

# HYDROGEN POWER PARK

## ***Business Opportunities Concept Project***

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*Arizona Public Service*

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*Project ID TV4*

*This presentation does not contain any proprietary or confidential information*

# Overview

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## ■ 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

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## ■ 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

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- 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

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- Core Power Parks Identified
  - 50 Kg/day grid connected with 100 kW of electricity generation.
  - 100 kW mobile electricity generation
  - 4 Kg/day H<sub>2</sub> 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

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## 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
  - H<sub>2</sub> production energy (kwh)
  - Dryer energy (kwh)
  - PDC compressor energy (kwh)

# Progress & Results

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## 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](http://www.aps.com), My Community, Future Fuels. 700 hits per month on website.



# Results

Energy Used: kWhrs to Make 1kg of H<sub>2</sub>  
Average Since August 2004

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

Hydrogen Motor Vehicle Fuel	
H <sub>2</sub> Production	80.78
Dryer	1.50
Compressor	2.67
Total	84.95
<b>39.3% efficient (LHV)</b>	
<b>DOE Target 64%</b>	

# 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
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<b><i>DOE Target for Energy Cost</i></b>	<b><i>\$1.80/kg</i></b>
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*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.

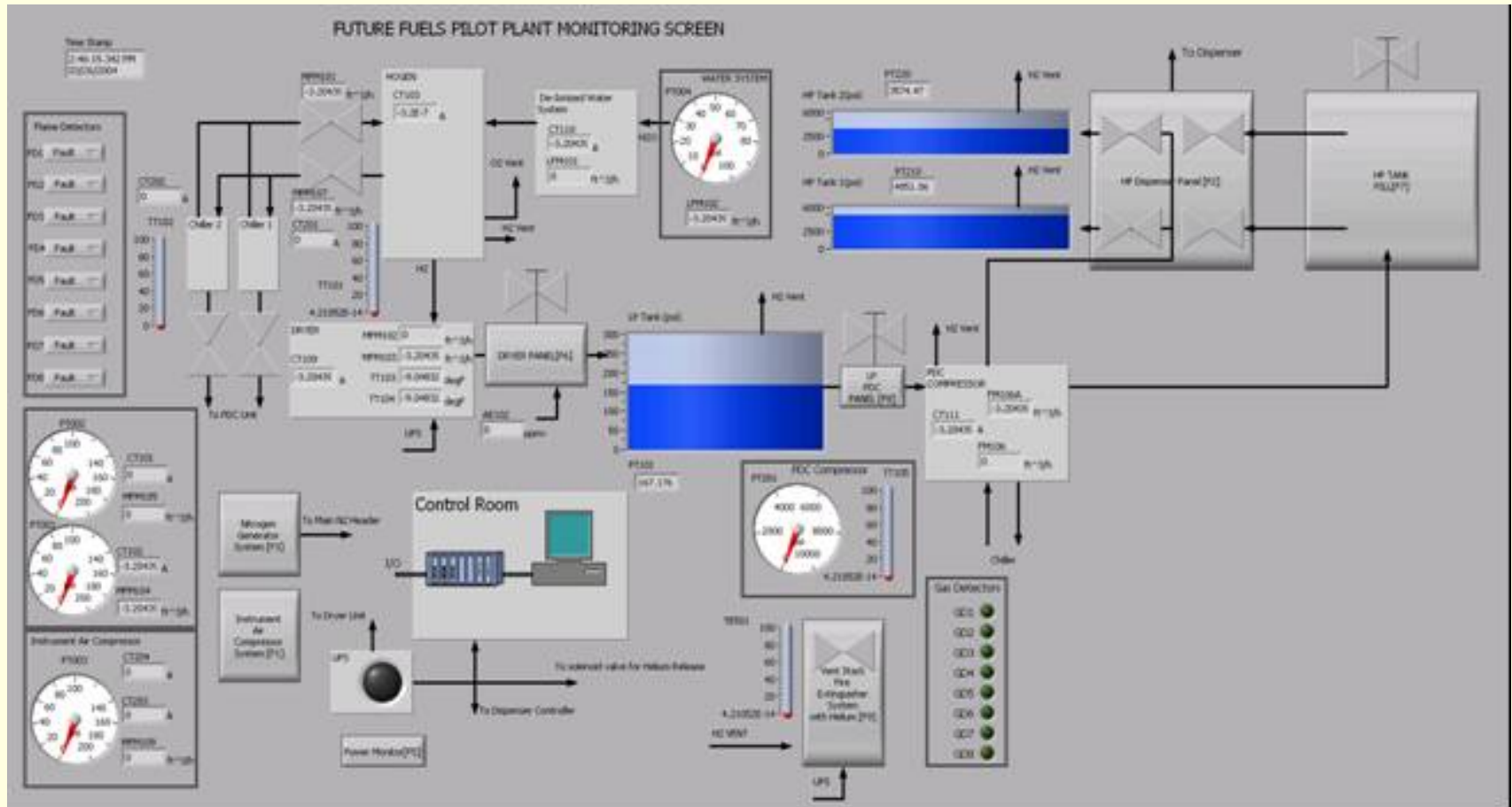
**Energy Cost for Hydrogen Production from Electrolysis at 68% Efficiency with Existing APS Electric Rate Classes (On Peak 9:00AM to 9:00 PM Monday thru Friday).**

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**

<b>Electricity Source</b>	<b>Type Generator</b>	<b>Peak Power (kw)</b>	<b>Energy (kwh)</b>	<b>Fuel (Kg of H2)</b>
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

		<b>Fuel</b>	<b>Peak Efficiency %</b>
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		
<b>PHASE #</b>	<b>1</b>	<b>2</b>	<b>3</b>
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
<b>RED</b>

**Vehicle Emission Test**

Test: FTP  
 Vehicle: Ford F150 5.4L V8  
 Low-Boost  
 Fuel: Hydrogen

**VARIABLES...**

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

**Bag Results...**

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

**Composite ...**

<b>Grams/mile</b>	<b>0.003</b>	<b>0.000</b>	<b>0.004</b>	<b>0.071</b>	<b>0.427</b>	<b>1.868</b>	<b>0.0033</b>
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# 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		
<b>PHASE #</b>	<b>1</b>	<b>2</b>	<b>3</b>
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...**

<b>FTP: (Hydrogen)</b>
<b>Preliminary Results</b>
<b>Pure CNG Fuel properties</b>
<b>Target Hydrogen conc: 15% by volume</b>
<b>Fuel economy correction factor: .95</b>
<b>Per request</b>
<b>Vin # 1FTPF17M8YKB39272</b>

**VARIABLES...**

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

WHITE

**Results...**

	NMHC	CH4	HC	CO	NOX	CO2	DF
<b>Phase 1 (CT)</b>	ppm	ppm	ppm	ppm	ppm	%	
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	
(gm)	0.170	1.146	1.512	2.834	1.134	1539.781	Particulate 0.0140
(gm/mile)	0.048	0.322	0.426	0.797	0.319	433.253	<b>14.32</b> 0.0039

	ppm	ppm	ppm	ppm	ppm	%	DF
<b>Phase 2 (CS)</b>							
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	
(gm)	0.000	0.310	0.360	0.364	0.527	1712.841	Particulate 0.0196
(gm/mile)	0.000	0.081	0.094	0.095	0.137	445.588	<b>13.99</b> 0.0051

	ppm	ppm	ppm	ppm	ppm	%	DF
<b>Phase 3 (HT)</b>							
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	
(gm)	0.031	0.567	0.691	0.286	0.600	1323.415	Particulate 0.0021
(gm/mile)	0.009	0.158	0.193	0.080	0.168	369.979	<b>16.83</b> 0.0006

**Composite ...**

<b>Grams/mile</b>	<b>0.012</b>	<b>0.152</b>	<b>0.190</b>	<b>0.236</b>	<b>0.183</b>	<b>422.267</b>	<b>MPG</b> <b>14.74</b>	0.0036
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**Vehicle Emission Test**

Test: FTP

Vehicle: Ford F150 5.4L V8  
 Low-Boost

Fuel: 70% CNG / 30% H2

# 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

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- 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

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- 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

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# Presentations & Publications

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- 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

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- 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

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- 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