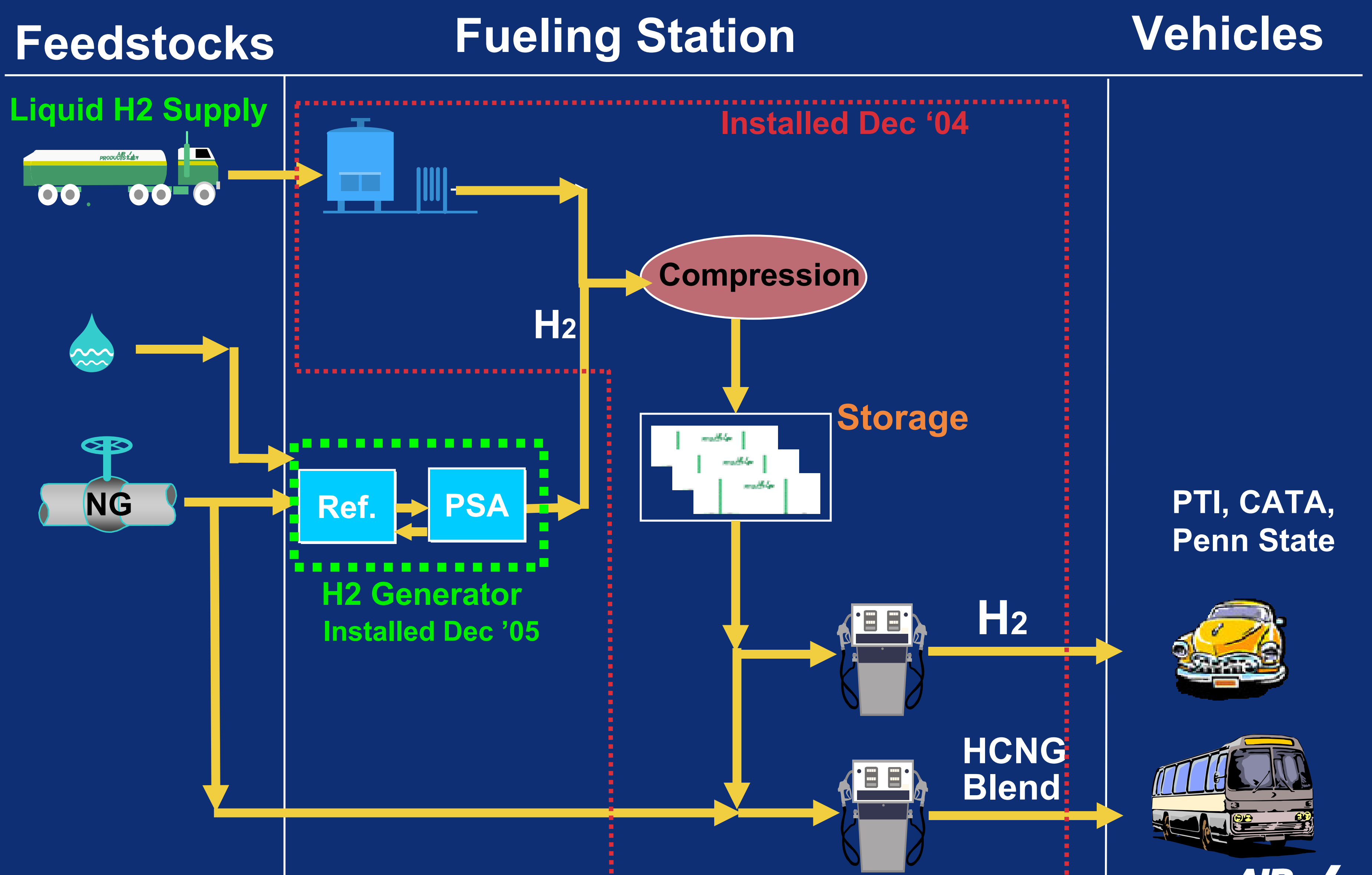
- Scale-up & detailed engineering
- Fabricate & install at Penn State
- Operate and Test – Vehicles Filled
- 6 Month Operations

Oct 2001 — **May 2002** — **Fall 2003** — Oct '04 Station On-Line — Dec '05 Generator On-Line

Phase 2: Subsystem Development

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

H_2 Fueling Station at Penn State



Budget

- **Total Project Budget**
  - $10.910 MM
  - 54% DOE / 46% AP & Partners

- **FY2006 Spending**
  - $1.951 MM
  - $ .960 MM DOE (49%)

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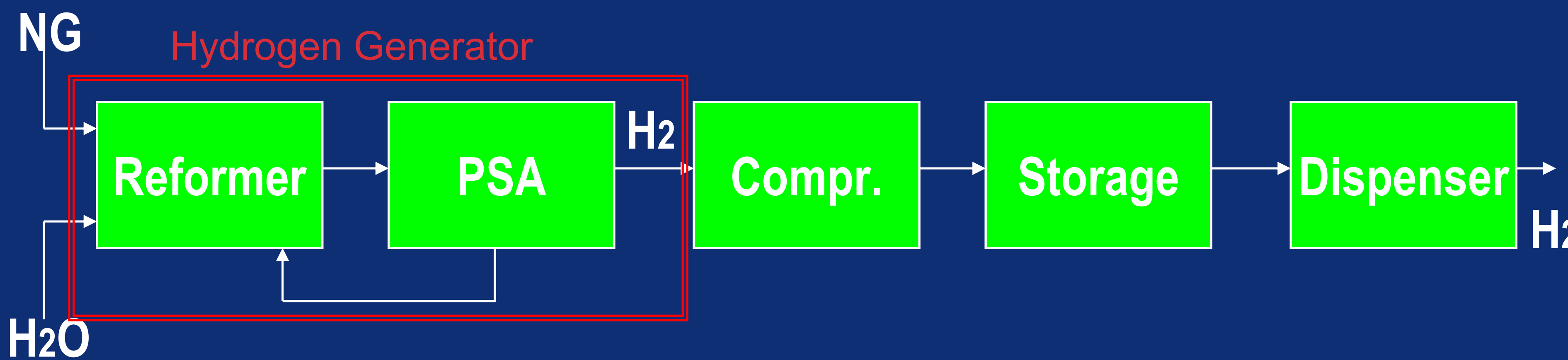
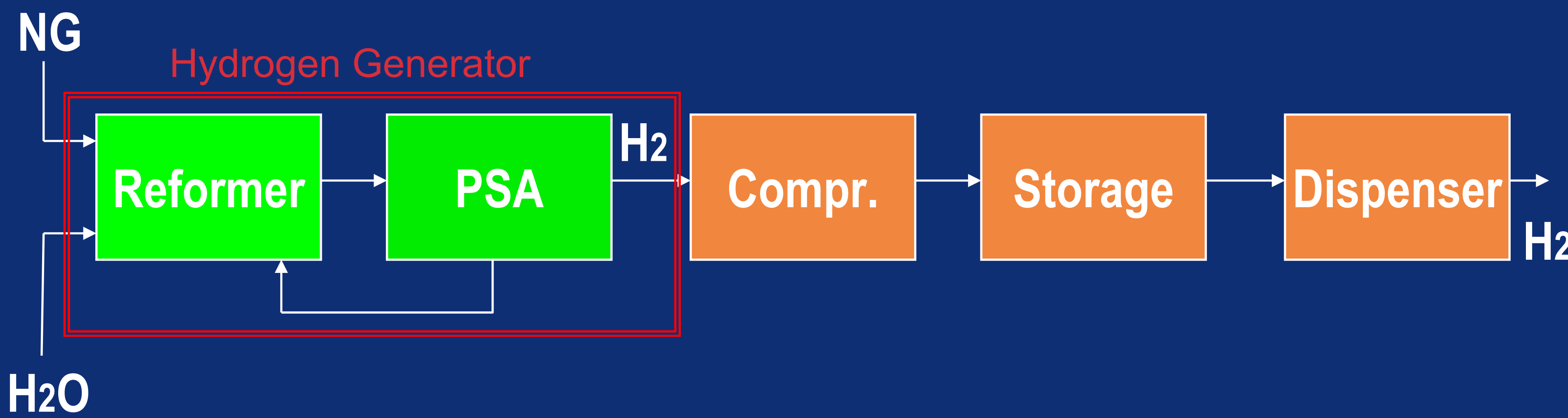
Approach Sub-System R&D



- **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

H2 Generator

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_2 Energy Station**
  - Nothing better than real-world operating data
  - Incorporating lessons learned

- **Engineering Development**
  - Optimization of desulfurization, reformer, and shift catalysts
  - Improved heat recovery system
  - Improved efficiency
  - Improved capital costs
  - Improved packaging and aesthetics
  - Designed for maintenance/operability

Desulfurizer Beds

- Ambient temperature adsorbent system chosen
  - Worked with catalyst supplier – developed multi-bed system
  - Sized for “national average” NG specification
  - 12 month run prior to change-out
  - Sample ports included at 75% and 100% up the bed for monitoring sulfur

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Shift Reactor

- Chose: Precious metal, monolithic catalyst
  - Start-Up faster and more robust
- Low pressure drop design
- Integrated heat exchange train for maximum heat recovery/overall efficiency
- CFD model used to design vessel and distributor

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Syngas Compressor

- Investigated multiple vendors
- Chose: reciprocating air-cooled compressor
- Significant reliability improvement expected
- More compact than L.V.

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PSA Summary

- **Engineering Work Completed**
  - System components specified
  - Mechanical design & manufacturing improvements implemented
  - DFMA, DfX, Flow CI Tools Used
  - System running at APCI H_2 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%

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H_2 Generator Development

- **Water Treatment / Cooling Water / Utilities:**
  - All reformer vendors put the utilities in the scope of the customer
    - We developed a utility sub-system (island) that incorporates water treatment, cooling water system, and instrument air
  - Water Treatment:
    - Low pressure reforming minimizes treatment required
    - Chose water softener and RO system
    - Upgraded water pump from L.V.
  - Cooling Water
    - Investigated air cooling and closed loop cooling water
    - Chose closed-loop water for process trim cooler
    - Chose air-cooled syngas compressor – economic choice
  - **Utility Island Approach**
    - Deployable with any Hydrogen Generator system

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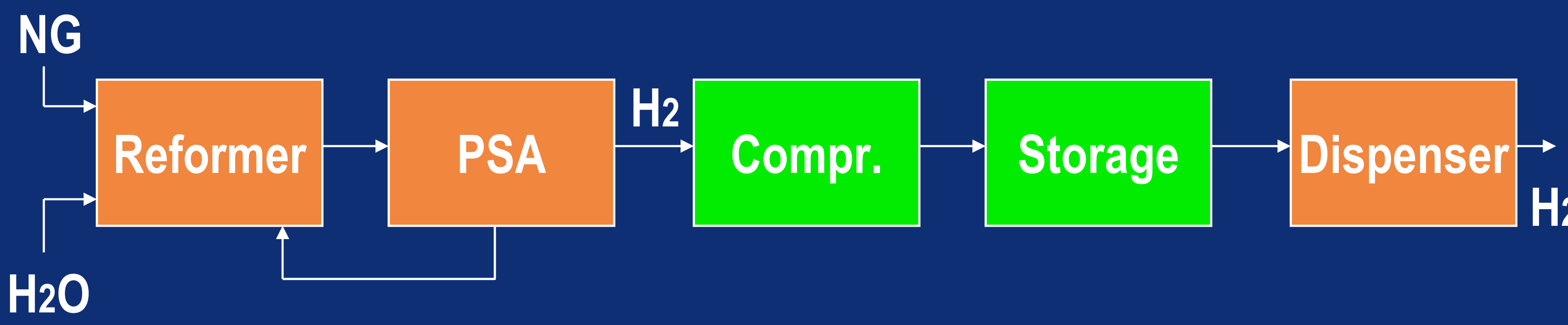
Utility "Island"

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_2 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

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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

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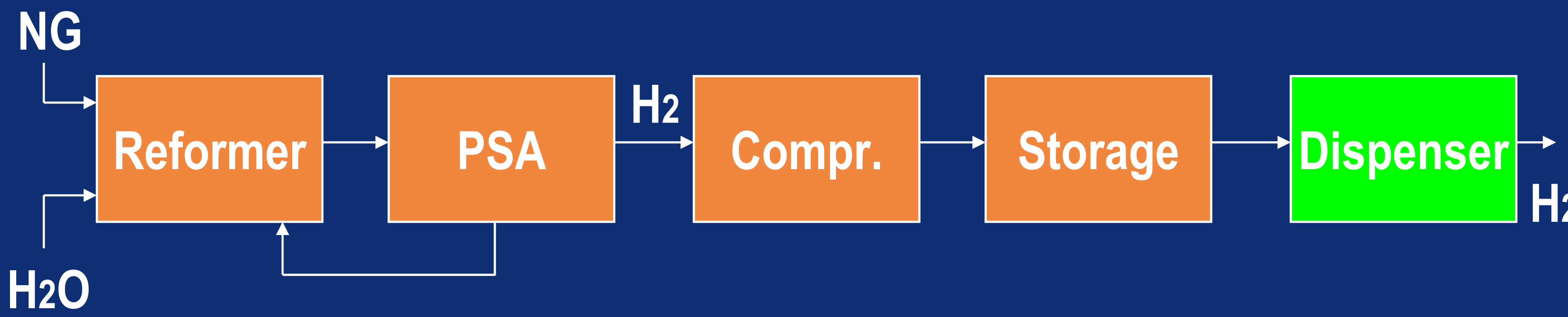
Series 300 Compression Module

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 Class 1 Div 1 electrical classification
  - High Pressure
    - Storage Vessels can supply up to 7,000 psig
    - Dispenser components selected for 14,000 – 20,000 psig
- **Design for Manufacturability and Aesthetics**
  - CI Tools – DFMA, Flow, DfX, Mistake-proofing
  - Involved fabricator in CI Events
  - Significant cost reduction and parts list reduction

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External Design

- From:

External Design

- To:

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 (late 2004)

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

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December 2005

December 2005

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System Operation

- Vehicles filled since December 2004
- H2 Generator Start-Up in December 2005
- H2 Generator Commissioning and 1^{st} Performance Test Through March 2006
  - Achieve 51 nm3/hr: 100% rates
  - Achieve overall efficiency of 65.1%
    - Assumed electrical consumption per design. Full Performance Test in summer.
    - System optimization continues.
    - 1 Generator Trip to date
- Start of “Operating Period” April 1, 2006

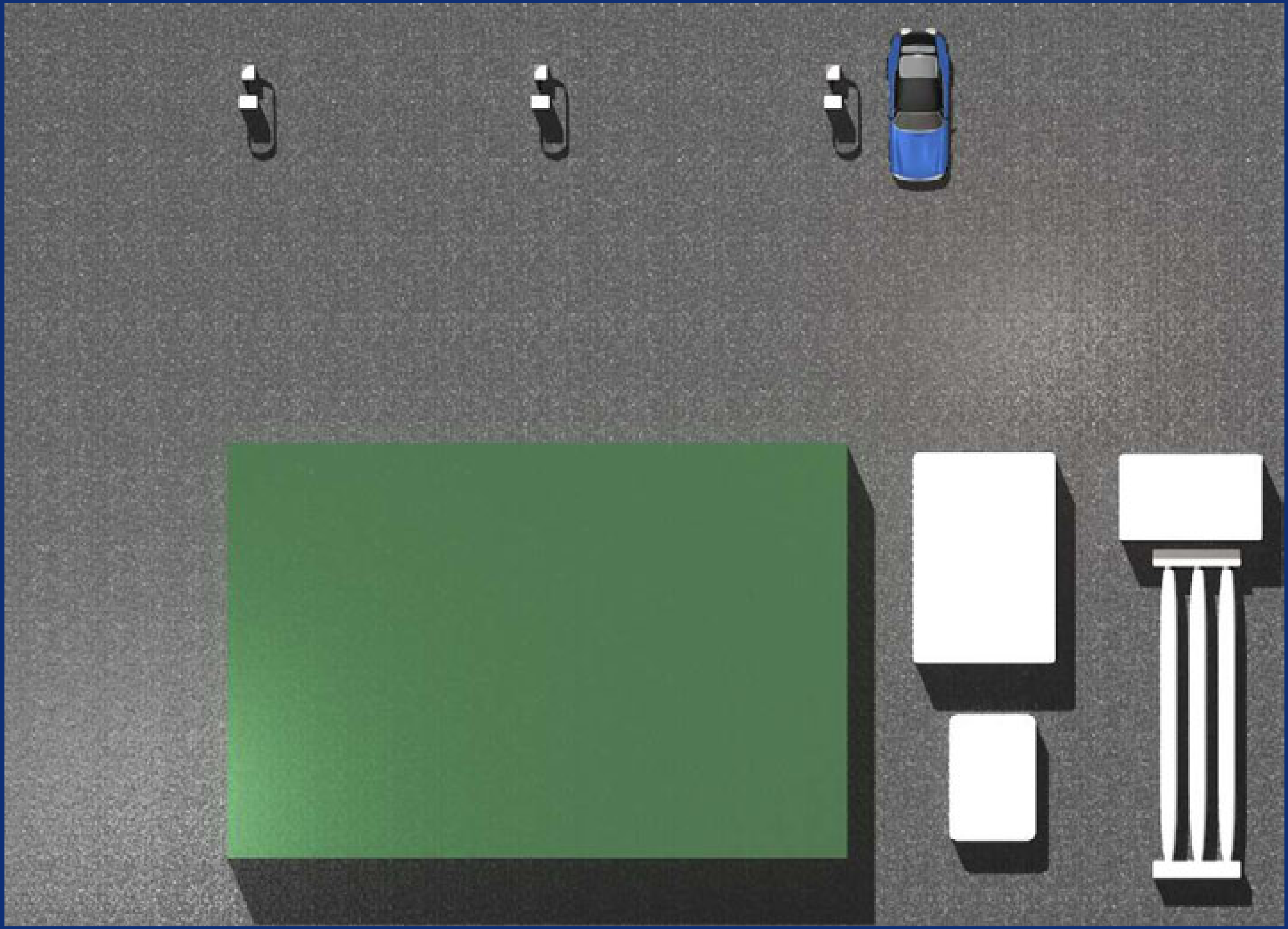
Economics: H2A Results

	Base	Large Scale, H2A Inputs
H2 Production, kg/d	108	1500
Utilization, %	70	70
Overall Efficiency, %	65.1	65.1
Units Produced per Year	5	500
IRR, %	10	10
Power Cost ($/kwh)	0.08	0.08
NG Cost ($/nm3)	0.175	0.175
Calc'd H2 Cost ($/gge)	13.98	3.03

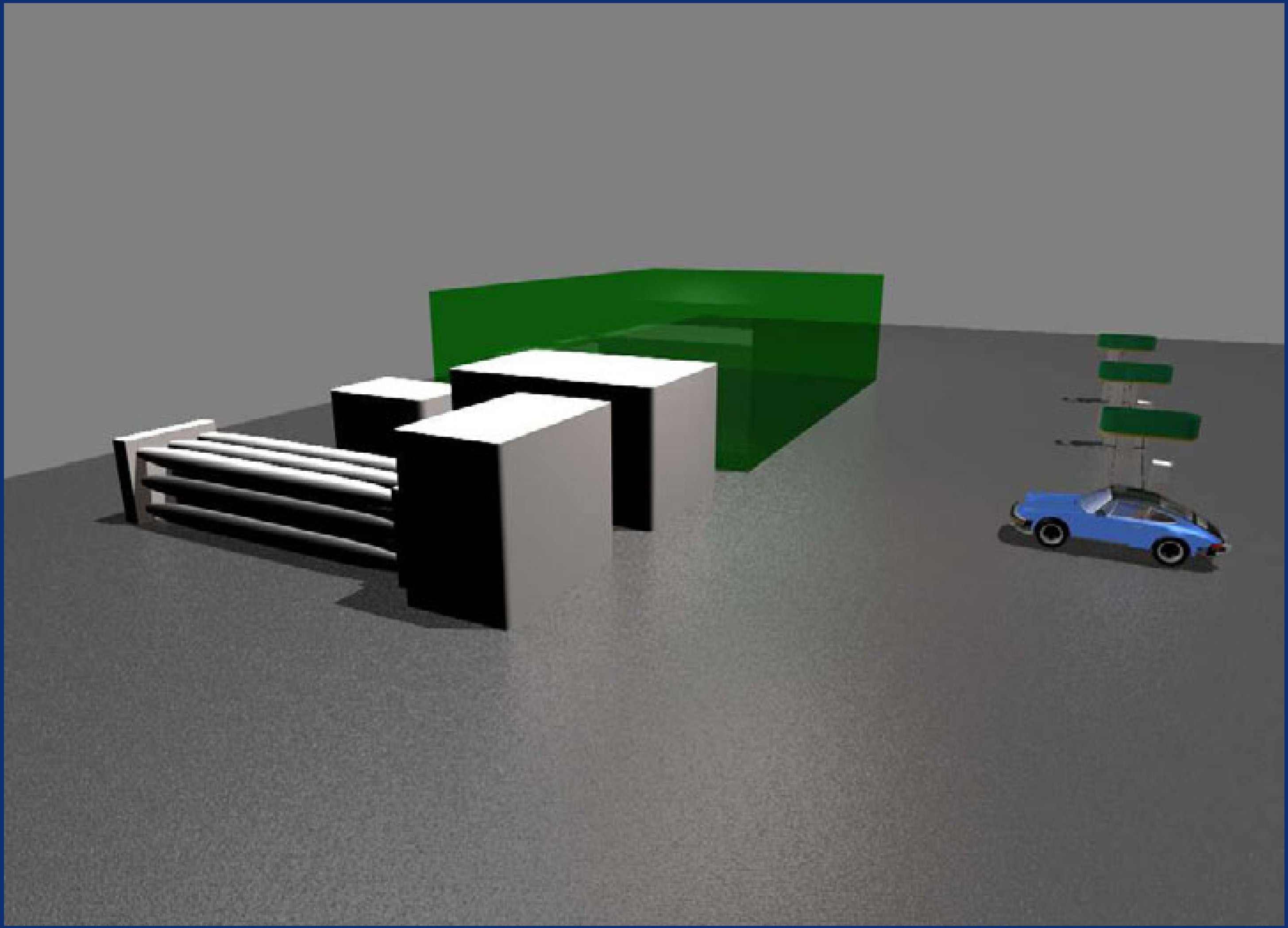
Target 65%

Target $3.00

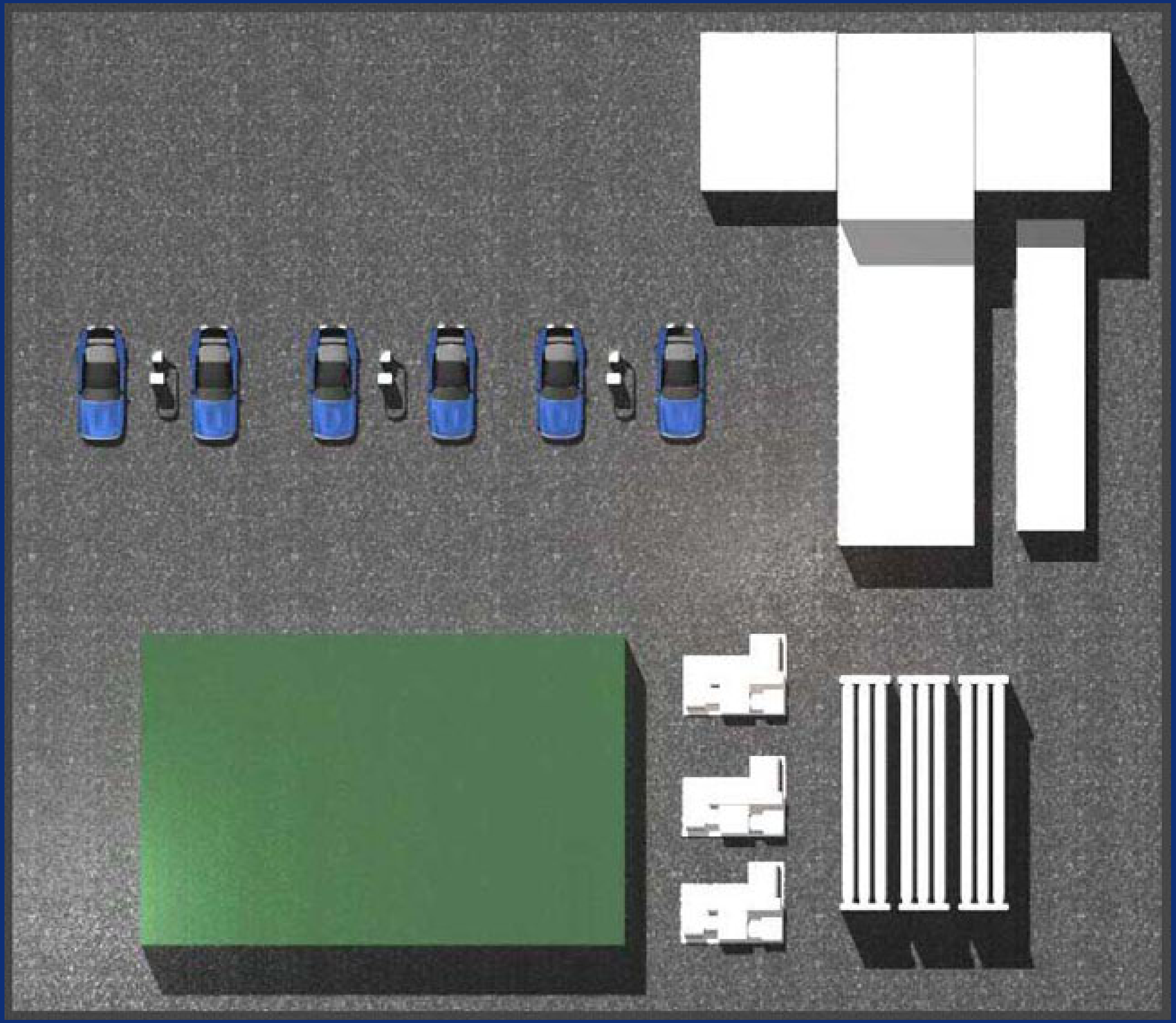
110 kg/day Station



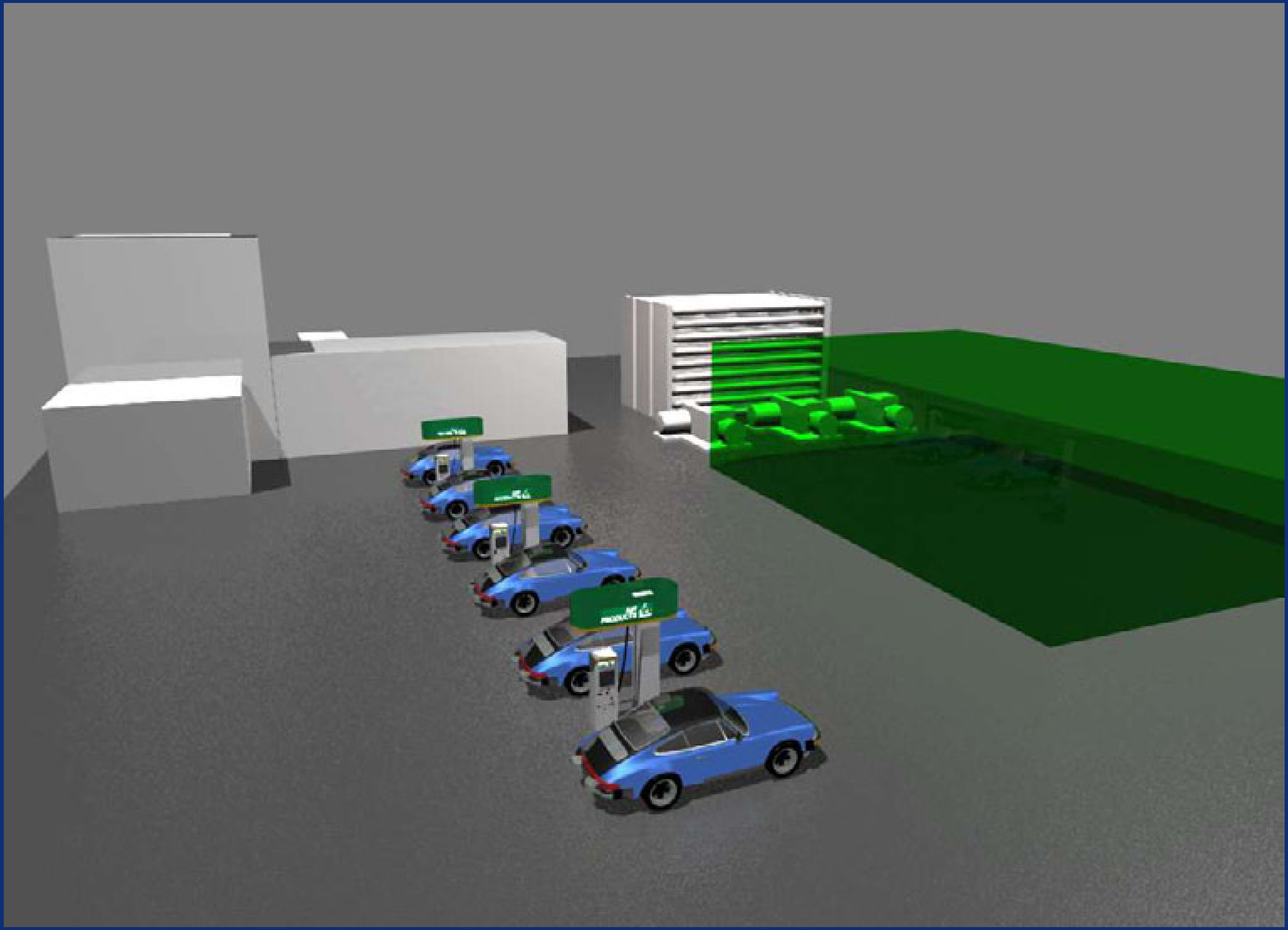
110 kg/day Station



1500 kg/day Station



1500 kg/day Station



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Future Work - Next Steps

- **Operating Period**
  - 6 Months
  - Collect and report data
  - Optimize efficiency

- **Execute Vehicle Plan – Load the Station**
  - HCNG Vans
  - HCNG CATA Buses
  - H_2 FCV Cars

Response to Reviewers' Questions

- **Next Generation Station**
  - Build on learnings of Las Vegas Station
  - Advance technology – improve efficiency
  - Address all aspects of H_2 refueling facility design
  - Reduce cost of H_2 delivered
  - Demonstrated efficiency improvement in first performance test
- **There will not be time available to collect data from overall system**
  - 6 month operating period, per Cooperative Agreement
  - Working with DOE for operating period and data collection extension

Thank you

tell me more

www.airproducts.com/H2energy

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Publications / Presentations

- DOE Annual Review Meeting – 2002-2005
- DOE Regional Meeting in Annapolis, MD - 2004
- NHA Annual Meeting – March 2005
- SAE Annual Meeting – 2004
- DOE Technical Team Review at Penn State – February 2006

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.*

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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_2 plants
    - > 15,000 H_2 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. Completed ORI during commissioning
  - All applicable industry codes are followed
  - APCI participates in SAE, ICC, ISO, NFPA, IEC committees

- **Site Selection and Personnel Training**
  - Site concurrent with existing CNG filling station
  - Personnel trained in H_2 handling and maintenance of H_2-related equipment
    - PTI and CATA people received classroom training on H2 and dispenser systems
    - PSU’s first-responders trained on H2 and site safety issues (excellent response – approx 30 people)

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