Development of a Turnkey H2 Refueling Station

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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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- Goal for Past Year: Complete Phase 2 – Subsystem Development (Accomplished scheduled tasks)

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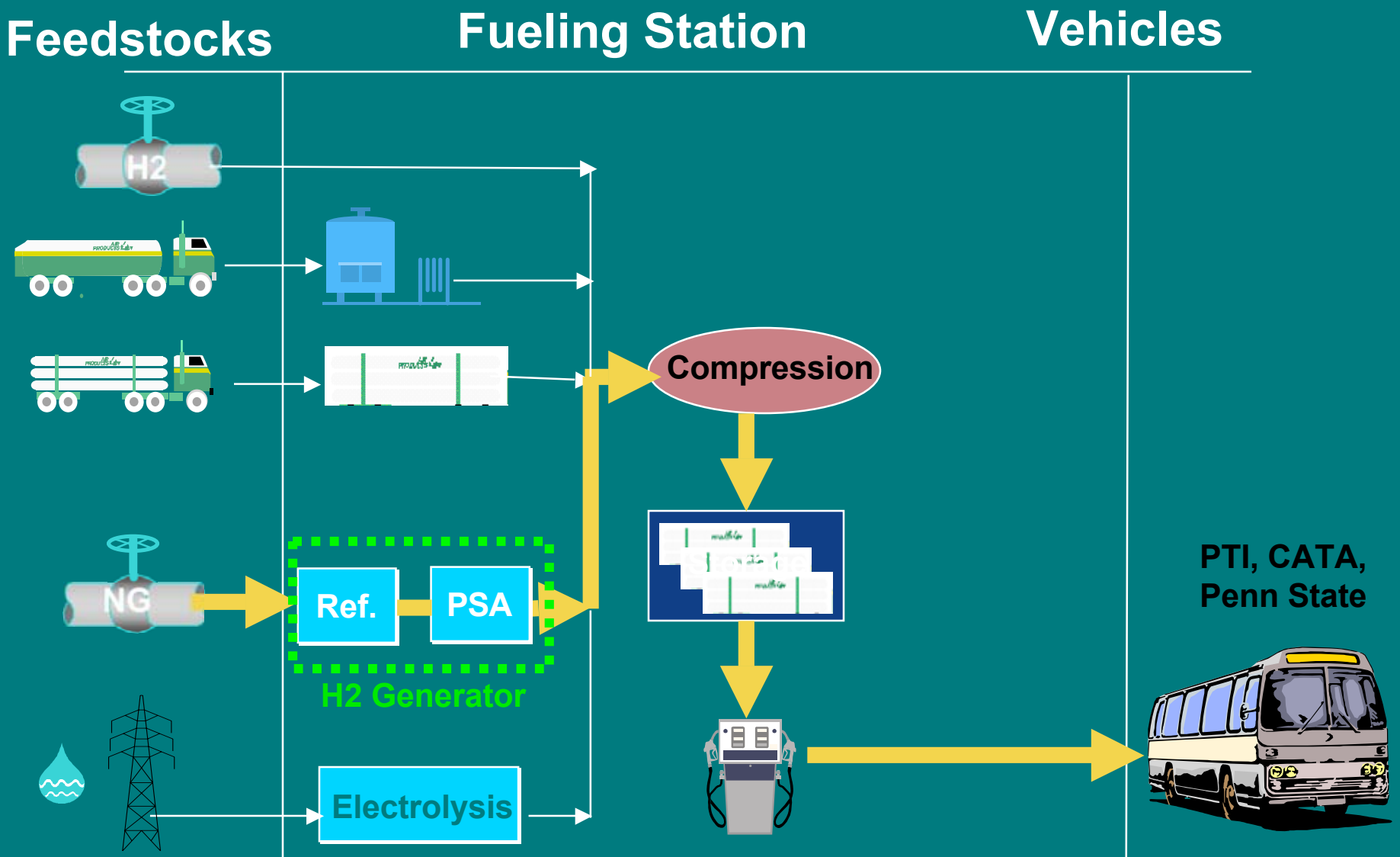
H_2 Fueling Station at Penn State



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Budget

- Total Project Budget:
  - $8.929 MM
- Cost Sharing:
  - DOE - $5.169MM
  - APCI and Partners – balance.
- FY2004 Funding
  - $938,000 Obligated by DOE

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Technical Barriers and 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)

- DOE Targets
  - H_2 Production (Table 3.1.2 of HFCIT Program Report), Task #3.
    - Cost of H_2:
      - $3/kg 2005.
    - Efficiency
      - PSA: 82% by 2005.
      - Overall: 68% by 2005.

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Three Phase Industry-DOE Project

AIR PRODUCTS

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

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

Phase 2: Subsystem Development

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

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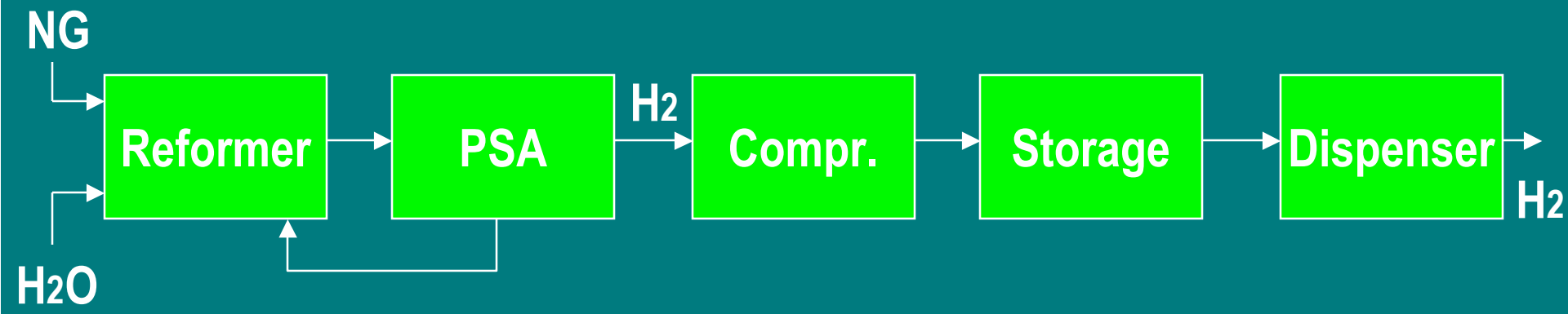
Approach for Phase 2 – Sub-System R&D



- **Comprehensive Development Program**
  - Work has been 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
  - Budget constraints required a re-adjustment of schedule, but not scope of reformer development

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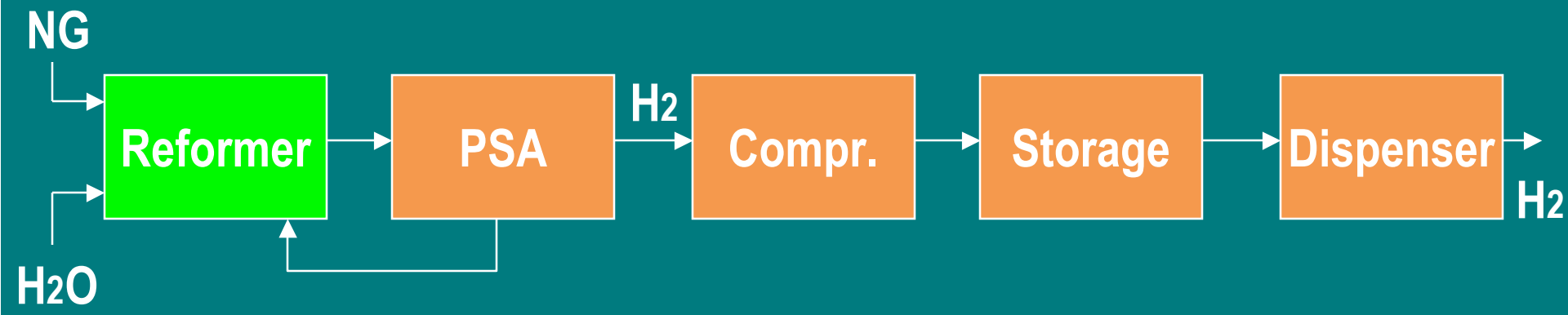
Task 2.1. & 2.2. Reformer



Goals:

1. Advance the most cost effective natural gas reforming technology for fueling station applications.
2. Complete preliminary design.

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Reformer

- **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 Design Underway**
  - Optimization of desulphurization, reformer, and shift catalysts
  - Improved heat recovery system
  - Improved Efficiency
- **Work Slowed – budget constraints**
  - To be completed in late FY2004.
  - Reformer installation in Spring 2005.

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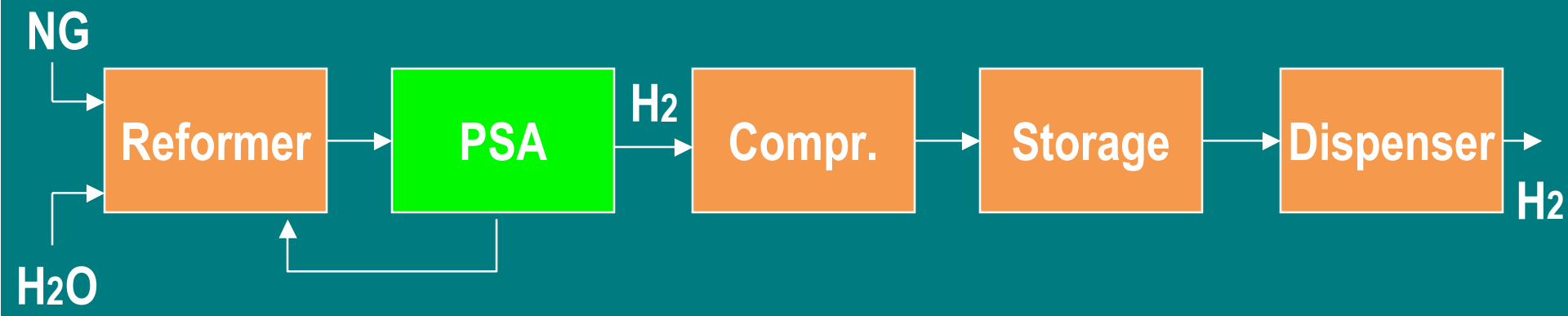
Task 2.3. Purifier Development



Goals:

1. Choose PSA Supplier
2. Conduct Lab and Field Testing of PSA Sub-System
3. Complete technical and economic analysis of ability to hit targets

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Purifier (PSA) Development

- **PSA Supplier Chosen – Air Products**
  - Highest H_2 Recovery at <2 ppm CO in H_2
  - Lowest capital cost
  - Maintainable
- **Air Products PSA: Innovative 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

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PSA Economics

- **Engineering Work Completed**
  - System components specified
  - Mechanical design & manufacturing improvements implemented
  - System running at APCI H_2 Facility
- **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 Exceeds DOE 2005 Target of 82%

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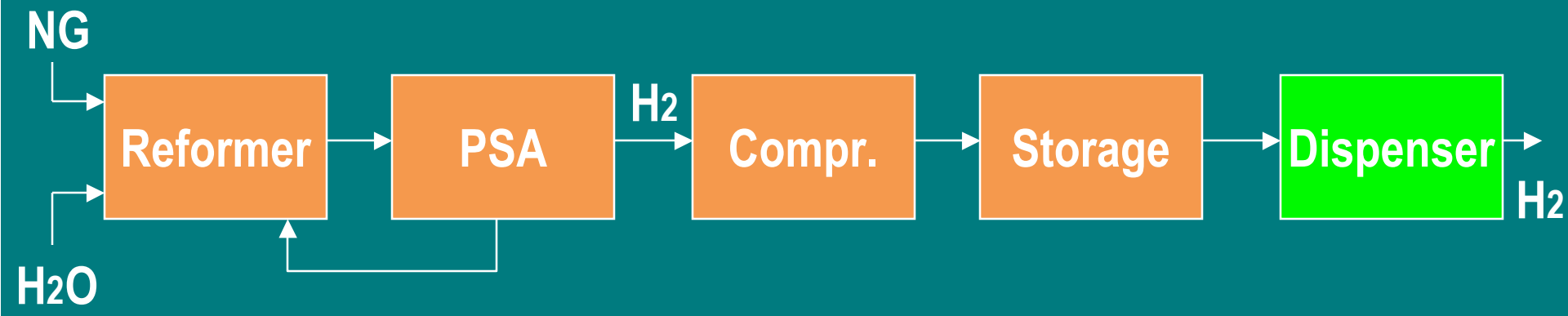
Task 2.4. Dispenser Development



Goals:

1. Use Sacramento and Las Vegas as starting point. Make dispenser less “industrial” and more aesthetic.
2. Establish cost targets and plan to achieve them.
3. Identify metering alternatives and test plan. Implement test plan.

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Dispenser Development

- **Component Selection Completed**
  - Good for classified area – Class 1 Div 1.
  - Custom microprocessor based controller
  - High Pressure
    - Vessels good for 7,000 psig
    - Other components selected for 14,000 – 20,000 psig

- **Flow Meter**
  - 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 +/- 8% Over All Fill Speeds
      - None performs to acceptable accuracy
      - Testing continues
  - Interfacing with NIST to help write certification rules

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Dispenser Progress

- **Customer Feedback used to Improve Aesthetics & User Interface**
  - Familiar look is better than “space-age”
- **DFMA underway**
- **Cost Reduction**
  - Factor of >2 reduction from starting point
- **DOE Barriers Addressed:**
  - B. **Storage – Fast Fill**
    - Ramp-rate control implemented
    - System will fill an empty auto in 1 minute with communication
  - C. **Infrastructure – Communications**
    - Communications implemented that will enable safe fast fill: hard-wire and infrared communications developed. Barrier – which vehicle?

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Task 2.5. Siting, System Integration

- **APCI Developed Preliminary Plot Plan for Site**

- **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)

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System Integration: Safety Reviews and Training

- **Safety**
  - APCI has >40 years experience in safe design, construction, & operation of H_2 plants.
    - > 10,000 H_2 fuel fills complete to date (>80 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 will be 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_2 handling and maintenance of H_2-related equipment

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System Integration Summary

- **PFD, Process Specs, and Plot Plan Developed**

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

- **H_2 Refueling Station Costs**
  - Las Vegas Station is Starting Point
  - Costs Reduced for Penn State Station.
  - Studied effect of scaling:
    - To larger H_2 production per generator
    - To mass production of stations (100 units)
  - $2.72/kg H_2 Price at Dispenser is feasible based on this program's technology*
    - Meets DOE 2005 Target of $3.00/kg H_2
    - Pathway Re-Validated that a Stand-Alone H_2 Station can be Technically and Economically Feasible

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

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Future Work

- **Scheduled Phase 2 Activities Are Complete**
  - PSA – continue data collection in field
  - Dispenser
    - Ongoing activity – flow meter testing
  - Cost and schedule estimates for Program have been updated
    - On target
- **Re-Scheduled Phase 2 Activities On-Track**
  - Reformer
  - Integration of H_2 Generator Sub-systems
- **Goals for Next Year (by May 2005):**
  - Complete Detailed design of station
  - Install & Start-Up Station – H_2 Supply, storage, compression, dispensing – In October 2004
  - Complete development and detailed design of H_2 Generator by Spring 2005
  - Install & Start-Up Generator for H_2 Supply to Station – July 2005.

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Response to 2003 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
- **Technical Advancements**
  - PSA System Efficiency Increased
  - H_2 Generator Efficiency Increased
  - Dispenser Metering Advanced
  - System Integration Optimized
  - Results in Reduced Cost of Dispensed H_2
- **Vehicles**
  - Sourcing of vehicles not part of this program
  - Significant effort spent with PSU and State of PA
    - Proposal Approved by PA DEP for funding vehicle conversions and stations operating costs
      - by PSU H_2 Institute, PSU PTI, CATA, Air Products
  - Contract changed to include CNG/H_2 blend dispenser and to match the timing of station start-up with vehicle availability

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