V.A.5 Hydrogen Power Park Business Opportunities Concept Project

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Objectives

- Identify component options for off-grid and grid connected power park systems.
- Develop models for off-grid and grid connected power park systems.
- Evaluate the performance of model power parks through testing of components.
- Identify model power park economic parameters.
- Develop operational envelopes for optimized models.
- Identify the customer value proposition.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation and Hydrogen Production sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

Technology Validation

- A. Vehicles
- C. Hydrogen Refueling Infrastructure
- D. Maintenance and Training
- E. Codes and Standards
- I. Hydrogen and Electricity Co-production

Hydrogen Production

- Q. Cost
- S. Emissions
- T. Renewable Integration
- U. Electricity Costs

Approach

- Develop four Power Park conceptual models based upon current understanding of regulations, costs, and benefits.
- Validate the performance of each model by testing of components.
- Analyze the business case for each power park model using actual performance and cost.
- Value-engineer each power park model to identify opportunities to improve economics.
- Identify opportunities to integrate Power Park with utility system operation.
- Identify the customer value proposition.

Accomplishments

- Four Power Park models defined for analysis.
- Small footprint design for hydrogen compression and storage approved by Phoenix Fire Department.
- Two years of safe operation at hydrogen refueling station.
- Compliance with all applicable regulations.
- Baseline performance test completed on hydrogen fueled internal combustion engines.
- Baseline performance tests completed on hydrogen-enriched natural gas fueled ICE engines.
- Comparison of APS power operations to automotive tailpipe emissions.

Future Directions

- Integrate test results with models.
- Determine efficiency and cost based on component test results.
- Compare costs to alternatives.
- Prepare energy and mass balance for each model.
- Finalize conceptual designs for models.
- Evaluate business case.
- Analyze current competitiveness.
- Evaluate improvements required to achieve competitiveness.
- Identify utility operations envelope.
- Identify customer value proposition.

Introduction

APS delivers energy in Arizona. Because APS is a natural monopoly, public commissions at the local and national level provide oversight and regulation. Under this regulatory framework, the customers of APS “pay” for the assets required to provide electricity. The APS load is much higher during “peak” times. Could APS customers be better served if these assets were used to produce hydrogen in off-peak times? Or, can a change in system operation serve APS customer needs by producing hydrogen for community use? APS is required under law to obtain a specified portion of its energy from renewable sources. Under this framework, renewable energy must be "metered" into the APS grid. Therefore, in utilizing renewable energy for hydrogen production, APS is behooved by Arizona regulations to direct renewable energy first to metered electricity into the grid, which can then be used to produce hydrogen via electrolysis. The electric grid solves many of the problems surrounding the distribution of hydrogen, identified as a barrier. The question remains, however: if hydrogen were available as a fuel, could it be economically harnessed?

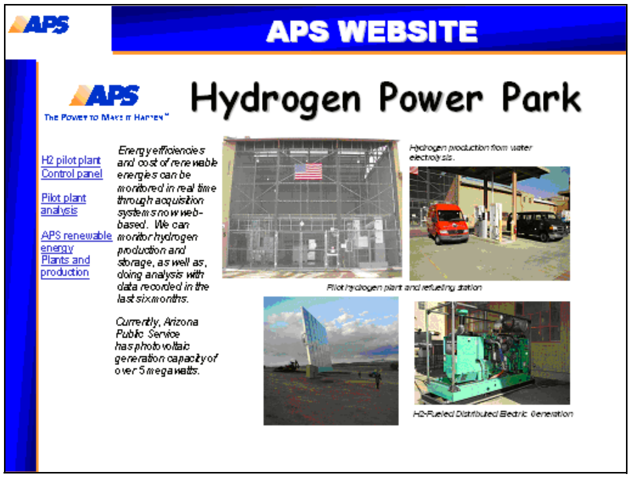
Approach

APS operates an existing pilot hydrogen fueling facility. This facility is incorporated into the Power Park project to create a real world basis to evaluate hydrogen production, vehicle refueling, and regulatory requirements. Using a collaborative group of utilities and consultants, and manufacturers' models, Hydrogen Parks will be identified as having the best chances of serving customer needs. Testing of model components will create "real" data upon which to build the economic case for the Power Park. Incorporating grid connected renewable energy sources will create the "real" database for renewable energy integration. Hydrogen and hydrogen-blended fuel will be tested in internal combustion engines (ICEs) to validate that distributed or contingency electricity generation can be a reality. Using APS operations data, the Power Park will be integrated with the utility system to create the business case and identify the value proposition (Figure 1).

Results

A roundtable meeting was conducted with several utilities, manufacturers, consultants, and universities to discuss the practicality of hydrogen power parks and what configuration may offer the best chance for commercial success. Four model parks where defined by the working group:

- 100 kW electric production – 50 kg H_2 grid connected
- 1 – 5 kW electric production – 4 kg H_2 RAPS/ UPS
- 5 MW electric producion – 1500 kg H_2 utilities connected
- 100 kW mobile



Hydrogen Power Park

Energy efficiencies and cost of renewable energies can be monitored in real time through acquisition systems now web-based. We can monitor hydrogen production and storage, as well as, doing analysis with data recorded in the last six months.

Currently, Arizona Public Service has photovoltaic generation capacity of over 5 megawatts.

Hydrogen production from water electrolysis.

Pilot hydrogen plant and refueling station

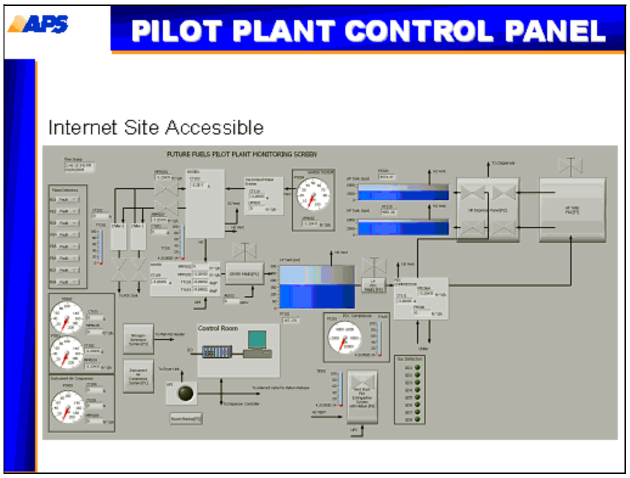
H2-Fueled Distributed Electric Generation

Figure 1. APS Hydrogen Park Internet Site

The existing hydrogen pilot facility is incorporated into the Power Park. Engineering, design, construction, testing, startup, and permitting, including modifications to the Park, have used existing regulations and codes as a basis. Regulatory officials, including building and fire officials, have issued approvals and permits for the Park. Safe operation of the existing Power Park and the thoroughness in design has facilitated excellent regulatory relationships.

An innovative hydrogen station design was approved by the Phoenix Fire Department. The new design focuses on hydrogen compression, storage, and dispensing, eliminating the hazards of flame impingement, deflagration, and detonation. The Gen II design incorporates the Coaxial Containment System (CCS, patent pending). The new design provides a much higher level of safety and a small footprint, reduces construction costs, and reduces construction time and approval. The new design will simplify siting requirements for future Power Parks.

The Hydrogen Power Park operational experience to date has been exceptional. Hydrogen production, compression, and storage reliability was 99% or 176 hours downtime over 18,960 calendar hours. The outages were caused by: a) electrolysis unit water leak (12 hours), pump impeller (48 hours),



PILOT PLANT CONTROL PANEL

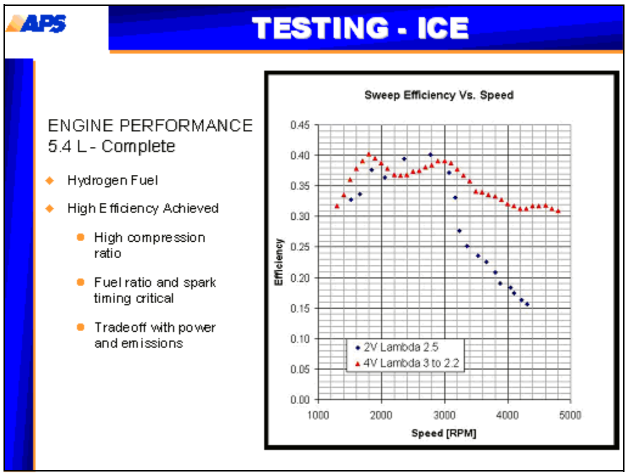
Internet Site Accessible

Figure 2. APS Hydrogen Park Internet Site - Interactive Hydrogen Production Screen

water pressure transducer (36 hours); b) hydrogen dryer water transfer valve (32 hours) failure; c) hydrogen compressor check valve failure (48 hours). There was also a failure of the high pressure hydrogen manual block valve seats and replacement of a 0.5 micron hydrogen filter but this caused no outage time. (Figure 2 shows the components of the control panel.)

The Hydrogen Power Park motor vehicle refueling pilot station has been refueling vehicles for more than two years. A total of 2,500 vehicle-fueling events have occurred with no accidents, and 5200 kg of hydrogen has been produced from water electrolysis for motor vehicle fuel (318 scfh with 6511.6 total hours of operation).

ICE testing has demonstrated good efficiency with low emissions using hydrogen fuel. Peak efficiency (lower heating value) of 40% was achieved with both low and high boost supercharging of mass produced V8 engines. NO_x emissions were very low when "lean-burn" fuel control was employed and lambda was greater than 2.5. Low emissions were demonstrated when 30% hydrogen was added to natural gas and a "lean-burn" fuel control was used. Hydrogen ICEs tested varied in power from 8 kW to 220 kW. Figures 3, 4, and 5 show some of the test results.

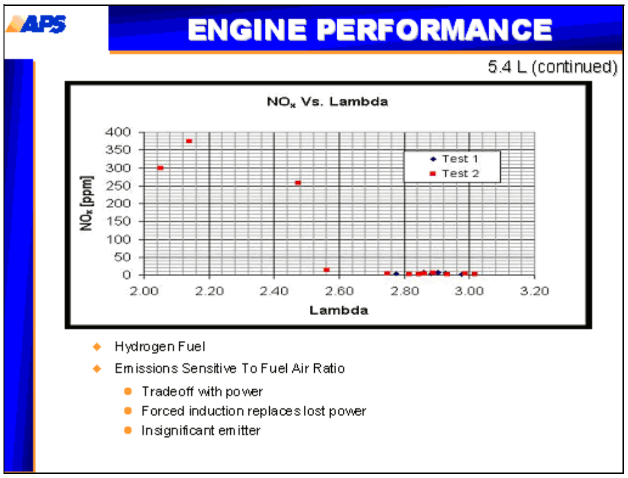


TESTING - ICE

ENGINE PERFORMANCE
5.4 L - Complete

- Hydrogen Fuel
- High Efficiency Achieved
    - High compression ratio
    - Fuel ratio and spark timing critical
    - Tradeoff with power and emissions

Figure 3. Hydrogen ICE Test Results - ICE Prime Mover for Distributed or Contingency Generation



ENGINE PERFORMANCE

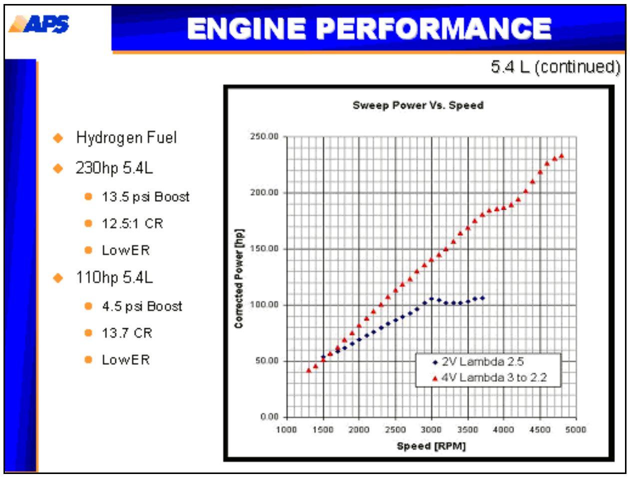
5.4 L (continued)

- Hydrogen Fuel
- Emissions Sensitive To Fuel Air Ratio
    - Tradeoff with power
    - Forced induction replaces lost power
    - Insignificant emitter

Figure 4. Hydrogen ICE Emission Test Results

The emissions barrier cited by the DOE hydrogen program for electrolysis using grid power may vary by utility. APS system emissions are lower than gasoline emissions from new vehicles, producing favorable comparison results.

The cost of electricity barrier, cited by the DOE hydrogen program, for electrolysis using grid power may vary by utility, time of day, and customer class. In the case of APS, commercial customers with more than 3 MW of demand can be charged $0.02 per kwh during off-peak hours. This cost translates to an energy cost to produce hydrogen from electrolysis of



APS

ENGINE PERFORMANCE

5.4 L (continued)

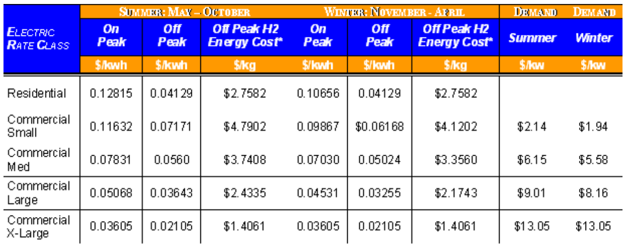
- Hydrogen Fuel
- 230hp 5.4L
  - 13.5 psi Boost
  - 12.5:1 CR
  - LowER
- 110hp 5.4L
  - 4.5 psi Boost
  - 13.7 CR
  - LowER

Figure 5. Hydrogen ICE Power Test as a Function of Boost

$1.40/kg, assuming 50% conversion efficiency, and compares favorably to the DOE technical target for electrolysis energy of $2.00/kg (Figure 6).

Conclusions

- Hydrogen can be safety dispensed as a motor vehicle fuel.
- Hydrogen can be safely handled at 6,000 psi.
- Hydrogen production, compression, and storage equipment and their appurtenances can provide high reliability and safety.
- Hydrogen can be used in internal combustion engines as a fuel or an additive for CNG.
- NOx emissions can be very low from hydrogen ICEs when lean burn is implemented.
- Power from hydrogen ICEs requires very high mass air flow to provide sufficient air to support lean burn for low emissions, while supporting enough combustion to produce high power.



ELECTRIC RATE CLASS	SUMMER: MAY – OCTOBER			WINTER: NOVEMBER - APRIL			DEMAND	DEMAND
	On Peak	Off Peak	Off Peak H2 Energy Cost*	On Peak	Off Peak	Off Peak H2 Energy Cost*	Summer	Winter
	$/kwh	$/kwh	$/kg	$/kwh	$/kwh	$/kg	$/kw	$/kw
Residential	0.12815	0.04129	$2.7582	0.10656	0.04129	$2.7582		
Commercial Small	0.11632	0.07171	$4.7902	0.09867	$0.06168	$4.1202	$2.14	$1.94
Commercial Med	0.07831	0.0560	$3.7408	0.07030	0.05024	$3.3560	$6.15	$5.58
Commercial Large	0.05068	0.03643	$2.4335	0.04531	0.03255	$2.1743	$9.01	$8.16
Commercial X-Large	0.03605	0.02105	$1.4061	0.03605	0.02105	$1.4061	$13.05	$13.05

* Gasoline energy (lhv 114,000 BTU/gallon) is equivalent to 33.4 kwhrs

Figure 6. Energy Cost for Hydrogen Production from Electrolysis at 50% Efficiency with Existing APS Electric Rate Classes (On Peak 9:00AM to 9:00 PM Monday thru Friday)

FY 2004 Publications/Presentations

1. National Hydrogen Association Conference, April 2004, Hollywood, California.

Special Recognitions and Awards/Patents Issued

1. "*Crescordia*" (growing in environmental harmony) from the Phoenix Area Valley Forward Association, September, 2003.
2. U.S. Department of Energy, 2004 Clean Cities Recognition, May, 2004.