

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

■ 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 |
|--------------------|--------|

| | |
|--|-------------------------|
| <i>DOE Target for Energy Cost</i> | <i>\$1.80/kg</i> |
|--|-------------------------|

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.

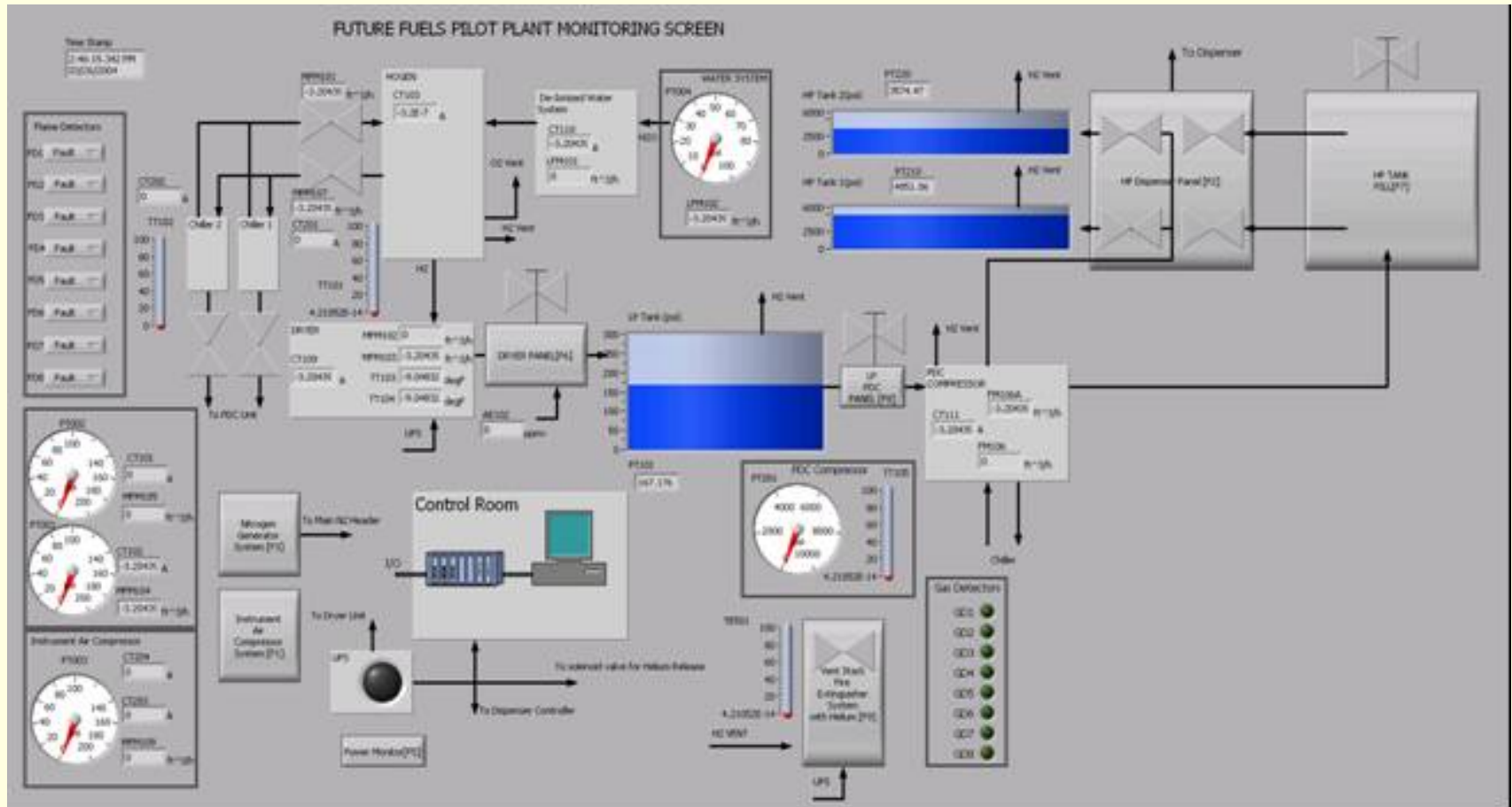
Energy Cost for Hydrogen Production from Electrolysis at 68% Efficiency with Existing APS Electric Rate Classes (On Peak 9:00AM to 9:00 PM Monday thru Friday).

| 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 |
| |
| |

Vehicle Emission Test

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

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 |

Bag Results...

| | NMHC | CH4 | HC | CO | NOX | CO2 | |
|----------------|-------|-------|-------|-------|--------|--------|-------------|
| | ppm | ppm | ppm | ppm | ppm | % | |
| Phase 1 | | | | | | | |
| 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 |
| Phase 2 | | | | | | | |
| 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 |
| Phase 3 | | | | | | | |
| 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 ...

| | | | | | | | |
|-------------------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|
| 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 |

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...

| | NMHC | CH4 | HC | CO | NOX | CO2 | DF | |
|----------------------|--------------|--------------|--------------|--------------|--------------|----------------|--------------|--------------------|
| | ppm | ppm | ppm | ppm | ppm | % | | |
| Phase 1 (CT) | | | | | | | | |
| 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 | 14.32 | 0.0039 |
| Phase 2 (CS) | | | | | | | | |
| 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 | 13.99 | 0.0051 |
| Phase 3 (HT) | | | | | | | | |
| 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 | 16.83 | 0.0006 |
| Composite ... | | | | | | | MPG | |
| Grams/mile | 0.012 | 0.152 | 0.190 | 0.236 | 0.183 | 422.267 | 14.74 | 0.0036 |

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

- 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