Development of a Turnkey H2 Fueling Station

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PSU Station: Goals and 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 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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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 | June 2003 | June 2004

Phase 2: Subsystem Development

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

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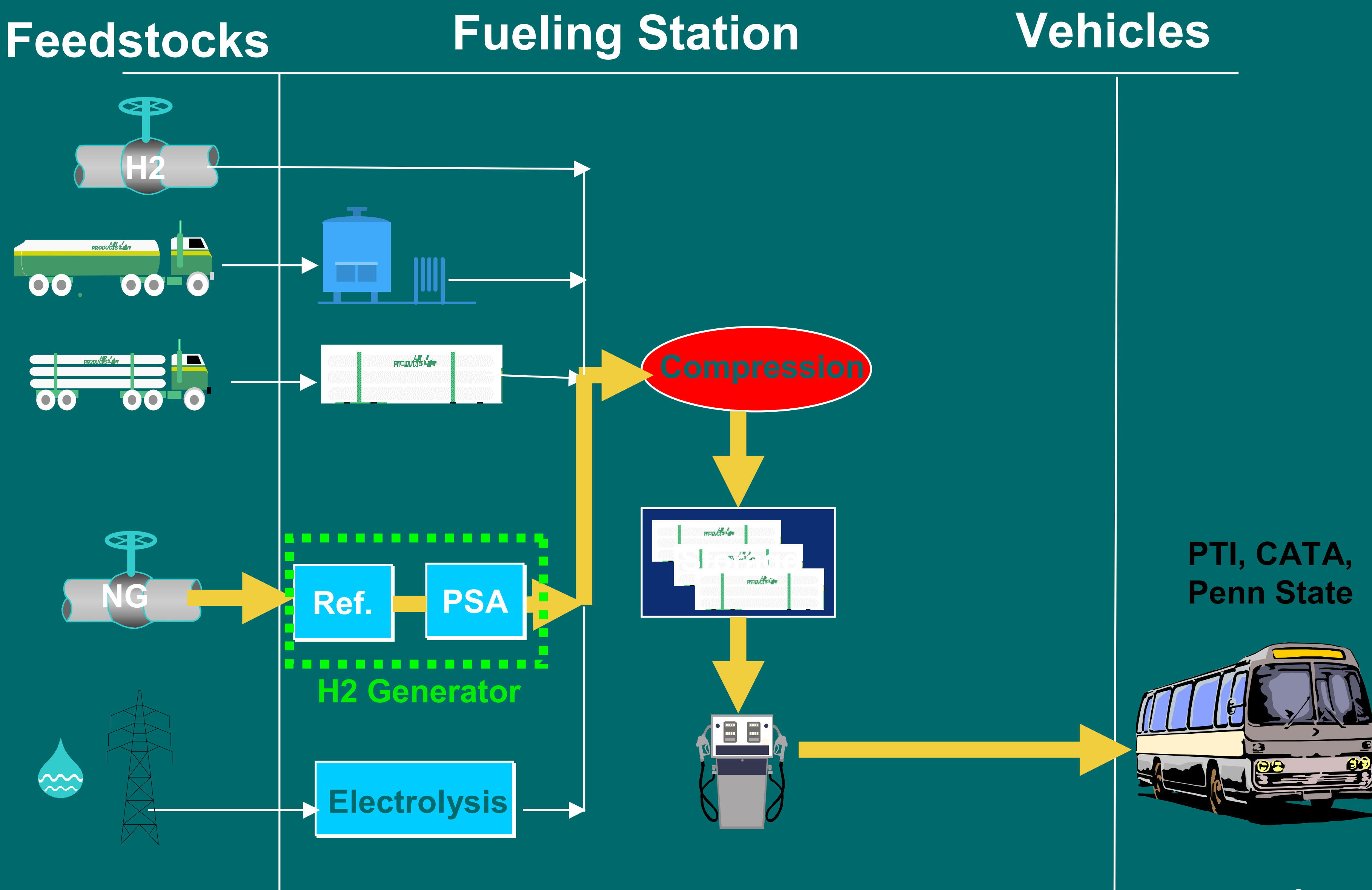
H_2 Fueling Station at Penn State



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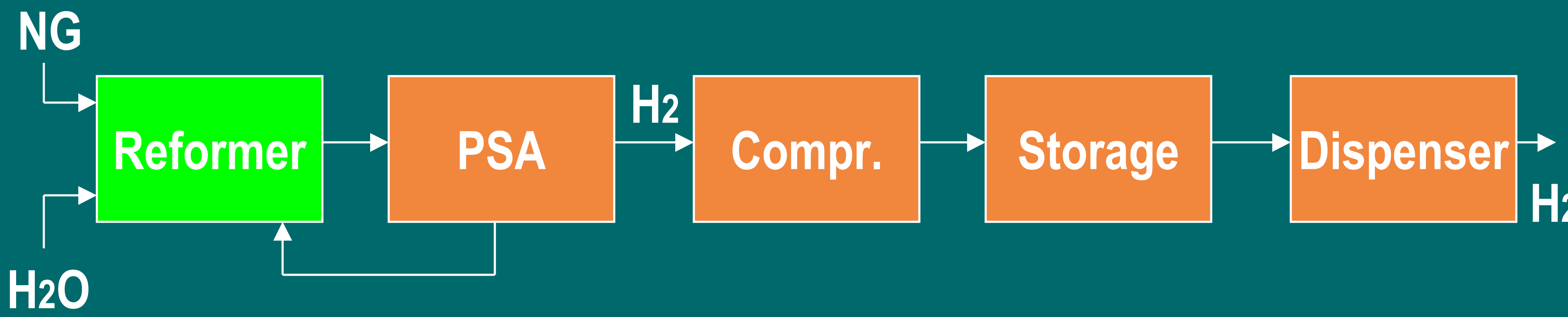
Task 1.1.1. Reformer



Goals:

1. Determine the most cost effective natural gas reforming technology for fueling station applications by evaluating a range of reforming technologies.
2. Produce preliminary specifications.

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Reformer Evaluation

- **All reformer companies were provided the same process specification**
  - Evaluated SMR, POX, ATR, CPOX
  - Received 10 quotations for commercial or near-commercial systems
- **Not all companies responded with the same quality of information**
  - APCI adjusted quotes to get them on the same capital and maintenance basis
  - To account for uncertainty and risk, statistical bands were associated with each vendors' capital and maintenance costs
- **Cost of hydrogen from each reformer was calculated using a discounted cash flow model, using a Monte Carlo Simulation.**
- **The result of the simulation is a range of hydrogen costs for each vendor**

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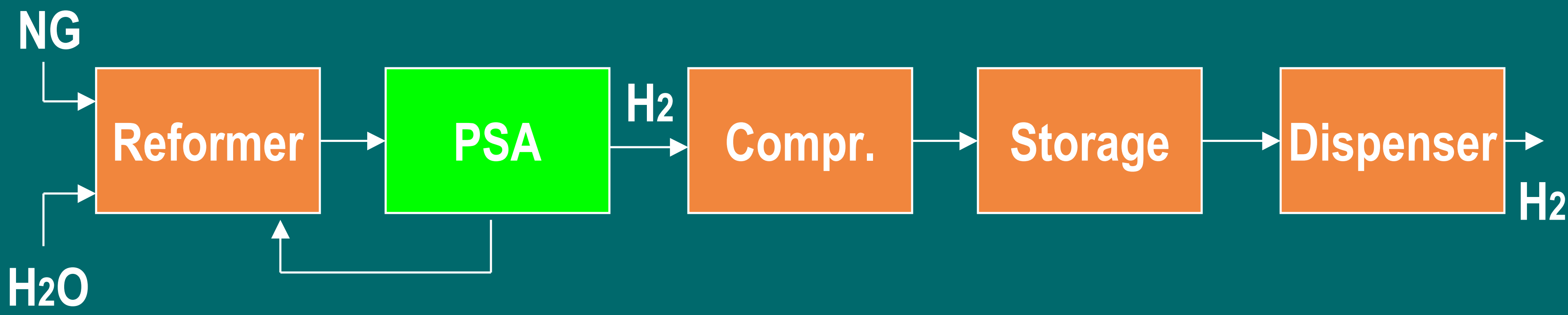
Phase 1 Reformer Study Results

- Advanced Technology SMR's are more cost competitive than the other evaluated technologies for small scale reforming applications used in hydrogen fueling stations

- SMR's tend to have lower greenhouse emissions than ATR's
  - Typically more efficient than ATR
  - Utilize less power

- Mass production of reformer, as well as building larger reforming systems, will reduce the cost of H2 produced.

Task 1.1.2. PSA Development



Goals:

1. Optimization by both Air Products and QuestAir – choose at end Phase 2
2. APCI to commence adsorbent testing
3. Conduct economic analysis of ability to hit target pricing
4. Compare with currently available technology

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PSA Development

- **QuestAir Engineering Services**
  - Extend Existing HyQuestor Product
  - Rotary Valve Enhancements
  - Cycle Optimization and Mechanical design

- **Air Products Development: Innovate in Multiple Areas and Functions**
  - More exotic adsorbents 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
  - New adsorbent masses allow significant adsorbent size reduction & lower PSA cost, while maintaining H2 recovery
  - Lab and operating plant data collected

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PSA Economics

- **Basis: The Adsorbent Research, Cycle Simulations, and Lab Tests That Are Underway**
  - Cycle selected
  - Process performance tested

- **Engineering Work Completed**
  - System components specified
  - Mechanical design & manufacturing improvements implemented

- **Cost 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
  - Evaluation of 2 Systems Underway

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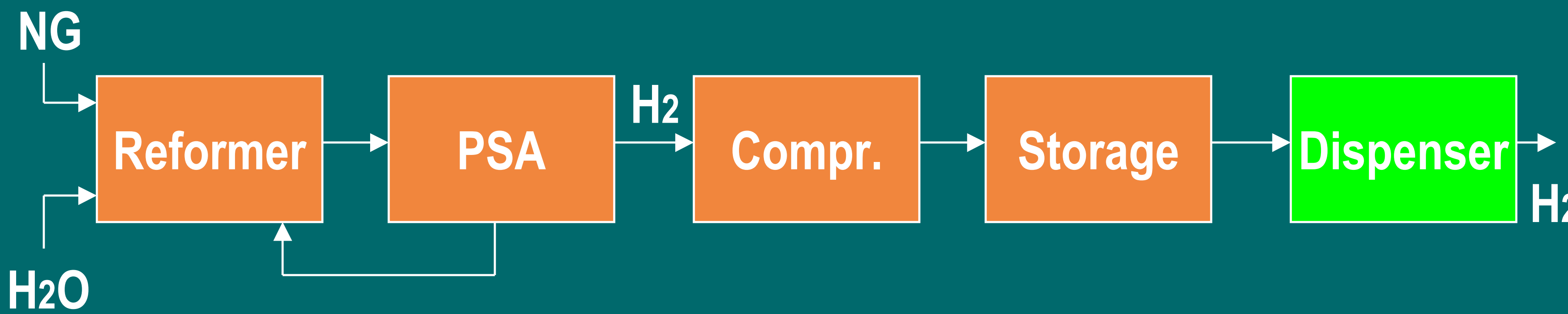
Task 1.1.3. Dispenser Development



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. Define test plan.
4. Canvass CNG dispenser vendors for consultation and/or supply.
5. Improve vehicle communications.

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Dispenser Development

- **Design Engineering and Customer Feedback used to Improve Aesthetics & User Interface. DFMA to be performed.**
- **High Pressure Piping Components**
  - Vessels good for 7,000 psig
  - Other components selected for 14,000 psig
- **Electronics**
  - Good for classified area
  - Custom microprocessor based controller
- **Cost**
  - Factor of 2 reduction from starting point.
- **Flow Meter**
  - Test program underway
  - 3 Meters identified

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Progress on the "Station"

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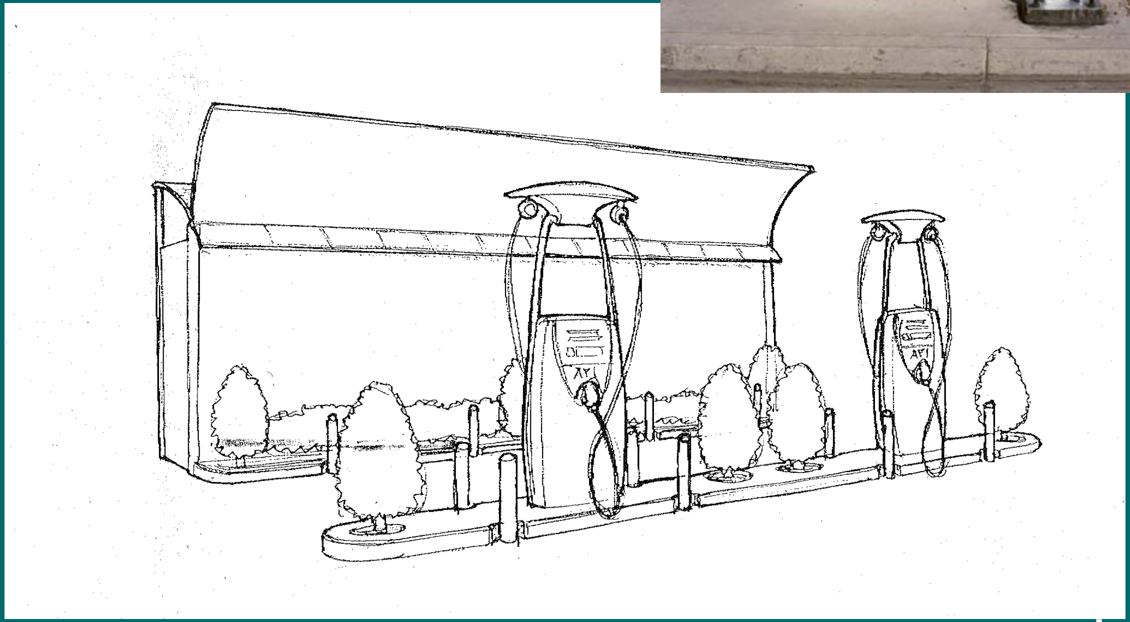

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Task 1.1.4. Siting

- **APCI Developed Preliminary Plot Plan for Site**
- **APCI, Penn State, and PTI Chose Site**
  - Goal: Site that meets needs of PTI and PSU "H2 Institute"
  - 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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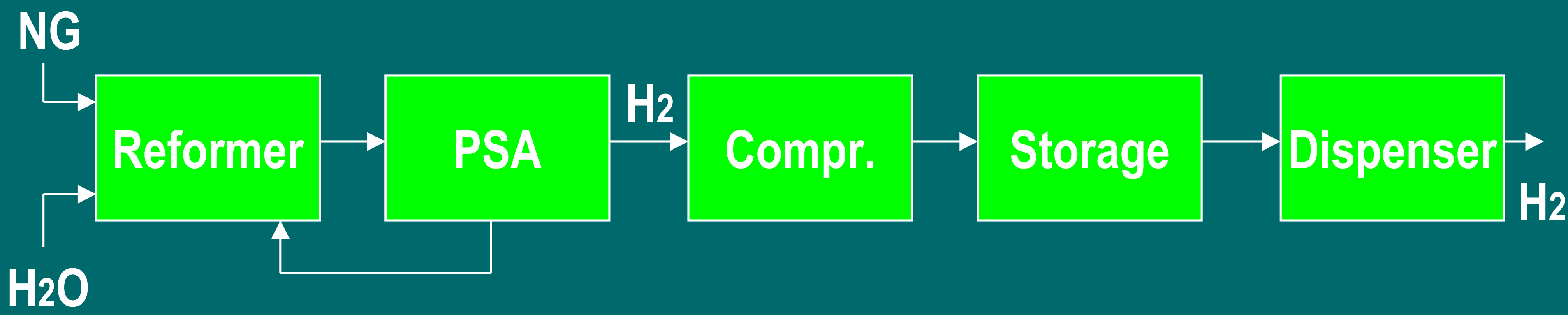
Task 1.1.5. Compression & Storage

- **Compression**
  - Cost-effective, quiet
  - Quotes obtained for H2 compression

- **Storage**
  - 7,000 psig delivery pressure current design
  - Composite materials and hydrides are being investigated
  - Current plan to use high pressure tubes

Task 1.2. System Integration



Goals:

1. Produce preliminary PFD and layout for system.
2. Determine process for turnkey system.
3. Confirm economics. Include capital, maintenance, and operating costs.

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System Integration

- **PFD, Process Specs, and Plot Plan Developed**
  - Serve as basis for all work
- **Safety**
  - APCI has >40 years experience in safe design, construction, & operation of H2 plants
  - 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
- **Fueling Station Costs**
  - Reformer Selected in Task 1.1 was used for all Fuel Station Cost and H2 Price Calculations. "Rest of Station" costs, utilities, and maintenance added.
  - Studied effect of scaling:
    - To larger H2 production per generator
    - To mass production of stations (100 units)

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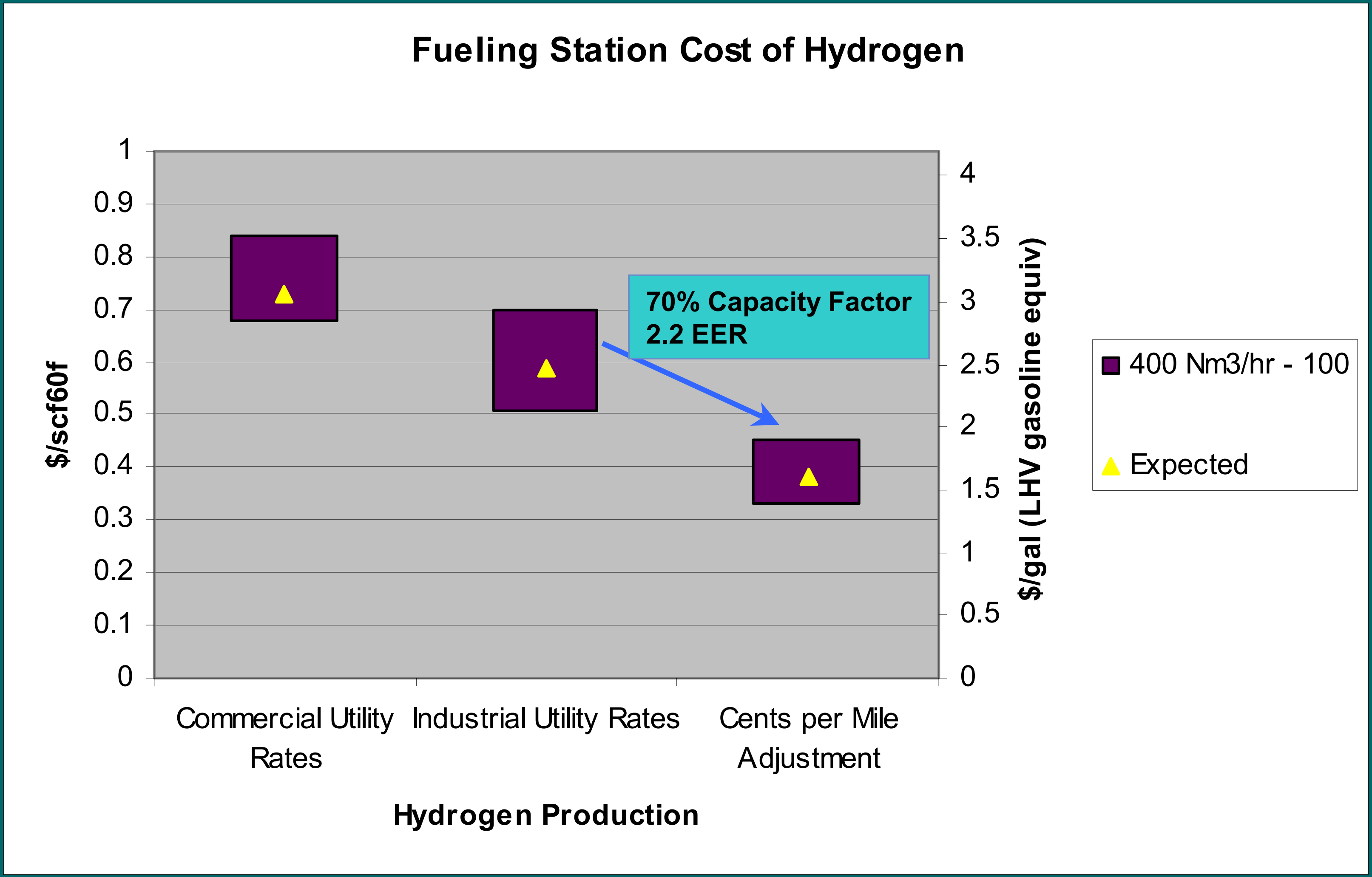
Fueling Station Cost of H2



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Summary of Activities

- **Phase 1 Complete**
  - Development activities are underway
    - Reformer
    - PSA
    - Dispenser
  - Cost and schedule estimates have been updated
    - On target
  - Conclusions:
    - Cost of H2 From Stations Improves with Mass Production and Scaling to Larger Station Sizes
    - $1.50/gallon Gasoline Equivalent is a Stretch Goal, but Attainable
    - Pathway Demonstrated that a Stand-Alone H2 Station can be Technically and Economically Feasible
- **Phase 2 Work Nearly Complete**
  - Significant development work accomplished
  - Engineering work underway

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Response to 2002 Questions

- **Next Generation Station**
  - **Build on learnings of Las Vegas Station**
  - **Advance technology – improve efficiency**
  - **Reduce cost of H2 produced**
- **Size of Station**
  - **Generation capacity of 50NM3/hr or 4 kg/hr H_2**
    - 100Kg/day of H2 full capacity
  - **24 car fills/day or 3-4 bus fills/day on pure H2**
    - 170 total cars could be served
  - **80 car fills/day or 10-12 bus fills/day on 30% H2/CNG blend**
    - 600 total cars could be served with blend
- **Vehicles**
  - Sourcing of vehicles not part of this program
  - Significant effort spent with PSU and State of PA
    - Proposal has been submitted for funding vehicle conversions and stations operating costs
      - by PSU H2 Institute, PSU PTI, CATA, Air Products
  - Requested a contract change to include CNG/H2 blend dispenser and to match the timing of station start-up closer to vehicle availability.

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