HYDROGEN POWER PARK

Business Opportunities Concept Project

Raymond Hobbs

Arizona Public Service

May 25, 2005

Project ID TV4

This presentation does not contain any proprietary or confidential information

Overview

- **Timeline**
  - Started CY: 2003
  - Finish CY: 2006
  - Percent Complete: 70%
- **Budget**
  - PTD CY 2004: $1,703,481
  - CY 2005: $500,00
  - CY 2006: $500,000
- **Collaborations**
  - The Three Amigos
    - APS, BC Hydro, SCE, GE
  - Department of Energy
  - Idaho National Engineering Lab
  - Sandia National Lab
  - National Renewable Energy Lab
  - State of Arizona Energy Office
  - City of Phoenix Fire Department
  - Valley of the Sun Clean Cities Coalition
- **Barriers**
  - **Hydrogen Production**
    - Cost
    - Emissions
    - Renewables Integration
    - Electricity Cost
  - **Technology Validation**
    - Vehicles
    - Hydrogen Refueling Infrastructure
    - Maintenance and Training
    - Codes and Standards
    - Hydrogen and Electricity co-production

Objectives Relevance to H2 Program

- **Objectives**
  - Execute field testing of park components including production systems, electric generation systems, vehicle refueling systems, renewable energy systems.
  - Use hydrogen as fuel for electricity generation and vehicle fuel.
  - Determine feasibility, safety, performance, and economic parameters.
  - Identify the value proposition in model power park applications.
  - Analyze integration with existing energy assets to determine scalability, technical barriers, and integrated business opportunities.
- **Relevance**
  - Real world validation of components and systems.
  - Real world safety records.
  - Establishes real world feasibility for the use of hydrogen.
  - Real world performance from hydrogen use.
  - Real world economics for hydrogen use.
  - The value proposition for hydrogen.

Approach

- Develop Power Park conceptual models based upon existing 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 costs.
- Value-engineer each park model to identify opportunities to improve economics.
- Identify opportunities to integrate Power Park with utility system operation.
- Identify the customer value proposition.

Prior Major Accomplishments

- Core Power Parks Identified
  - 50 Kg/day grid connected with 100 kW of electricity generation.
  - 100 kW mobile electricity generation
  - 4 Kg/day H2 production with 5 kW of electricity generation.
  - 1500 Kg/ day hydrogen generation grid connection, with & without natural gas, and 5 MW of electricity generation.
- Compact fueling station approved by PFD with approvals for commercial installations.
- Low emissions from ICE fueled by hydrogen.
- Low emissions from ICE fueled by hydrogen enriched natural gas.
- Efficiency improvement over gasoline with hydrogen fueled ICE using “lean-burn” ignition control.

APS Pilot Hydrogen Park

Hydrogen Systems

- RO and DI System
- H2 Electrolysis Proton Unit
- H2 Dryer
- H2 LP Storage (22 kg)
- H2 Compressor (0.7 and 6 kg/hr)
- H2 Tube Trailer (100 – 300 kg)
- H2 HP Storage (44 kg)
- H2 Dispensing
- Fuel Cell (1 and 5 kW)
- H2 ICE Genset (10 and 70 kW)
- CHyNG Genset (100 kW)
- Composite Storage Vessels
- H2 ICE Vehicles
- CHyNG Vehicles
- Control/Monitoring/Instrumentation
- H2/CNG Blend Fuel Dispensing
- Website

Other Park Systems

- CNG
  - Booster Compressor
  - Main Compressor
  - LP, MP, HP Storage (50k scf)
  - CNG Dispensing
  - Credit Card System
  - CNG Vehicles (fleet)
- Photovoltaic Array and Inverters
- Advanced Battery Lab
- EV Fast Chargers

Common Systems

- Instrument Air
- Fire System (ESD, IF/UV scanners, combustible detectors, alarms)
- Nitrogen System
- Chiller System
- Electrical Power and Lighting System
- Control Room and HVAC
- Security System

Energy to Make Hydrogen

Hydrogen Production

- Ready for use at 99.999% pure at 150 psi
  - RO and DI System energy (kwh)
  - Proton Hogen 300 energy (kwh)

Hydrogen Motor Vehicle Fuel

- Ready for vehicle fueling at 99.999% pure at 6,000 psi
  - H2 production energy (kwh)
  - Dryer energy (kwh)
  - PDC compressor energy (kwh)

Progress & Results

Validation

Electric Industry: Safety, Reliability, Quality

- Perfect safety record for three years of hydrogen operations; no accidents, no close calls, and no equipment damage.
- 99.33% availability from hydrogen production equipment, during 26,000 calendar hours of operation, and 8,500 hours of electrolyzer operation.
- 99.99975% pure hydrogen produced for 8,500 hours of electrolyzer operation.
- Monitoring systems installed and operating since August 2004. Continuous component and system efficiency and performance evaluations.
- Internet accessible at www.aps.com, My Community, Future Fuels. 700 hits per month on website.

Results

Energy Used: kwhrs to Make 1kg of H2
Average Since August 2004

Hydrogen Production	
RO/DI Water	0.26
Hogen 300	80.52
Total	80.78
41.3% efficient (LHV)	
DOE Target 68%	

Hydrogen Motor Vehicle Fuel	
H2 Production	80.78
Dryer	1.50
Compressor	2.67
Total	84.95
39.3% efficient (LHV)	
DOE Target 64%	

Results

Pilot Park Hydrogen Production

Total Hydrogen Produced	2,742,636 scf
	6,588 kg
Conversion efficiency at 41.35%	
Energy to Produce Hydrogen	532,178 kwh
Energy cost to Produce Hydrogen	$14,858
Energy cost per Kg	$1.70
Conversion Efficiency at 68% DOE Target	
Energy cost per Kg	$1.03
DOE Target for Energy Cost	***$1.80/kg***

Based upon APS Commercial Rate Class E35 ($0.02105 off peak)

Hydrogen Production and Efficiency

- Hydrogen production from electricity
  - APS electric basic rates for customer classes.

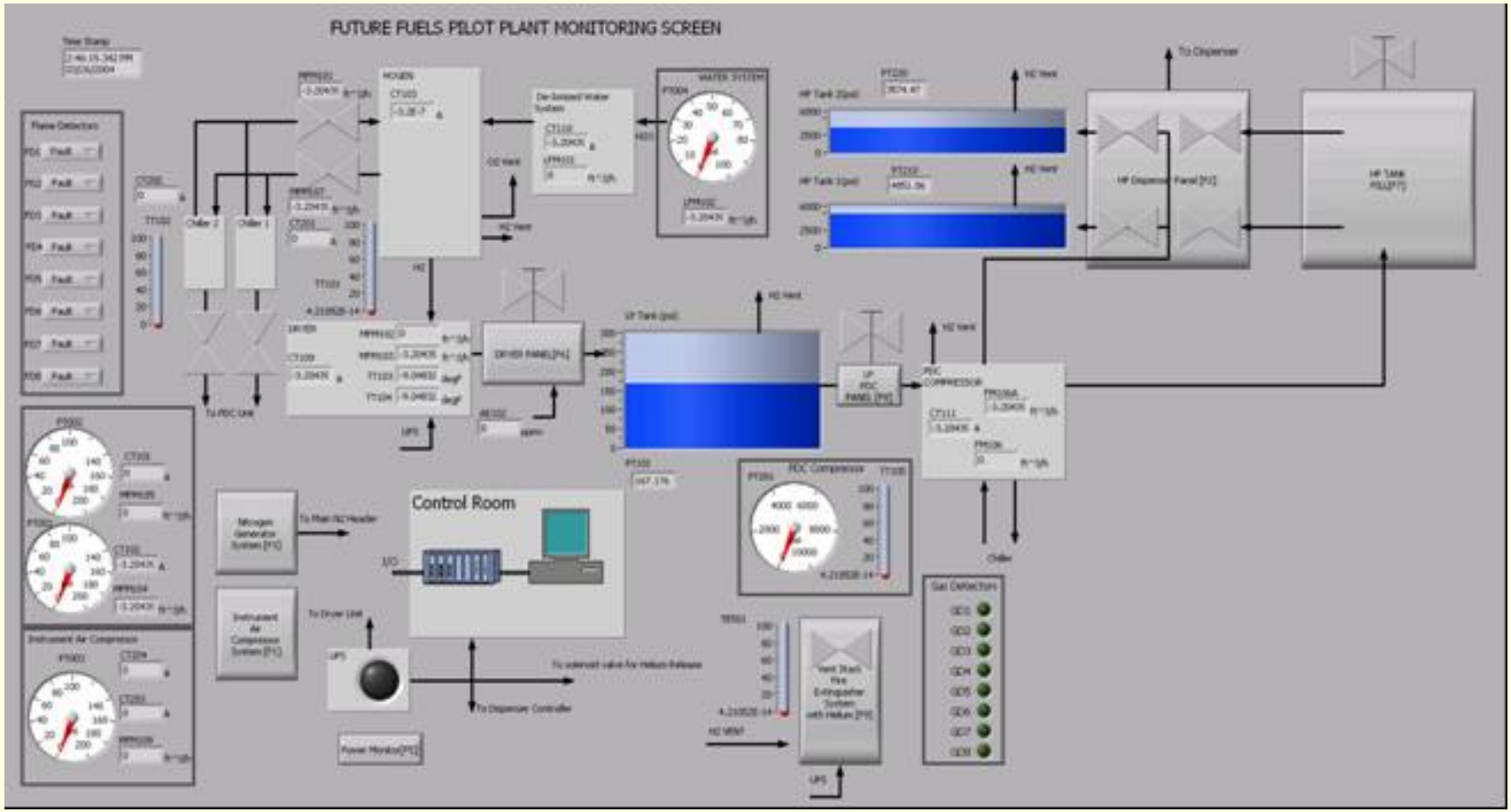
Energy Cost for Hydrogen Production from Electrolysis at 68% Efficiency with Existing APS Electric Rate Classes (On Peak 9:00AM to 9:00 PM Monday thru Friday).

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	$2.03	0.10656	0.04129	$2.03		
Commercial Small	0.11632	0.07171	$3.52	0.09867	$0.06168	$3.03	$2.14	$1.94
Commercial Med	0.07831	0.0560	$2.75	0.07030	0.05024	$2.47	$6.15	$5.58
Commercial Large	0.05068	0.03643	$1.79	0.04531	0.03255	$1.60	$9.01	$8.16
Commercial X-Large	0.03605	0.02105	$1.03	0.03605	0.02105	$1.03	$13.05	$13.05

** Gasoline energy (LHV 114,000 BTU/gallon) is equivalent to 33.4 kWhrs*

Results

Pilot Hydrogen Park Control Panel



Results

Electricity Production - 32.7 MWH
"On-Peak" Energy Price - Small Commercial $3,804

Electricity Source	Type Generator	Peak Power (kw)	Energy (kwh)	Fuel (Kg of H2)
Plug Power	Fuel Cell	5 kw	6,733	439
Proton	Fuel Cell	1 kw	511	
Lister Petter	ICE Genset	7 kw	816	
Onan	ICE Genset 50% EGR	70 kw	1,948	359
Onan	ICE Genset 70/30%	100 kw	54	
Renewable	PV Array	7 kw	23,061	

Results

Electricity Production Efficiency

		Fuel	Peak Efficiency %
Plug Power	Fuel Cell	Hydrogen	46
Lister Petter	ICE	Hydrogen	28
Onan	ICE – 50% EGR	Hydrogen	28
Onan	ICE	70/30%	28
Sharp	PV Array	Sun	12.5

Results

Motor Vehicle Refueling

Refueling Events

Hydrogen	236
CHyNG	717
CNG	2,938
Total	3,891
Accidents	0

Fuel Dispensed*

Hydrogen	259 kg
CHyNG	2,378 gge
CNG	14,218 gge

** Dispensed amounts are from credit card transactions.*

Results

TEST CELL	Q-Cell
Test #	4097
Date	2/2/2005
Time	13:49
Driver	KB
Operator	KB

VEHICLE...	
Model	F-150
Vehicle #	F-150
Odometer	3049
Dyno Inertia	5000

FUEL...	
ATL Code	Diesel
HC_density	16.33

AMBIENT CONDITIONS...

Baro (inHg)	28.84		
PHASE #	**1**	**2**	**3**
Temp ('F)	72.8	73.3	73.1
Wet blb ('F)	53.6	53.8	53.2
Humidity	25.8%	25.2%	23.6%
Abs (gr/lb)	31.9	31.7	29.5
NOx K fac	0.831	0.831	0.824

Comments...

FTP

w/ Hydrogen

RED

VARIABLES...

PHASE #	1	2	3
VMIX (ft3)	2852.1	4791.4	2819.3
Distance	3.586	3.855	3.582
Time (sec)	507.8	868.9	508.6

Vehicle Emission Test

Test: FTP

Vehicle: Ford F150 5.4L V8 Low-Boost

Fuel: Hydrogen

Bag Results...

	NMHC	CH4	HC	CO	NOX	CO2		
Phase 1	ppm	ppm	ppm	ppm	ppm	%	DF	
Sample Conc.	4.436	1.590	6.296	3.768	15.746	0.043	15.0	
Ambient Conc.	4.424	1.619	6.317	1.342	0.235	0.046		
Net Conc.	0.307	0.079	0.400	2.516	15.526	0.000		
								Particulate
(gm)	0.014	0.004	0.019	0.237	1.994	0.375		0.010
(gm/mile)	0.004	0.001	0.005	0.066	0.556	0.104		0.003
Phase 2							DF	
Sample Conc.	4.195	1.499	5.949	3.423	8.484	0.049	15.0	
Ambient Conc.	4.203	1.627	6.107	1.463	0.425	0.050		
Net Conc.	0.250	0.000	0.250	2.057	8.087	0.003		
								Particulate
(gm)	0.020	0.000	0.020	0.325	1.744	6.509		0.013
(gm/mile)	0.005	0.000	0.005	0.084	0.452	1.688		0.003
Phase 3	ppm	ppm	ppm	ppm	ppm	%	DF	
Sample Conc.	3.487	1.481	5.220	3.204	8.628	0.050	15.0	
Ambient Conc.	3.564	1.746	5.606	1.403	0.630	0.045		
Net Conc.	0.000	0.000	0.000	1.894	8.040	0.009		
								Particulate
(gm)	0.000	0.000	0.000	0.176	1.011	12.669		0.013
(gm/mile)	0.000	0.000	0.000	0.049	0.282	3.537		0.004

Composite ...

Grams/mile	**0.003**	**0.000**	**0.004**	**0.071**	**0.427**	**1.868**	**0.0033**

Results

TEST CELL	Q-Cell
Test #	4106
Date	2/4/2005
Time	13:03
Driver	RZ
Operator	KB

VEHICLE...	
Model	F-150
Vehicle #	72
Odometer	47784
Dyno Inertia	6500

FUEL...	
ATL Code	CNG
FE_num	1778
CWF	0.718
Spc Grv	0.5976
HC_density	18.75

AMBIENT CONDITIONS...

Baro (inHg)	28.76		
PHASE #	**1**	**2**	**3**
Temp ('F)	73.3	73.5	75.0
Wet blb ('F)	53.3	53.6	54.5
Humidity	23.9%	24.4%	23.8%
Abs (gr/lb)	30.1	30.9	31.8
NOx K fac	0.826	0.828	0.831

Comments...

FTP: (Hydrogen)
Preliminary Results
Pure CNG Fuel properties
Target Hydrogen conc: 15% by volume

Fuel economy correction factor: .95
Per request
Vin # 1FTPF17M8YKB39272

Vehicle Emission Test

Test: FTP

Vehicle: Ford F150 5.4L V8 Low-Boost

Fuel: 70% CNG / 30% H2

VARIABLES...

PHASE #	**1**	**2**	**3**
VMIX (ft3)	2871.7	4884.9	2851.3
Distance	3.554	3.844	3.577
time	506.7	868.9	508.0

WHITE

Results...

Phase 1 (CT)	**NMHC ppm**	**CH4 ppm**	**HC ppm**	**CO ppm**	**NOX ppm**	**CO2 %**	DF	
Sample Conc.	6.324	23.102	33.354	31.735	9.171	1.082	8.87	
Ambient Conc.	3.326	2.231	5.937	2.032	0.382	0.053		
Net Conc.	3.372	21.123	28.086	29.932	8.832	1.035		
								Particulate
(gm)	0.170	1.146	1.512	2.834	1.134	1539.781	***mpg***	0.0140
(gm/mile)	0.048	0.322	0.426	0.797	0.319	433.253	14.32	0.0039

Phase 2(CS)	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	DF	
Sample Conc.	4.040	5.339	10.286	4.212	2.782	0.729	13.22	
Ambient Conc.	4.367	2.140	6.871	2.112	0.408	0.057		
Net Conc.	0.003	3.360	3.935	2.260	2.405	0.677		
								Particulate
(gm)	0.000	0.310	0.360	0.364	0.527	1712.841	***mpg***	0.0196
(gm/mile)	0.000	0.081	0.094	0.095	0.137	445.588	13.99	0.0051

Phase 3 (HT)	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**%**	DF	
Sample Conc.	4.885	12.452	19.454	4.050	5.002	0.949	10.16	
Ambient Conc.	4.727	2.143	7.235	1.120	0.360	0.059		
Net Conc.	0.623	10.520	12.931	3.040	4.678	0.896		
								Particulate
(gm)	0.031	0.567	0.691	0.286	0.600	1323.415	***mpg***	0.0021
(gm/mile)	0.009	0.158	0.193	0.080	0.168	369.979	16.83	0.0006

Composite ...							**MPG**	
Grams/mile	**0.012**	**0.152**	**0.190**	**0.236**	**0.183**	**422.267**	**14.74**	0.0036

Hydrogen

Hydrogen from Solar Energy with Electrolysis

Solar Type	Cost $/watt	Cost $/kwh	Energy kWwh/ kW-yr	Cost Kwh/$	Cost $/kwh	Cost H2 $/Kg @ 41.3% Eff	Cost H2 $/Kg @ 68% Eff
PV Fixed Horizontal	5.25	0.01	1,250	4.75	0.220	$17.79	$10.81
PV Fixed Latitude	5.25	0.01	1,630	6.20	0.171	$13.83	$8.40
PV Tracking Horizontal	5.50	0.01	2,350	8.55	0.127	$10.27	$6.24
PV Tracking Latitude	6.50	0.01	2,450	8.25	0.131	$10.59	$6.43
PV High-Concentration	6.00	0.01	2,030	6.75	0.158	$12.78	$7.76
PV High-Concentration (Future)	3.00	0.01	2,400	16.00	0.0725	$5.86	$3.56
Organic Rankine Cycle Trough	4.00	0.03	2,000	10.00	0.130	$10.51	$6.39
Dish Turbine	2.50	0.03	2,400	19.20	0.082	$6.63	$4.03

Response to FY 2004 Review

- Weaknesses:
  - None
- Specific Recommendations:
  - Continue project.
  - Provide details. Are all the components hooked into the system at once? How would they interact if they were?
- Response:
  - The Pilot Park is fully integrated within regulatory and code limits. The internet accessible site provides both historical and real time integrated hydrogen production component efficiencies and costs. The hydrogen side of the Pilot Park has a 99.96% availability.
  - Performance testing of the electric production equipment, including fuel cells and ICE genset, was initiated in September 2004.

Future Work

- Collaborate with team members.
- Continue Pilot Hydrogen Park operation.
- Continue PEM fuel cell performance and durability testing.
- Continue performance testing of ICE gensets.
- Continue motor vehicle refueling.
- Evaluate hydrogen production from:
  - Wind
  - Biomass
  - Biogas
  - Bromine Cell
  - Solar Metal Oxide Reduction
  - Traditional Fuels
- Acquire and performance test new electrolyzers.
- Construct mobile model.
- Identify value propositions for hydrogen use.
  - Implement, if time permits.

Production Vehicle Fueling Renewable Energy Electricity Production

Public Acceptance Maintenance Training

Supplemental Slides

Presentations & Publications

- Presentation by Ray Hobbs at AFV Odyssey Days event at Gateway Community College in Phoenix, AZ on April 2, 2004.
- Presentation/paper by Ray Hobbs at NHA event in Hollywood, CA on April 26-30, 2004.
- Recognition by Clean Cities at annual U.S. DOE Clean Cities Conference in Ft. Lauderdale, FL on May 3-5, 2004.
- Presentation by Ray Hobbs on APS Hydrogen Park at DOE Conference in Philadelphia, PA on May 24-27, 2004.
- Presentation to National Renewable Energy Laboratory (NREL) in June 2004.
- Presentation at the National Solar Energy Conference in Portland, OR in July 2004.
- Article submitted on APS Hydrogen Park to National Hydrogen Association for publication in their August Newsletter.
- Presentation at the Southwest Sustainability Expo in Flagstaff, AZ in August 2004.
- “APS Establishes Value of H2 Park”, National Hydrogen Association Newsletter, Summer 2004.
- Presentation at the SAE Regional Meeting, October 2004.
- Presentation at National Renewable Energy Lab (NREL), October 2004.
- Presentation at US DOE Solar Hydrogen Workshop, November 2004.
- Tour of the H2 Park by the Deputy Secretary General of the United Nations and representatives of the Chinese government, December 2004.
- Clean Cities Legislative Event “Arizona’s Road to Clean Air and Energy Independence,” February 24, 2005 at Arizona House of Representatives.
- APS awarded Clean Cities Champion Award for “Advanced Technologies” on February 24, 2005.
- East Valley Tribune Article, “Alternative-Fuel Technologies Gain Respect in Valley,” February 25, 2005.
- Presentation at the Tres Rios Festival, March 2005.
- Submitted article on APS Hydrogen Refueling Station for AZPA Chapter Newsletter, March 2005.

Hydrogen Safety

- The most significant hydrogen hazards associated with this project are:
  - Hydrogen Leaks
    - Compression fitting leaks
    - Valve stem leak
    - Hose connection leaks
    - Threaded pipe leaks
    - Fueling nozzle leaks

Hydrogen Safety

- Approach to deal with hazard
  - Monthly refueling hose assembly inspection by certified technician
  - Quarterly test of combustible gas detectors by certified technician
  - Quarterly test of UV/IR scanners by certified technician
  - Quarterly inspection of all hydrogen piping by technician using hand scanner and snoop
  - Daily plant walk-down
    - Fire system inspection
    - Piping
    - Vessels
    - Equipment
    - Sounds
    - Any unusual condition