2006 DOE HYDROGEN PROGRAM

Business Opportunities Concept Project

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Arizona Public Service
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This presentation does not contain any proprietary or confidential information

Project ID TVP 2

OVERVIEW

Timeline

- Started CY: 2003
- Finish CY: 2006
- Percent complete: 90%

Budget

- Total project funding
  - DOE share: $784,000
  - APS share: $2,252,145
- Funding received in FY05: $1,035,465
- Funding for FY06: $319,341

Barriers

- Barriers addressed
  - Cost
  - Emissions
  - Renewable Integration
  - Electricity Cost

Partners

- BC Hydro
- Southern California Edison
- Sandia National Lab
- Idaho National Lab
- State of Arizona
- Valley of the Sun Clean Cities Coalition

APPROACH

Phase I. Tasks 1 & 2

Create Conceptual Models

Identify potential applications for H2 Parks

Define size and function

Phase II. Task 3, 4, 6, 7

Validate H2 Pilot Park

Real world testing of components and function

Performance, efficiency, O& M cost

Safety, reliability, quality, public acceptance

Validate the four Power Park functions

Phase III. Tasks 2 & 5

Refine Conceptual Models

Revise Models using actual component performance, cost, emissions and reliability

Engineer and integrate into systems, utility operations and renewable energy

Consider impacts of codes, standards and safety

Phase IV. Task 5

Identify the Value Proposition

If possible, implement conceptual model.

FUNCTIONS of a POWER PARK

A. Produce Hydrogen
   - Distributed electrolysis
   - Advanced production methods
   - Integration - systems to produce, store and manage

B. Produce Electricity – Grid Connect and Isolated
   - Fuel cells (H2)
   - ICE gensets (H2 and Blends of NG/H2)

C. Fuel Motor Vehicles – Private/Public
   - Fuel motor vehicles (H2 and Blends of NG/H2)
   - Vehicle emissions from H2 and NG/H2 fueled vehicles

D. Incorporate Renewable Energy
   - Arizona RPS requires renewable to electricity
   - Use of APS grid to move renewable to hydrogen

PHASE I: CONCEPTUAL MODELS

Project Phase I: Define Potential Power Park Business Models

Model 1.   1 - 10 Kg/day, 5 Kw FC, Solar PV

Small, Remote, Energy System or UPS

Applications: Telecom, Roadside Park

Model 2. 20 - 100 Kg/day, 30-100 Kw, Solar PV, Grid

Vehicle Refueling by dispenser, backup or peaking power by H2 ICE

Application: Vehicle fueling station, fleet or corporate applications

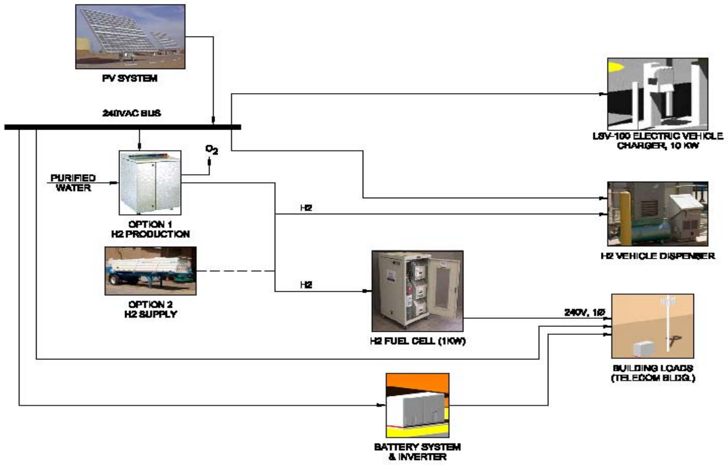
Model 3. 400 - 1500 Kg/day, 400kW - 5 MW, Solar PV Grid

Application: Utility Distributed Power

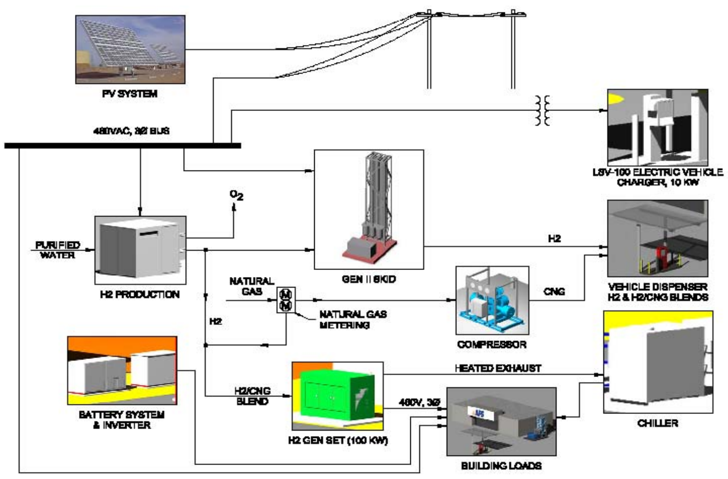
Model 4. Mobile Distributed Power up to 100 kW

Application: Utility Contingency Power, Feeder Overload

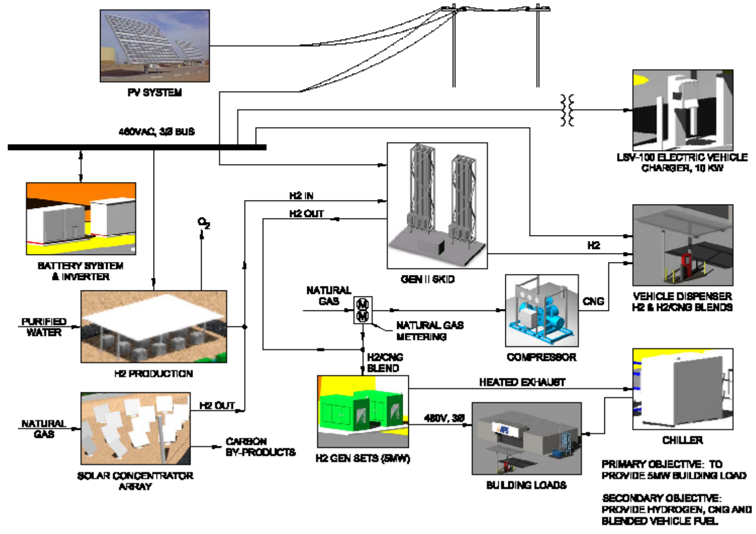
Model 1. 1 - 10 Kg/day, 5 Kw FC, Solar PV



Model 2. 20 - 100 Kg/day, 30-100 Kw, Solar PV, Grid



Model 3. 400 - 1500 Kg/day, 400kW - 5 MW, Solar PV Grid



Model 4. Up to 100 Kw Mobile

PHASE II: PERFORMANCE TESTS COMPLETED

- Proton H2 Electrolysis Unit 318 scfh
- Proton H2 Electrolysis Unit 220 scfh
- Plug Power 5 kW Fuel Cell (4 – units)
- Hydrogen Bromine 10 kW Stack
- Onan Genset (100 kW):
  - H2 with 50% EGR NOx control
  - H2 with lean burn ignition control
  - 30/70 CHYNG blend

- Ford 5.4L V8 H2 ICE (2 supercharged variations)
- Vehicle Emissions Testing (FTP drive cycle)
  - F150 high-boost, super-charged H2 fueled
  - F150 low-boost, super-charged H2 fueled
  - Silverado Natural aspiration H2 fueled
  - F150 low-boost, super-charged 30/70 blend fueled
  - Dodge power wagon natural aspiration 15/85 blend fueled

IN THE HISTORIC DISTRICT IN DOWNTOWN PHOENIX

Classified as an indoor hydrogen facility in a historic building

PHASE II: H_2 PILOT PARK FUNCTION VALIDATIONS

- **_Hydrogen Production_**
  - 8,261 Kg of H_2 produced by distributed electrolysis
- **_Fuel Motor Vehicles_**
  - 438 H_2 fueling events
  - 3,495 H_2 blend fueling events (15%, 20%, 30%, 50% H2 with CNG)
  - 9,730 total fueling events (including CNG)
  - Credit card transactions to procure motor fuel.
  - Taxis cabs, police vehicles, fire department vehicles, general public, fleet vehicles
- **_Produce Electricity_**
  - 47,000 kilowatt hours of electricity
- **_Renewable Energy Integrated_**
  - 7 kW Photovoltaic Array

"0" ZERO – accidents, near-misses, equipment damage, a perfect Safety Record

PHASE II: COMPONENTS INTEGRATED AND TESTED IN PILOT PARK

Qty.	Description
3	Electrolysis Units
4	Fuel Cells
2	Hydrogen Compressors
1	Nitrogen System
3	10-Ton Chillers
1	Hydrogen Dryer
2	RO/DI Water Purification Systems
1	70 kW – H2 ICE Genset
3	ICE Vehicles Converted to H2
1	7 kW – H2 ICE Genset
1	50 kW – H2 ICE Genset
1	100 kW – H2/NG (30/70%) ICE Genset
2	ICE vehicles converted to blend of hydrogen and natural gas
9	Hydrogen Mass Flow Meters
7	Hydrogen Pressure Regulators
11	Hydrogen Pressure Transmitters
2	6,000 psi Micron Hydrogen Filters
2	Fuel Dispensers

Qty.	Description
15	Hydrogen Check Valves and Safety Valves
1	APS H2/CNG/CHyNG Fuel Dispenser
2	Credit Card Systems
3	ASME H2 Pressure Vessels
2	Hydrogen Fire Systems
1	Helium System
1	Sprinkler System
15	Carbon Composite DOT Pressure Vessels
1	10 kW HBr Cell Stack
1	7 Kw Solar Array – Flat Plat Horizon
35	10,000 psi Swagelok H2 Valves
15	6,000 psi Parker H2 Valves
2	10,000 psi Butech H2 Valves
1	Metal Hydride Canister Fueling System
2	Metal Hydride Canisters for Small Fuel Cell
Lots of H2 hoses, break-a-ways, and nozzles	
Lots of 316SS O2 cleaned tubing and fittings	
Tube trailers 120,000 scf to 300,000 scf	

PHASE II: EFFICIENCY CALCULATIONS

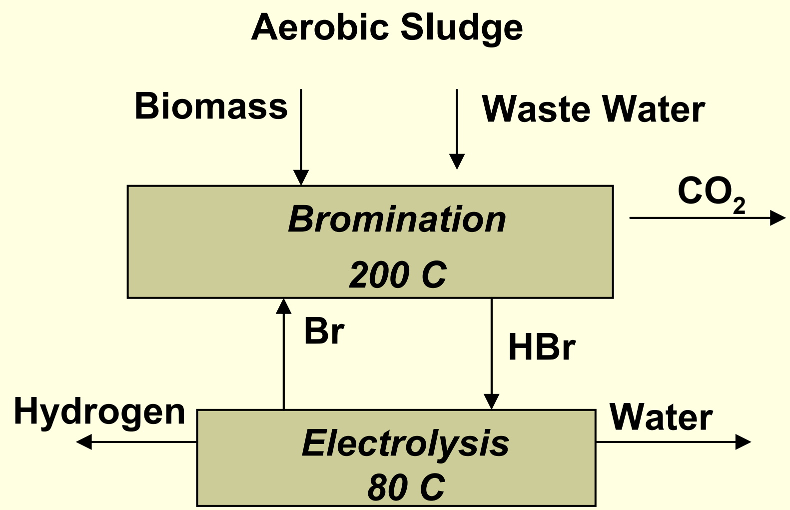
Electrolysis Efficiency	*FM102 (scf) / 414 x 33.34* / *Electrolysis kilowatt hour usage*
H2 Dryer Efficiency	*FM103 (scf) / 414 x 33.4* / *Dryer kilowatt hour usage + FM102/414 x 33.4*
H2 Compressor Efficiency	*FM106 (scf) / 414 x 33.4* / *Compressor kilowatt hour usage + FM106/414 x 33.34*
RO/DI System Efficiency	*RO system Flow Out (gallons)* / *Water Flow Line In (gallons)*
H2 ICE Genset Efficiency	*FM115 (H2 Kg) x 33.4* / *Kilowatt-hours from Genset*
H2 Fuel Cell Efficiency	*FM 116 (H2 Kg) x 33.4* / *kilowatt hours DC out (net)*

PHASE II: H_2 PILOT PARK COMPONENT OPERATION RESULTS

Equipment	Reliability (Annual hrs-Force outage hrs)	Quality (Mission)	Safety (Risk Assessment)	Annual Maint Hrs	Efficiency
Proton 318	99+%	99.9997	100%	4	41%
Proton 220	95%	99.9997	100%	5	42%
PDC (5 scfm)	99%	100%	100%	8	92%
PDC (40 scfm)	99%	100%	100%	8	92%
Electrodryer	100%	100%	100%	2	83%
Water DI/RO	95%	100%	100%	12	8%
ASME Vessels	100%	100%	100%	0	NA
H2 Safety Valves	100%	100%	100%	0	NA
H2 Control Valves	100%	100%	100%	2	NA
H2 Block Valves	70%	80%	70%	16	NA
H2 Combustible Gas	75%	75%	75%	16	NA
H2 UV/IR Scanner	100%	100%	100%	4	NA
N2 System	90%	75%	95%	8	NA
H2 Mass Flow Meter	100%	100%	100%	1	NA
5000 psi Carbon Tank	100%	100%	100%	0	NA
Plug Power #1	25%	25%	100%	Poor	46%
Plug Power #2	95%	99%	100%	6	46%
Plug Power #3	25%	25%	100%	Poor	46%
Plug Power #4	25%	25%	100%	150	46%
Onan Genset	90%	75%	100%	24	28%
OPW H2 Nozzle	100%	95%	100%	1	NA
OPW H2 Break-away	100%	100%	100%	1	NA
TESCOM H2 soleniod	100%	100%	100%	0	NA

PHASE II: HIGH EFFICIENCY HBr ELECTROLYSIS TESTING

Hydrogen produced with electricity at 18.57 whr/kg.
Performance testing will validate manufacturer's claim.



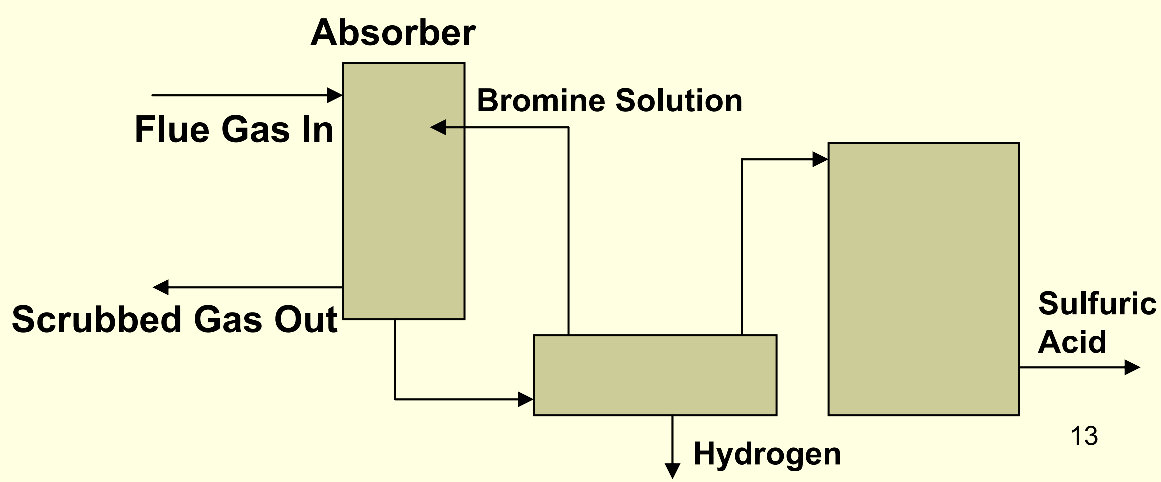
Waste Water Process

$C_6H_{10}O_5 + 7H_2O + Br_2 \longrightarrow 12HBr + 6CO_2$

$e + 24HBr \longrightarrow 12H_2 + 12Br_2$

SO_2 Emission Control

$Br_2 + 2H_2O + SO2 \longrightarrow 2HBr + H_2SO_4$



PHASE II: 10 kw HBr ELECTROLYSIS PERFORMANCE TEST SET-UP

PHASE IV: H2 PILOT NEW CUSTOMER CONVERTS HIS TRUCK TO BI-FUEL; H2 AND GASOLINE

Vehicles Emissions Test Report

TEST CELL	Q-Cell	VEHICLE...		FUEL...	
Test #	4467	Make	Chevrolet	Fuel	Hydrogen
Date	4/13/2006	Vehicle #	117VJA		
Time	11:08	Odometer	2528		
Driver	KB	Dyno Inertia	4750		
Operator	KB				

AMBIENT CONDITIONS...

Baro (inHg) 28.73

PHASE #	1	2	3
Temp (°F)	73.1	74.1	73.9
Wet blb (°F)	54.0	54.5	54.6
Humidity	26.5%	26.0%	26.6%
Abs (gr/lb)	33.1	33.6	34.3
NOx K fac	0.836	0.837	0.839

Comments...

FTP

Hydrogen

Trace Violations: 112sec total duration

VARIABLES...

PHASE #	1	2	3
VMIX (ft3)	2855	4850	2831
Distance	3.484	3.845	3.514

Bag Results...

	HC	CO	NOX	CO2	
Phase 1	ppm	ppm	ppm	%	DF
Sample Conc.	7.395	5.426	5.260	0.049	13.0
Ambient Conc.	7.589	1.822	0.033	0.045	
Net Conc.	0.389	3.744	5.229	0.007	
(gm)	0.018	0.352	0.676	10.761	
(gm/mile)	0.005	0.101	0.194	3.089	
Phase 2					DF
Sample Conc.	7.267	5.063	0.641	0.049	13.0
Ambient Conc.	7.423	2.893	0.116	0.047	
Net Conc.	0.415	2.392	0.534	0.005	
(gm)	0.033	0.383	0.117	12.420	
(gm/mile)	0.009	0.099	0.031	3.230	
Phase 3	ppm	ppm	ppm	%	DF
Sample Conc.	6.341	5.504	8.161	0.049	13.0
Ambient Conc.	6.574	3.145	0.116	0.047	
Net Conc.	0.273	2.600	8.055	0.005	
(gm)	0.013	0.243	1.037	7.509	
(gm/mile)	0.004	0.069	0.295	2.137	
Composite ...					
Grams/mile	**0.007**	**0.092**	**0.136**	**2.904**	

Automotive Testing Laboratories, Inc.

Customer Value Proposition

PHASE IV: HYDRIDE CANISTER FILLING FOR SMALL FUEL CELLS INCORPORATED INTO H2 PARK

New Value Proposition for Hydrogen Power Park

- Japan Steel Company developed a hydride canister filling appliance.
- Hydride canister appliance has been incorporated into the APS Pilot Hydrogen Park.
- Hydride canister appliance installation was approved by Phoenix Fire Department.
- This value added feature to the Park may support the marketing of small fuel cells.
- Hydride appliance may provide market assistance to small electrolysis equipment.
- Hydride appliance may support the marketing of consumer electronics or devices powered by fuel cells.

PUBLIC ACCEPTANCE OF HYDROGEN PILOT

1,751 people have toured the Pilot Park since 2003.

Pilot weekly tours: public groups, individuals, politicians, congressmen, international visitors, even NRC commissioners.

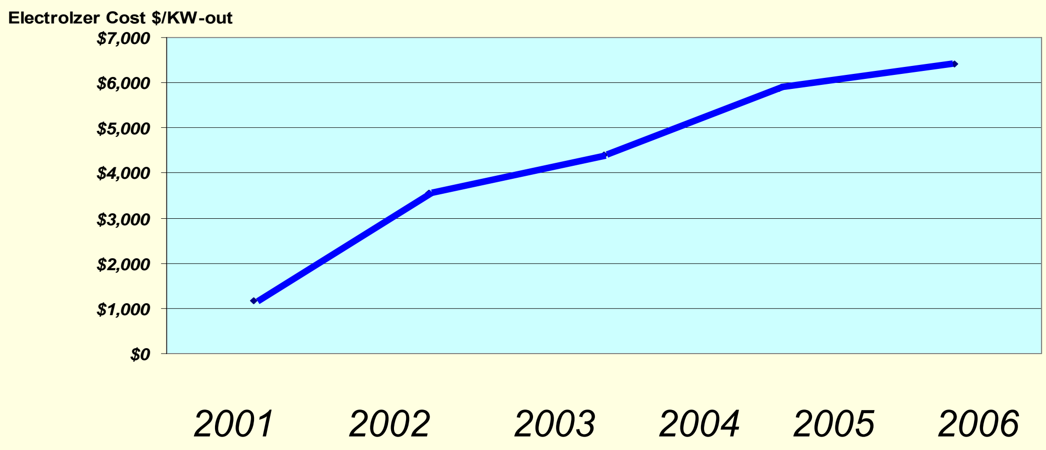
PHASE III: REFINE CONCEPTUAL MODELS

Engineering, Design, Testing, Permitting	
Codes	NFPA (50A, 50B, 52, 70, 853, 496, 68, 69,54) ASME Pressure Vessel Code (B PV Section VIII, XII) Power Piping Code (B31.1, B31.3, B31.12)
Standards	CGA (S-1.3, H-1, 2, 3, 4; G-5, 5.3,5.4, 5.5, 5.6, 5.7) SAE (J2578, J2579, J2600, J2601, J2719)
Regulations and Statutes	Professional Engineering Regulations OSHA (CPL 02-02-045, 29CFR1910.119, 1910.103) ACR: Air Emissions City of Phoenix Zoning Codes City of Phoenix Fire Requirements City of Phoenix Motor Vehicle Fueling Permit City of Phoenix Compressed Gases Permit

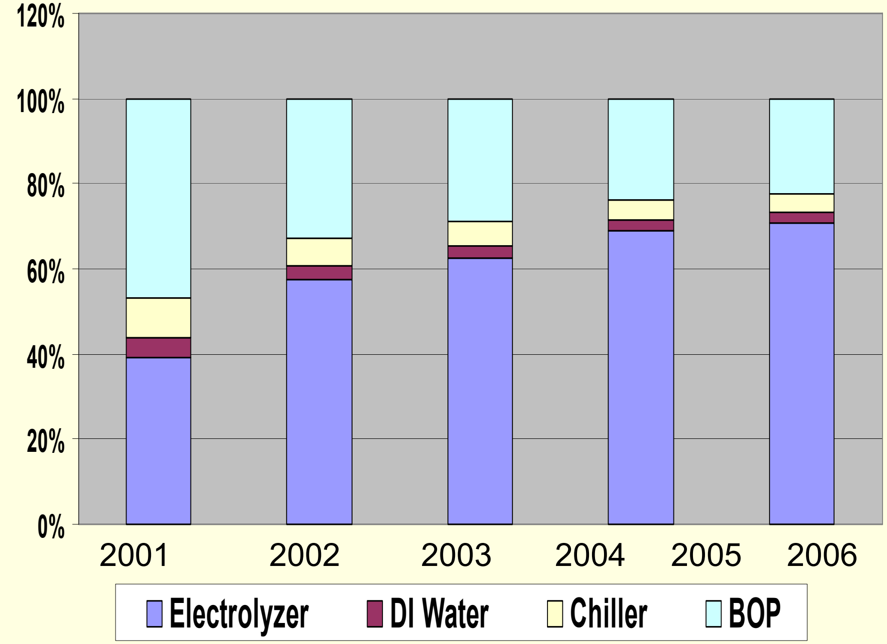
PHASE III: REFINE CONCEPTUAL MODELS

- The cost of small electrolysis equipment is increasing.
- Electrolysis unit rose from 40% of total hydrogen production system cost in 2001 to 75% of the total by 2006.
- Fixed cost ($/Kg) of small distributed hydrogen electrolysis systems, after tax, rose from $2.76 in 2001 to $8.36 in 2006.

Cost of Electrolysis Units at APS (after tax - $/kw-out)

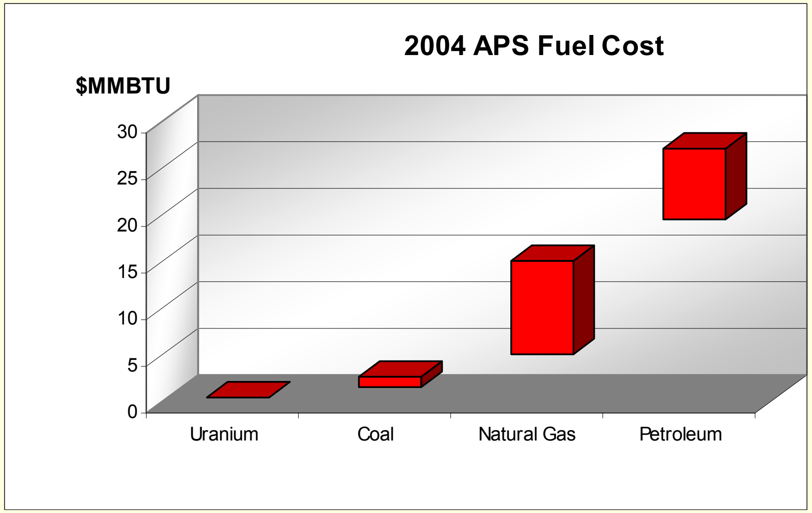


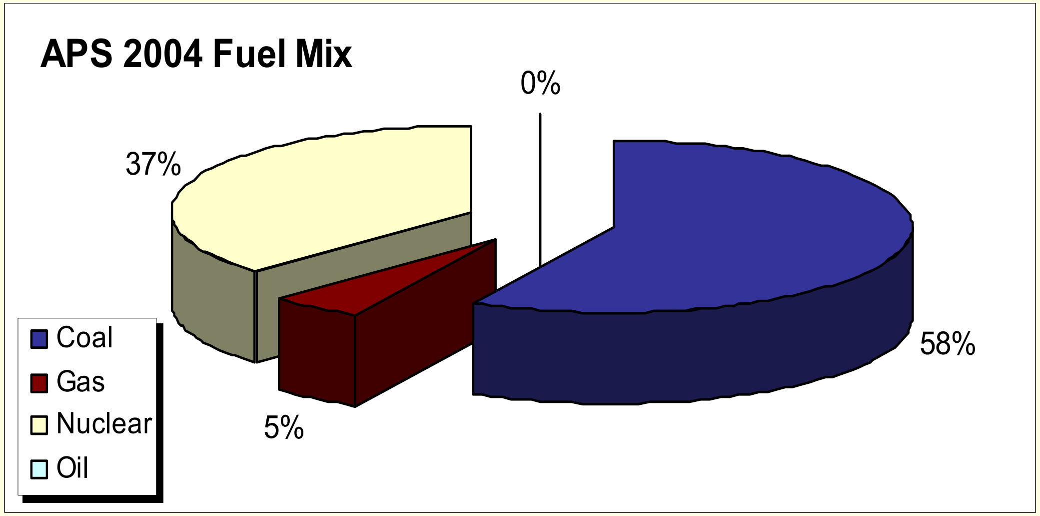
Cost Elements for small Hydrogen Electrolysis Systems, % of total cost.



(BOP – Balance of Plant, DI – RO/DI water treatment)

PHASE III: ECONOMICS REFINE CONCEPTUAL MODELS





APS Electric Rates By Customer Class

ELECTRIC RATE CLASS	Summer: May – October		Winter: November – April		Demand	Demand
	On Peak	Off Peak	On Peak	Off Peak	Summer	Winter
	$/kwh	$/kwh	$/kwh	$/kwh	$/kw	$/kw
Residential	0.13310	0.04299	0.10918	0.04167		
Commercial Small	0.09610	0.04429	0.08610	0.03429		
Commercial Med	0.07938	0.04175	0.06945	0.03182	$11.334	$11.334
Commercial Large	0.05283	0.03797	0.04723	0.03393	$9.390	$8.510
Commercial X-Large	0.03529	0.02792	0.03529	0.02792	$12.209	$12.209

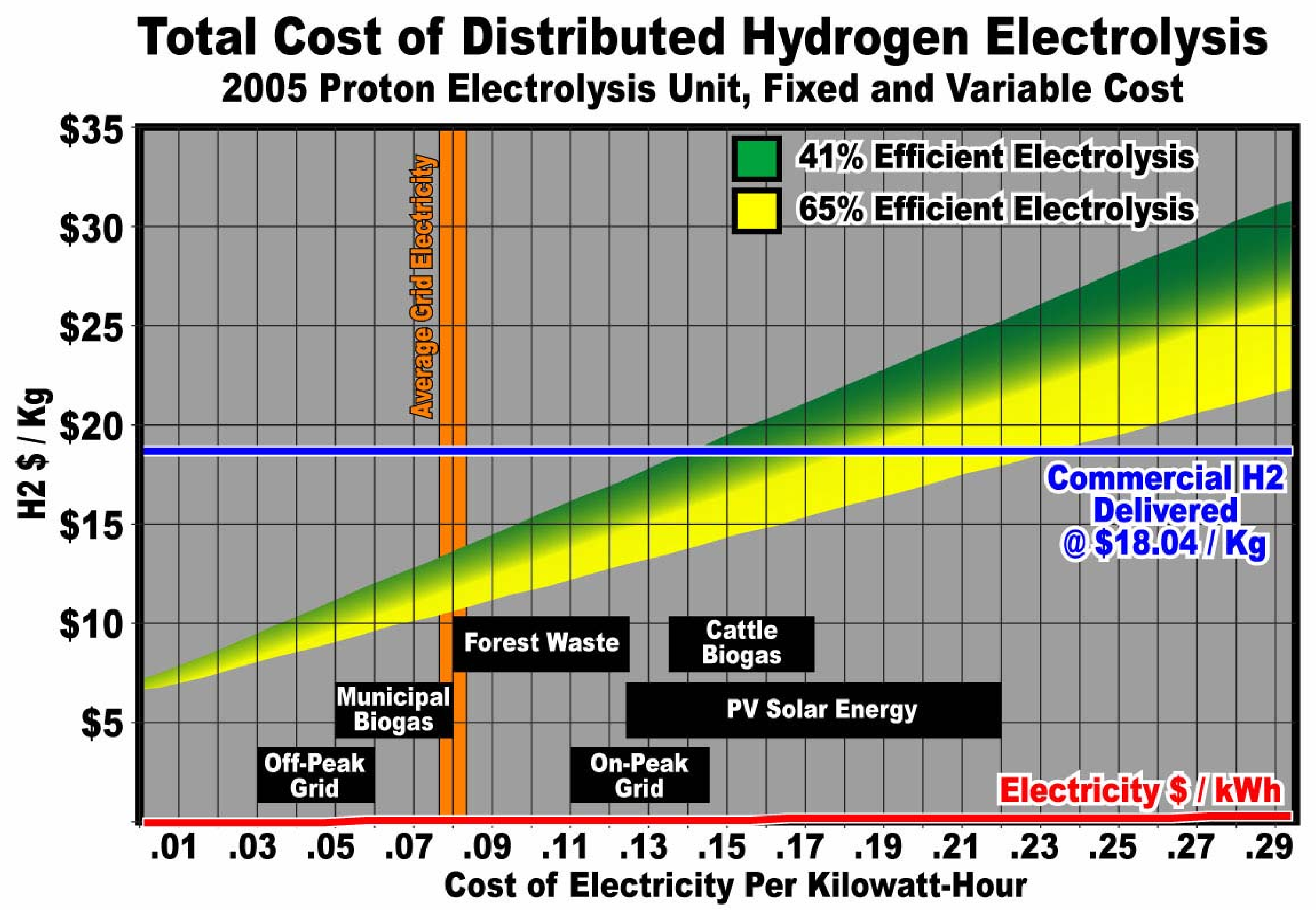
Note: Gasoline energy (LHV 114,000 BTU/gallon) is equivalent to 33.4 kWhrs. Rates effective 4-1-2005.

PHASE III: RENEWABLE ENERGY

APS Solar Test and Research (STAR) Center Data					
Solar Type	**Cost $/Watt Capital**	**Cost $/kWh O&M**	**Energy kWwh/kW-Yr**	**Cost Energy kWh/$**	**Cost Energy $/kWh**
PV Fixed Horizontal	5.25	0.01	1,250	4.75	0.220
PV Fixed Latitude	5.25	0.01	1,630	6.20	0.171
PV Tracking Horizontal	5.50	0.01	2,350	8.55	0.127
PV Tracking Latitude	6.50	0.01	2,450	8.25	0.131
PV High-Concentration	6.00	0.01	2,030	6.75	0.158
PV High-Concentration (goal)	3.00	0.01	2,400	16.00	0.0725
Organic Rankine Cycle Trough	4.00	0.03	2,000	10.00	0.130
Dish Turbine	2.50	0.03	2,400	19.20	0.082

APS Biomass Data – Cost to Produce Electricity from APS RPS Program					
Biomass Fuel Type	**Cost $/Watt Capital**	**Cost $/kWh O&M**	**Energy kWwh/kW-Yr**	**Cost Energy kWh/$**	**Cost Energy $/kWh**
Forest Products	$3000	$0.04 - $0.06	NA	NA	0.08 - 0.120
Biogas Municipal Waste Water Ops	$1500 - $2000	$0.02 - $0.05	NA	NA	0.05 – 0.08
Biogas Agriculture Cattle Dairy/Feed-lot			NA	NA	0.136 – 0.171

•Eager Az Forest Products, City of Phoenix Waste Water Facility, AZ Dairymen Asso., AZ Cattlemen's Asso.



Total Cost of Distributed Hydrogen Electrolysis
2005 Proton Electrolysis Unit, Fixed and Variable Cost
$35
$30
$25
$20
$15
$10
$5
H2 $ / Kg
41% Efficient Electrolysis
65% Efficient Electrolysis
Average Grid Electricity
Commercial H2 Delivered @ $18.04 / Kg
Forest Waste
Cattle Biogas
Municipal Biogas
PV Solar Energy
Off-Peak Grid
On-Peak Grid
Electricity $ / kWh
.01
.03
.05
.07
.09
.11
.13
.15
.17
.19
.21
.23
.25
.27
.29
Cost of Electricity Per Kilowatt-Hour

PHASE III: REFINE MODELS

REALITY CHECK: ENGINEERING FEASIBILITY

Model 1: Small Remote System

Issue: Fuel cell testing in Phase II demonstrated reliability problems

Issue: Cost of electrolysis equipment

Model 2: 20 to 100 kg/day, 30 – 100 kw System

Issue: Reputable H_2 fueled Genset manufacturers

Issue: Cost and reliability of electrolysis units

Issue: Cost, life, reliability of fuel cells

Issue: H_2 purity for fuel cell cars

Model 3: 500 – 1500 kg, 500 kw to 5 MW System

Issue: Reputable H_2 fueled Genset manufacturers

Issue: H_2 purity from KOH electrolysis units (fuel cell cars)

Issue: Cost of electrolysis equipment

Issue: Reputable manufacturer of integrated systems

PHASE IV: INSTALLED VALUE PROPOSITION

MODEL 1 – REMOTE DISTRIBUTED HYDROGEN SYSTEM INSTALLED

The Value Proposition:

Economic:

- Installed System Cost……….$207,000
  (Proton 220, chiller, DI system, meter)
- Fixed …………………………. $2.53/kg
- Variable Cost ………………. $2.28/kg
- Total Cost ……. …………… $4.81/kg

Cost of Delivered Hydrogen….. $24.14/kg
Annual Savings…………………$89,981

Additional Benefits:

- Reduced Hazardous Material Storage
- Increased Reliability

(Fixed cost uses CRF 23%)

FUTURE WORK

- Phase II Performance Testing
  - Complete performance testing of HBr Cell
  - Continue to validate Pilot Park Functions
  - Complete Assessment of Hydride Canister Refueling System
  - Complete Assessment of Components for Model IV
  - Complete Task Reports
- Phase III Model Refinement
  - Update assessment of electrolysis options
  - Complete Model II refinement for substation or hospital application
  - Complete Model III
  - Complete Model IV
  - Complete Task Reports
- Phase IV
  - Complete Model I & Model II Value Proposition
  - Write Final Project Report

SUMMARY

Relevance: Determine if Hydrogen Power Parks are feasible, safe, and provide a value proposition to potential customers.

Approach: Validate Hydrogen Park Models by testing components, systems, and concepts obtaining "real-world" performance and operating results.

Functional Accomplishments: Validated all power park functions including potential customer acceptance including; public vehicle refueling, cost of renewable energy to produce hydrogen, distributed hydrogen electrolysis, electricity production from fuel cells and H_2ICE. Perfect safety record after 4 years of operation.

Goal Accomplishment: Identified and implemented one value proposition, resulting in "satisfied – customer".

Conclusion: Hydrogen Parks are safe and feasible. Difficult to compete on cost with gasoline and diesel fuel, unless there exists a ***need*** for hydrogen.

Biggest Issue: Cost of Electrolysis Equipment.

REVIEWER'S COMMENTS (May 2005)

Lack of Partnerships

APS has "partnered" with BC Hydro and SCE, both of which have installed hydrogen operations.

APS assisted in the formation of HUG (Hydrogen Utility Group) which now has 12 utility members and meets quarterly.

Did not include all data analysis (didn't include capital costs of fuel cells)

Phase III address the business case while phase II was the validation phase. The fuel cells must earn their right for incorporation into a business case by first demonstrating they will worked when called upon, then meeting the minimum economic hurdle. There were FC performance issues.

Include Cost reduction strategy, mainly for PV-based hydrogen production.

The Project is part of the Technology Validation Program, and therefore it is out of our scope to create new products. APS has significant success in reducing the cost (kw & kwh) of solar PV systems. Currently our lowest cost PV complete system is $5/watt installed. Hydrogen produced by PV electricity needs both to meet the criteria of low cost and high efficiency. Electrolysis equipment is expensive, in the case of small electrolysis units costs are greater per kw than the entire PV systems. The low operating voltages of this equipment triggers large losses in the form of heat.

CRITICAL ASSUMPTIONS AND ISSUES

ISSUES:

- The lack of reasonably priced electrolysis equipment.
- The lack of reputable hydrogen fueled H2 ICE Gensets with performance warrenties & guarantees.
- The short life of PEM fuel cells.
- The lack of reasonably priced fuel cells.
- The lack hydrogen fueled vehicles.
- The lack of public policy facilatating the market for hydrogen.