



# Development of a Turnkey H<sub>2</sub> Refueling Station

## Project ID # TV5

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

# 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.
- 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<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. (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

# 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  
Station  
On-Line

Dec '05  
Generator  
On-Line

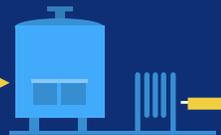
# H<sub>2</sub> Fueling Station at Penn State

## Feedstocks

## Fueling Station

## Vehicles

Liquid H<sub>2</sub> Supply



Installed Dec '04

Compression

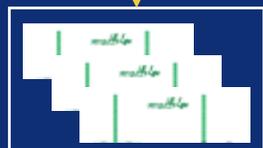
H<sub>2</sub>

Storage

Ref.

PSA

H<sub>2</sub> Generator  
Installed Dec '05



H<sub>2</sub>

HCNG  
Blend

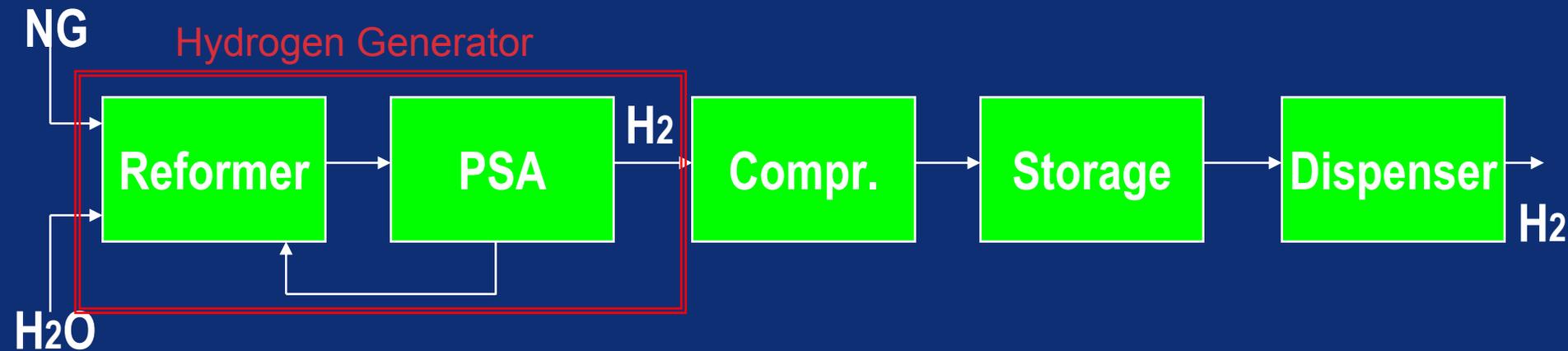
PTI, CATA,  
Penn State



# Budget

- **Total Project Budget**
  - \$10.910 MM
  - 54% DOE / 46% AP & Partners
  
- **FY2006 Spending**
  - \$1.951 MM
  - \$ .960 MM DOE (49%)

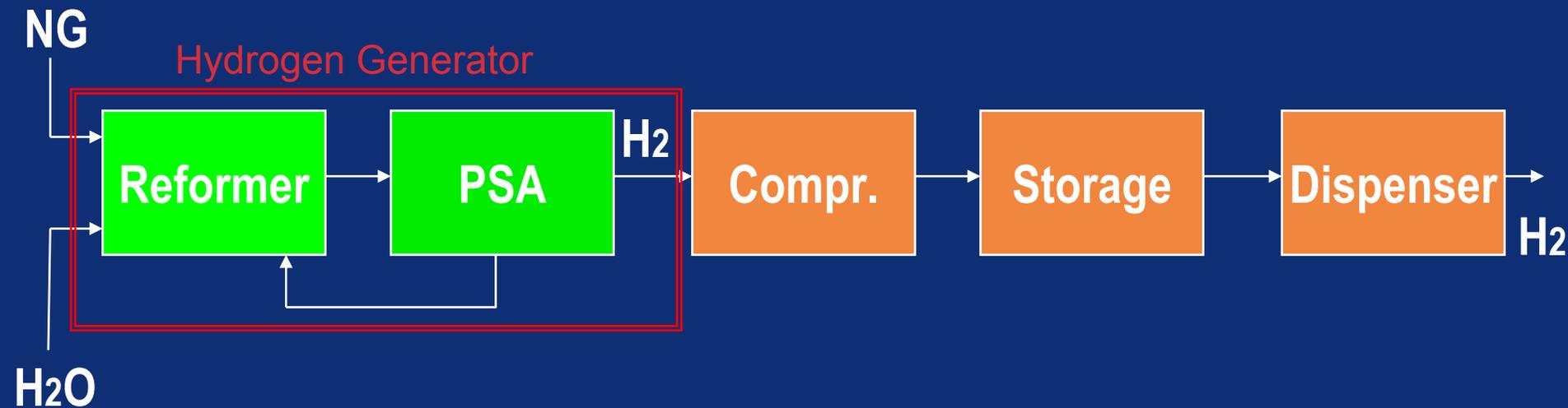
# Approach Sub-System R&D



- **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<sub>2</sub> 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



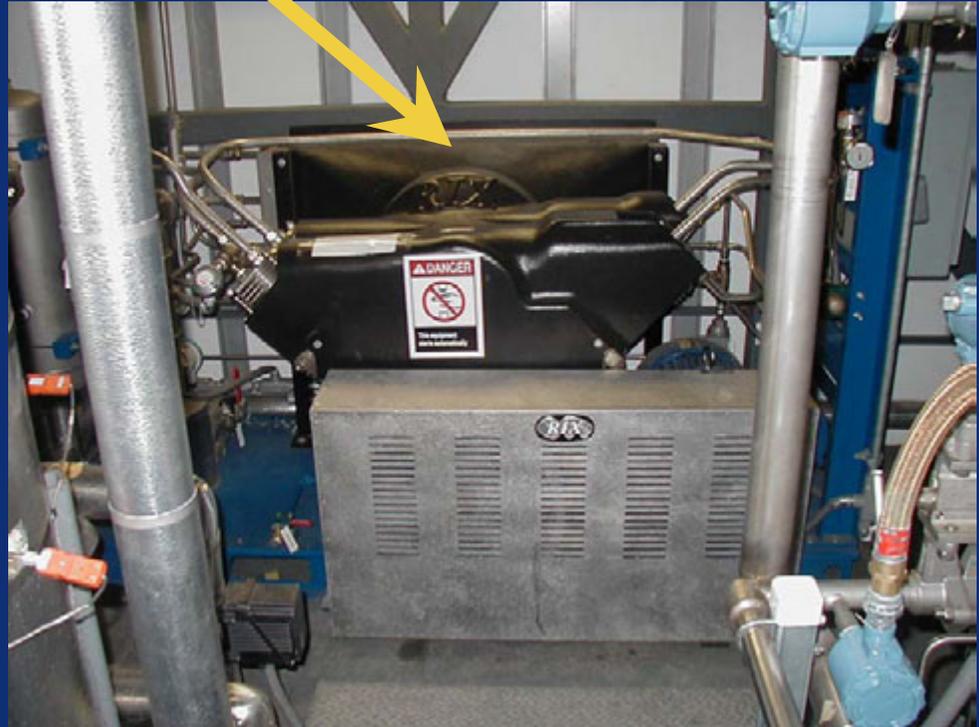
# Shift Reactor

- 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



# Syngas Compressor

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



# 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%



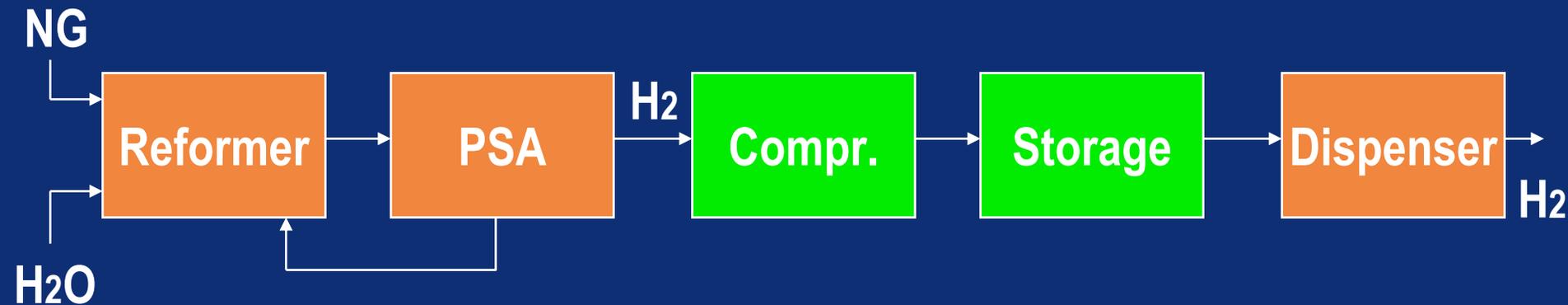
# H<sub>2</sub> Generator Development

- **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

# 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<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



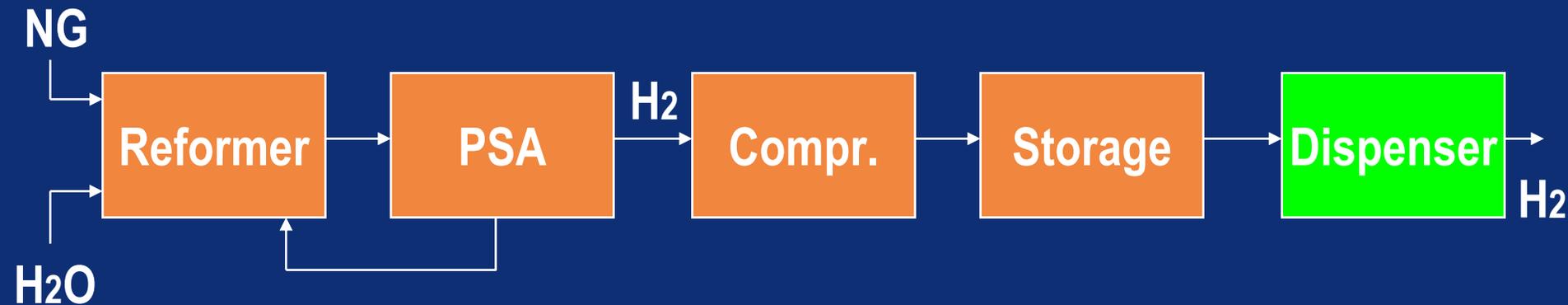
# Compression/Storage Sub-System Attributes

- 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

# 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

# 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.

# December 2005



# December 2005







# System Operation

- Vehicles filled since December 2004
- H2 Generator Start-Up in December 2005
- H2 Generator Commissioning and 1<sup>st</sup> Performance Test Through March 2006
  - Achieve 51 nm<sup>3</sup>/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

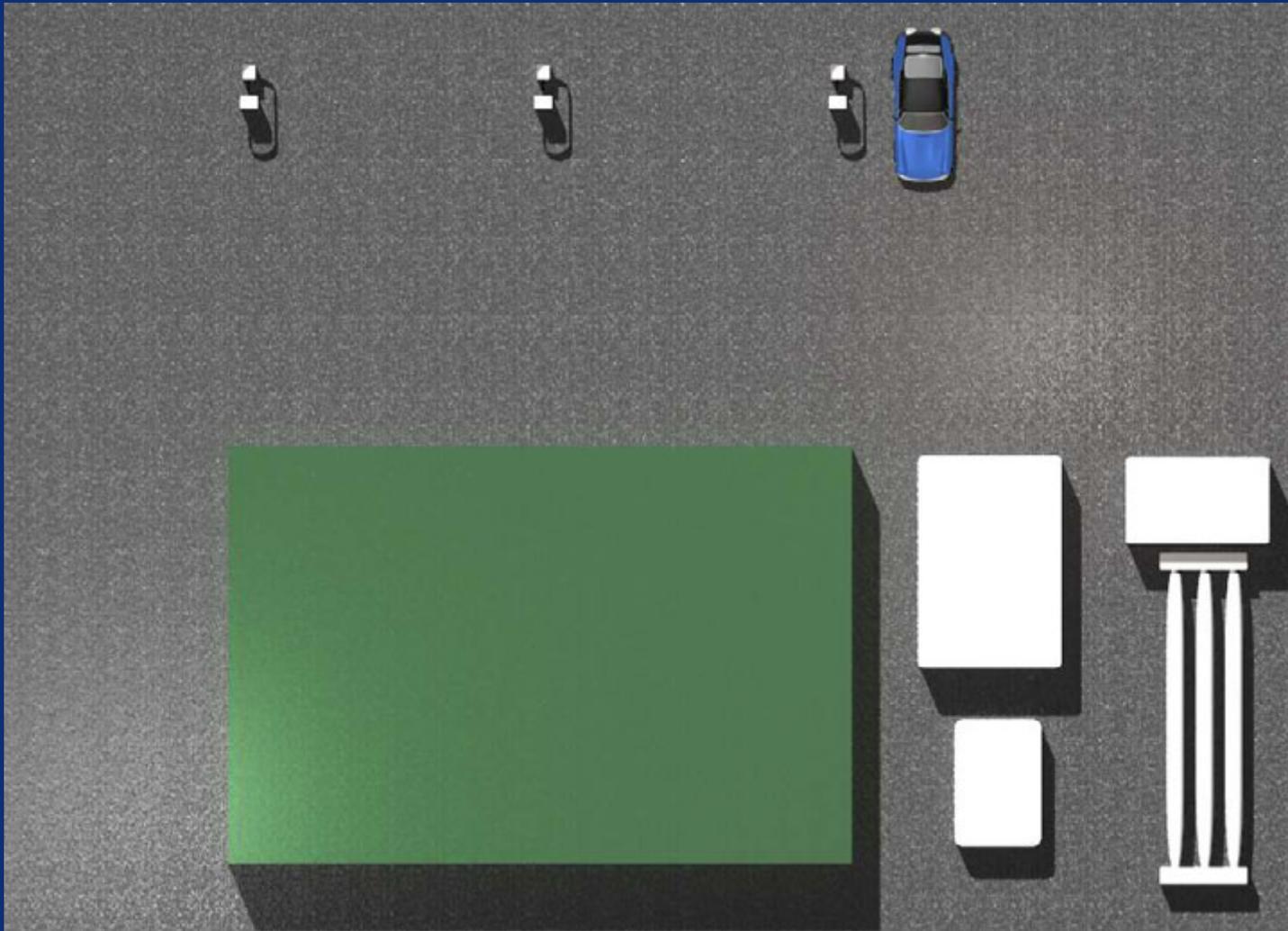
# Economics: H2A Results

	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

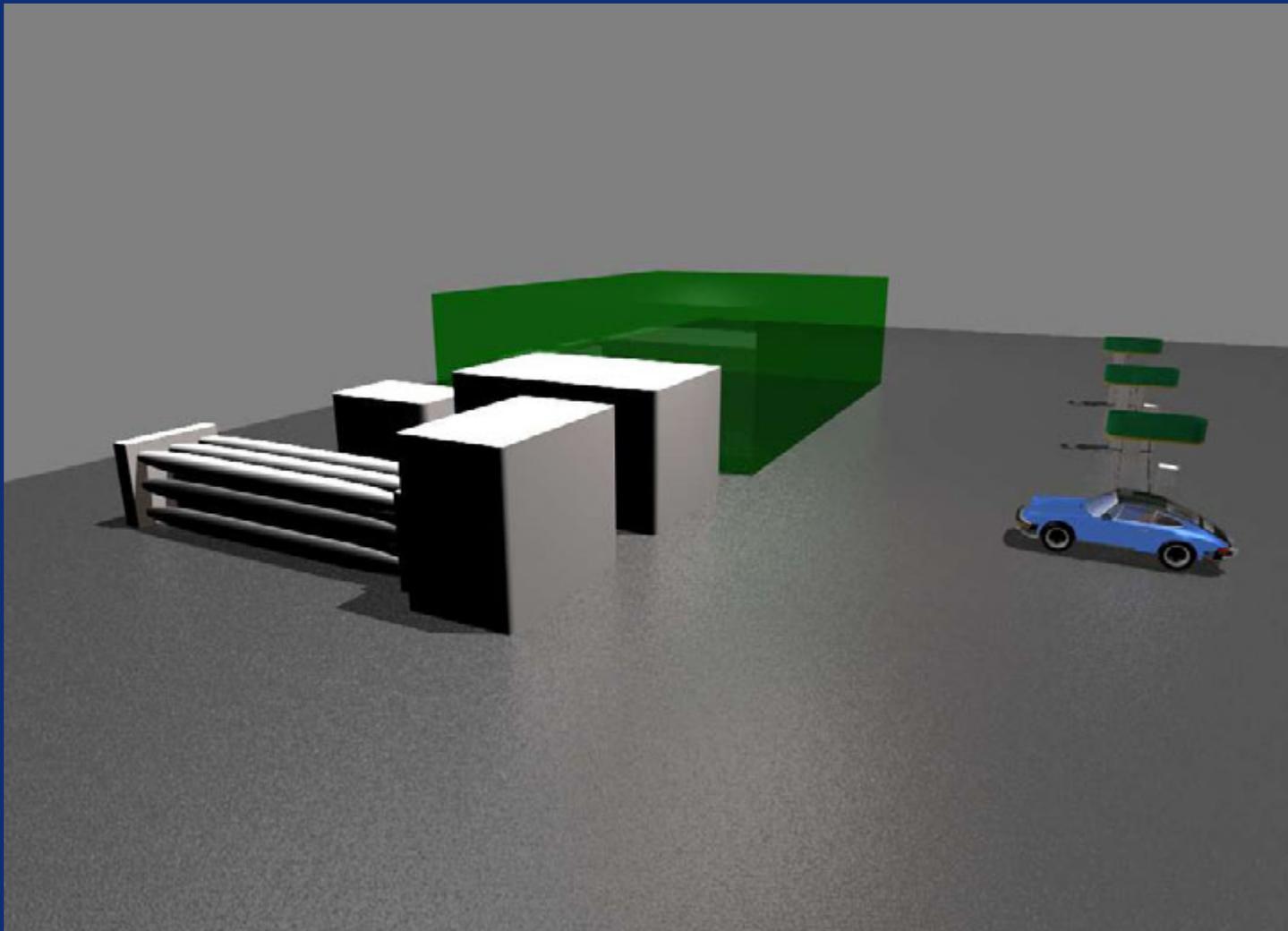
Target 65%

Target \$3.00

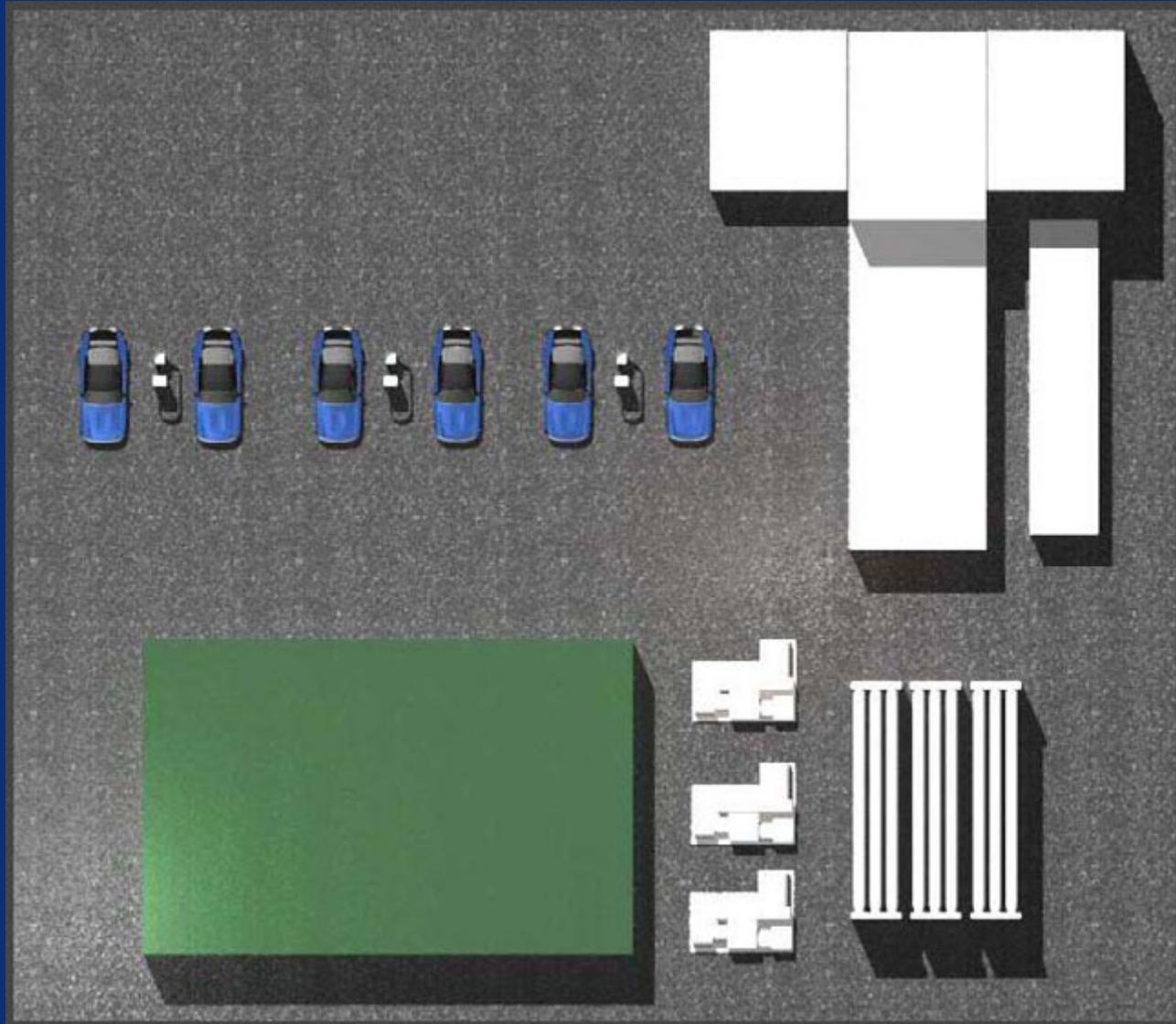
# 110 kg/day Station



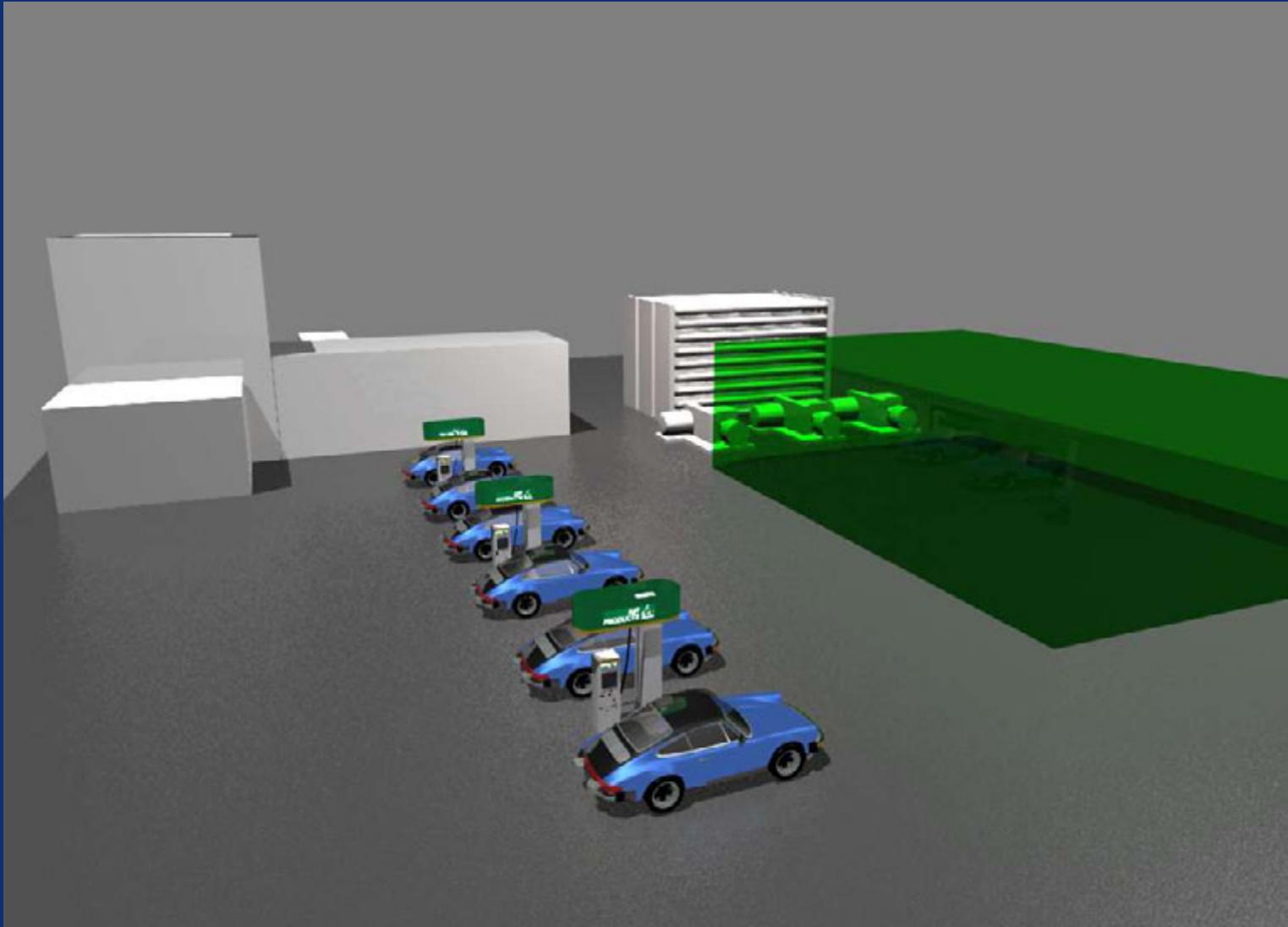
# 110 kg/day Station



# 1500 kg/day Station



# 1500 kg/day Station



# 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<sub>2</sub> FCV Cars

# 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
- 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](http://www.airproducts.com/H2energy)

# 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.*

# 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
    - > 15,000 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. 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<sub>2</sub> handling and maintenance of H<sub>2</sub>-related equipment
    - PTI and CATA people received classroom training on H<sub>2</sub> and dispenser systems
    - PSU's first-responders trained on H<sub>2</sub> and site safety issues (excellent response – approx 30 people)