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HYDROGEN POWER PARK BUSINESS OPPORTUNITIES CONCEPT PROJECT

Design, Analysis & Demonstration

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OBJECTIVES

- To Identify Component Options For Off-Grid and Grid-Connected Power Park Systems
- To Develop Models For Off-Grid and Grid-Connected Power Park Systems
- To Evaluate The Performance Of Model Power Parks Through Testing Of Components
- To Identify Model Power Park Economic Parameters
- To Develop Operational Envelopes For Optimized Power Park Models
- To Identify The Customer Value Proposition

BUDGET

- **Total Project Funding = $2,2426,979**
  - **Contractor Funding = $1,426,979**
  - **DOE Funding = $800,000**
- **Expenditures To Date = $822,242**
  - **2003 = $553,401**
  - **1st Quarter 2004 = $268,841**

DOE TECHNICAL TARGETS

- **Hydrogen Production By Electrolysis**
  - **2005 Total H_2 Cost = \$3.80/kg**
  - **2005 Energy Efficiency = 65%**
  - **Electrolysis Cell Stack = \$0.48/kg**
  - **Compression = \$0.32/kg**
  - **Electricity = \$1.80/kg**
  - **Power Conversion = \$0.28/kg**

DOE TECHNICAL BARRIERS

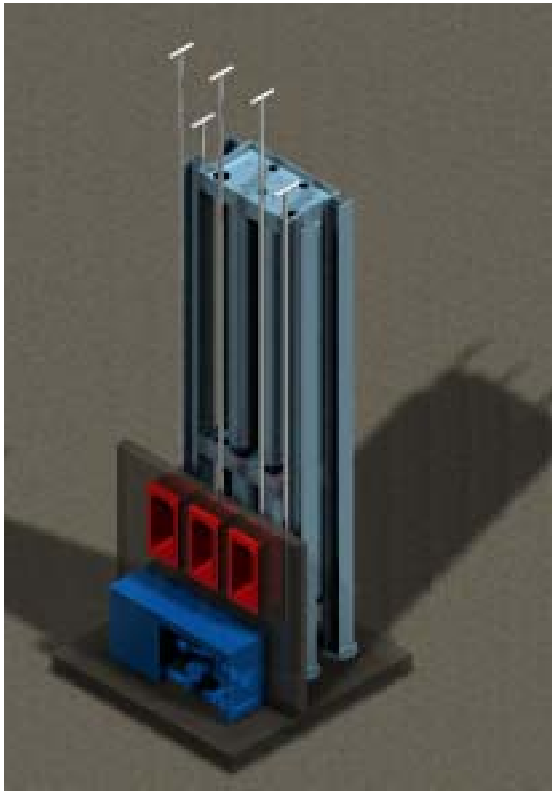
- Cost
  - Electricity
  - Hydrogen Fuel
  - Production Equipment
- Efficiency
- Grid Emissions (Carbon Reduction)
  - Generation Mix
  - Renewable Integration

TECHNICAL APPROACH

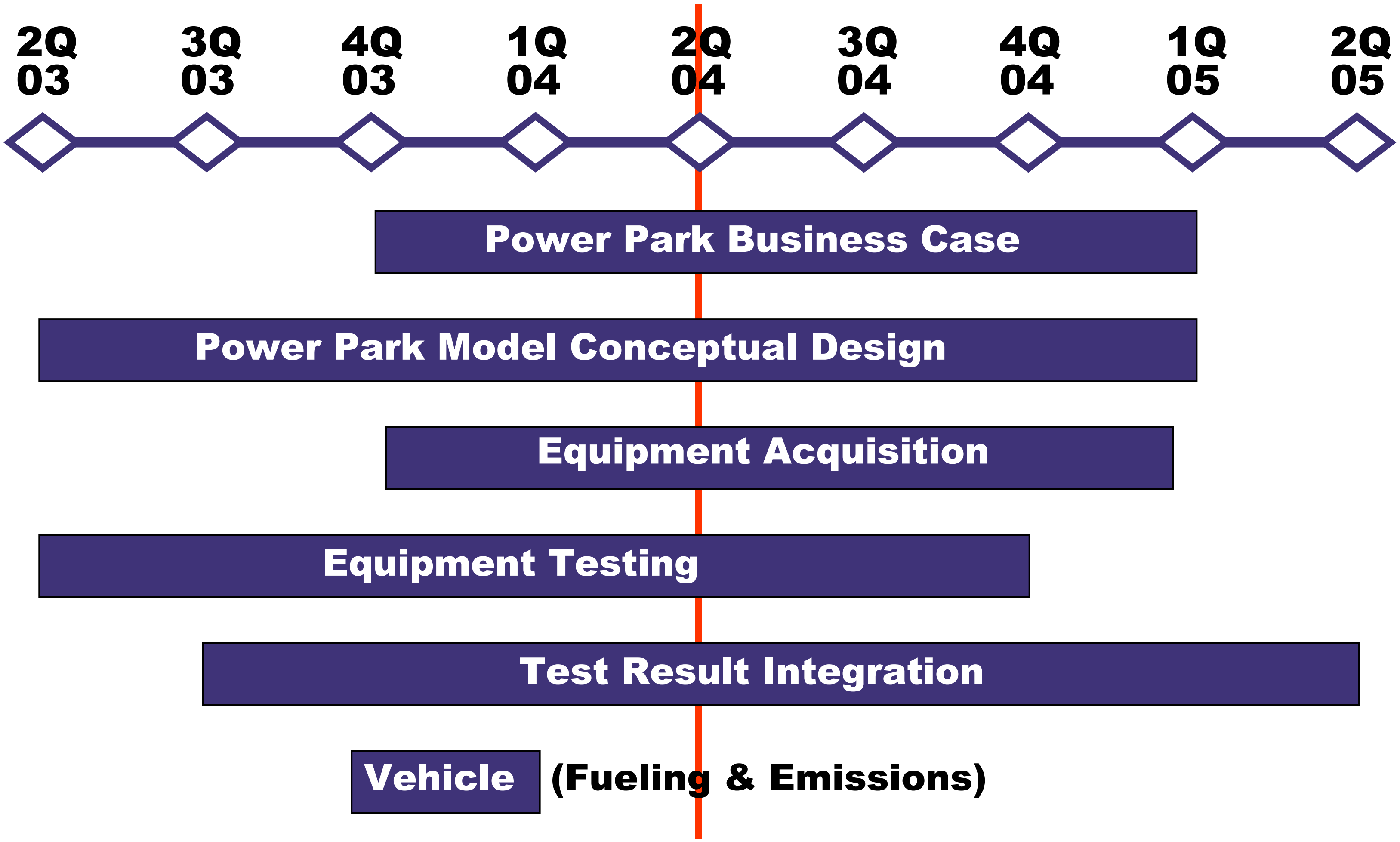
- **Develop Four Power Park Models Based On Current Knowledge Of Costs & Benefits**
- **Validate The Performance Of Each Model By Testing Of Components**
- **Analyze The Business Case For Each Power Park Model Using Actual Performance and Cost**
- **Value Engineer Each Power Park Model To Identify Opportunities To Improve Economics**
- **Identify System Operations for Opportunity**
- **Identify Customer Value Propositions**

PROJECT SAFETY

- **Hydrogen Storage and Handling**
  - **Utilize Coaxial Containment System™**
- **Power Park Component Testing**
  - **Test Plans Include HAZOP Issues**
  - **Qualify Test Personnel**



PROJECT TIMELINE



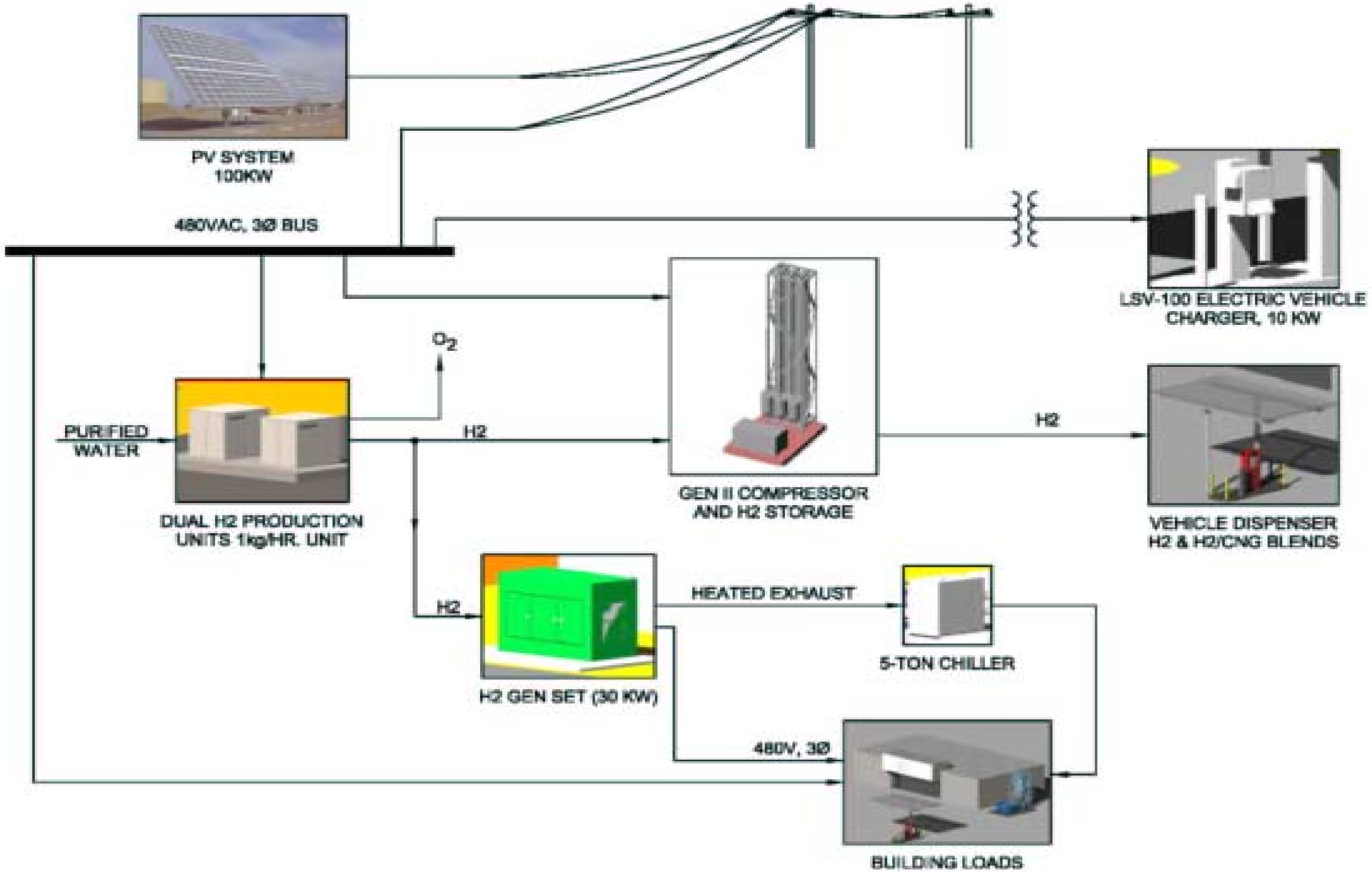
KEY ELEMENTS OF THE POWER PARK

- Renewable Energy Source
- Hydrogen Production
- Vehicle Refueling
- Electric Generation

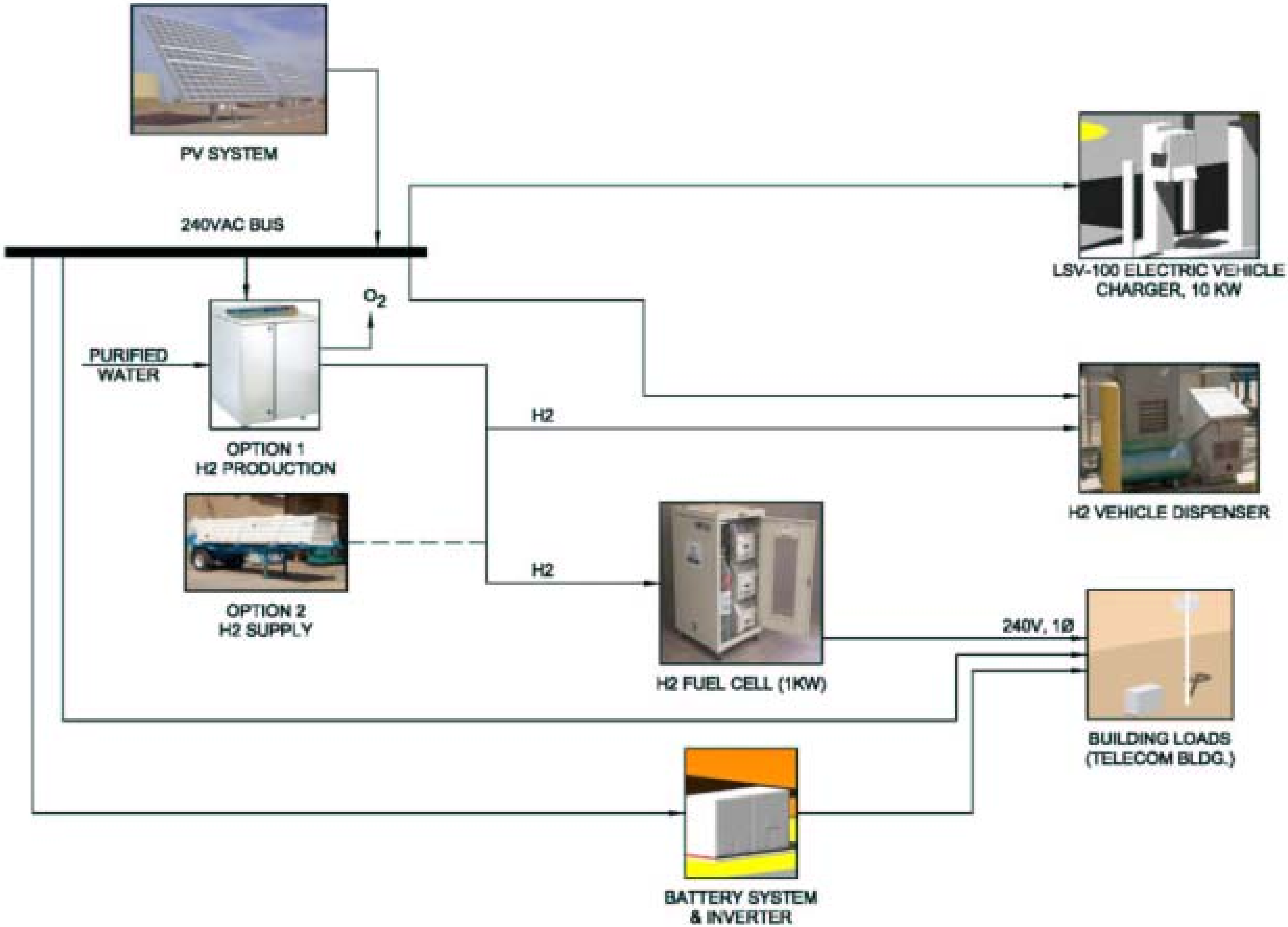
POWER PARK MODELS

- Four Models Defined
  - 50 kg/day Grid Connected
  - 4 kg/day RAPS/UPS
  - 1,500 kg/day Grid Connected
  - 150 kW Mobile
- Use Existing Utility Assets
- Maximize Economic Value

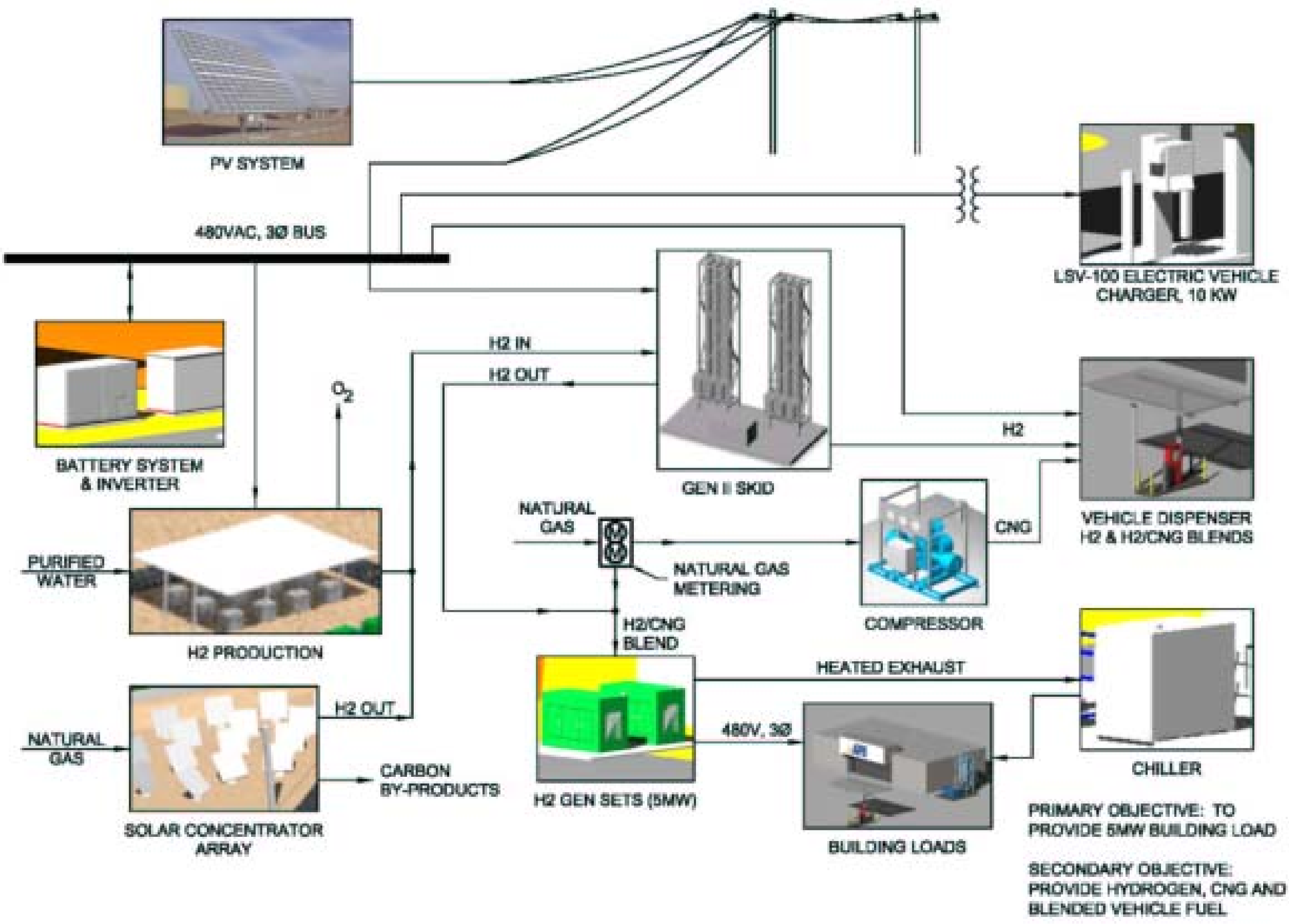
50 kg/day GRID CONNECTED



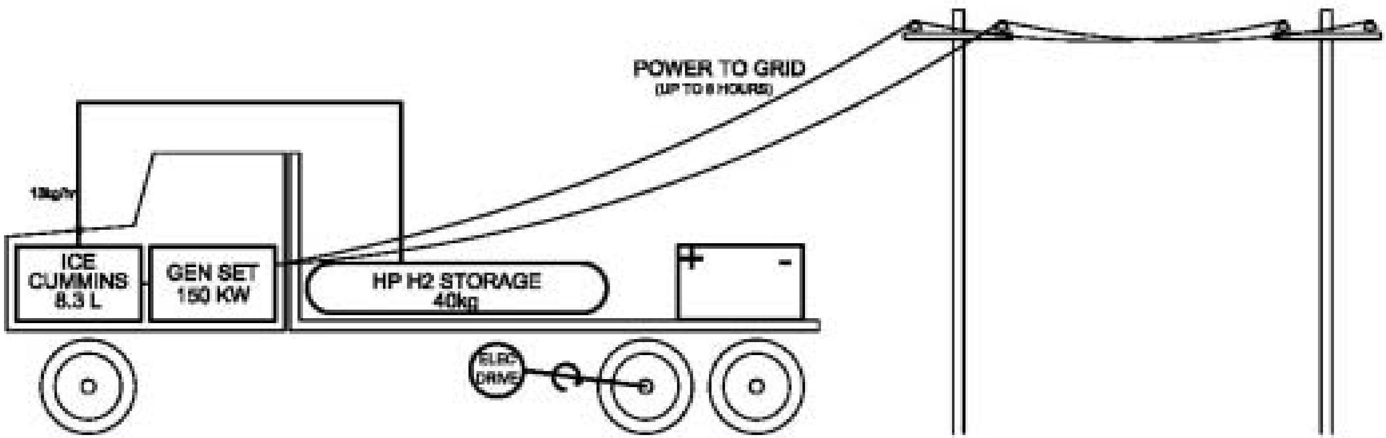
4 kg/day RAPS/UPS



1,500 kg/day GRID CONNECTED



150 kW MOBILE



- HYBRID
- 480V 3Ø
- 208V 3Ø
- 240V 1Ø
- AVERAGE OF 22 MILES/DAY

PRIMARY OBJECTIVE:
TO PROVIDE 100kW OF
ELECTRICAL POWER

EQUIPMENT

- Control System – Installation Underway
- Hydrogen Production
  - Pilot Plant Operating
  - Acquiring Additional Electrolysis Equipment
  - Acquiring Increased Compressor Capacity
- Refueling Dispensers Installed and Operating
- Fuel Cells
  - Acquiring Proton Unigen - 1 kW
  - Acquiring Plug Power backup power – 5 kW
- ICE
  - 5.4L low and high boost
- ICE Genset
  - 70 – 125 kW with NG, HCNG, & H_2 Fuel
  - 11 kW with propane and H_2 Fuel
- Chiller
  - Acquiring 5 ton chiller with waterless cooling
- Line Truck
  - Acquiring Class 8 Utility Line Truck
- Renewable Energy
  - 7 kW PV Array Installed

EQUIPMENT TESTING

- Hydrogen
  - Production by Electrolysis (Proton)
  - Commercial Delivery
- Vehicle Refueling and H_2 Storage/Handling
  - CNG, CHyNG, Hydrogen (6,000 psi)
  - 2,350 fueling events
- Vehicle ICE Emissions
  - Blends 15%, 30%, 50%
  - Hydrogen
- Vehicle ICE Performance
  - Blends 15%, 30%
  - Hydrogen

APS WEBSITE

THE POWER TO MAKE IT HAPPEN℠

Hydrogen Power Park

H2 pilot plant
Control panel

Pilot plant
analysis

APS renewable
energy
Plants and
production

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.

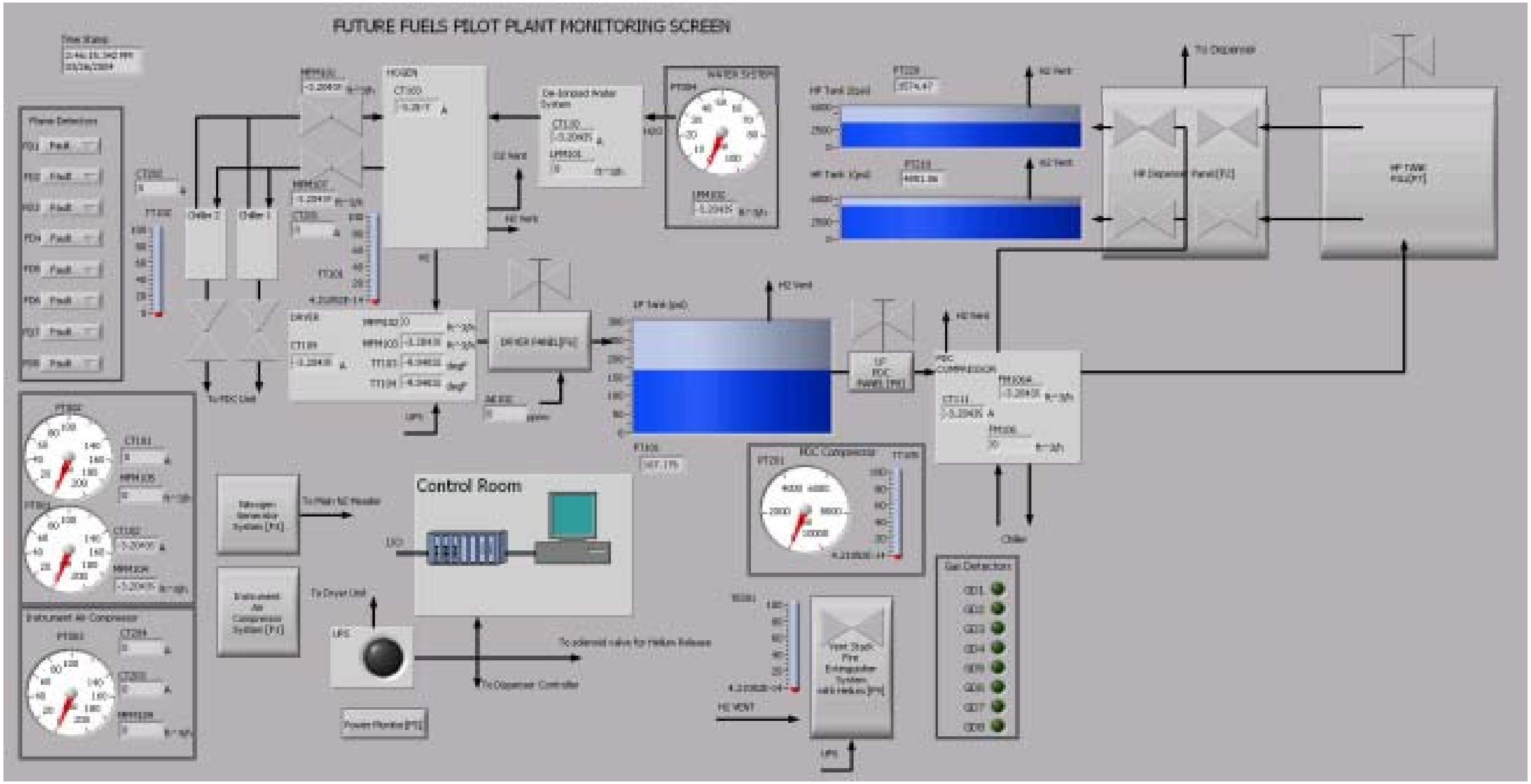
Hydrogen production from water electrolysis.

Pilot hydrogen plant and refueling station

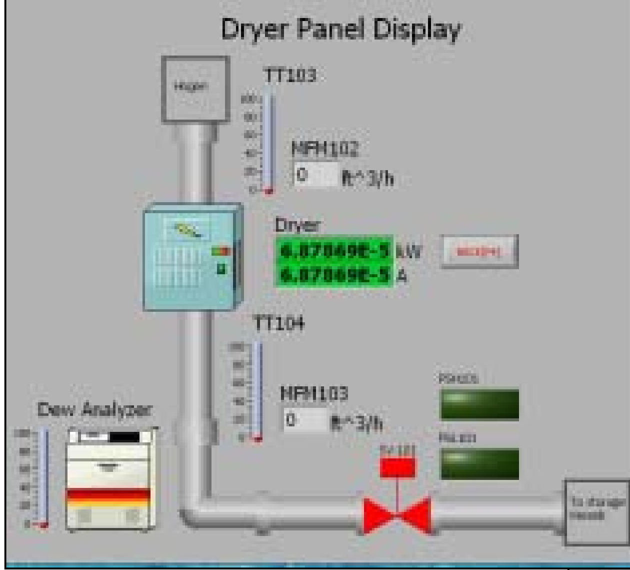
H2-Fueled Distributed Electric Generation

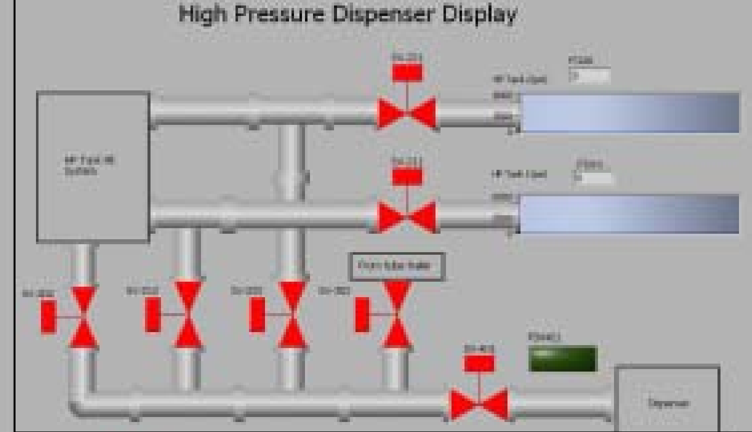
PILOT PLANT CONTROL PANEL

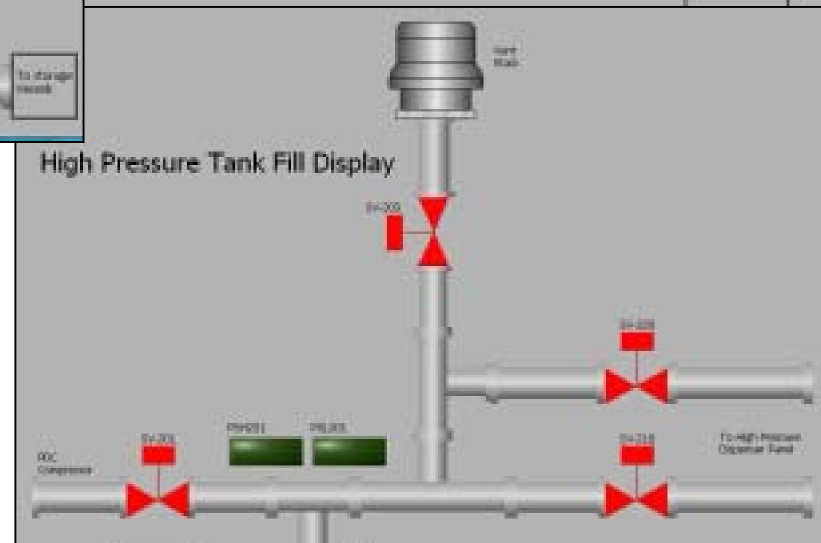
Internet Site Accessible

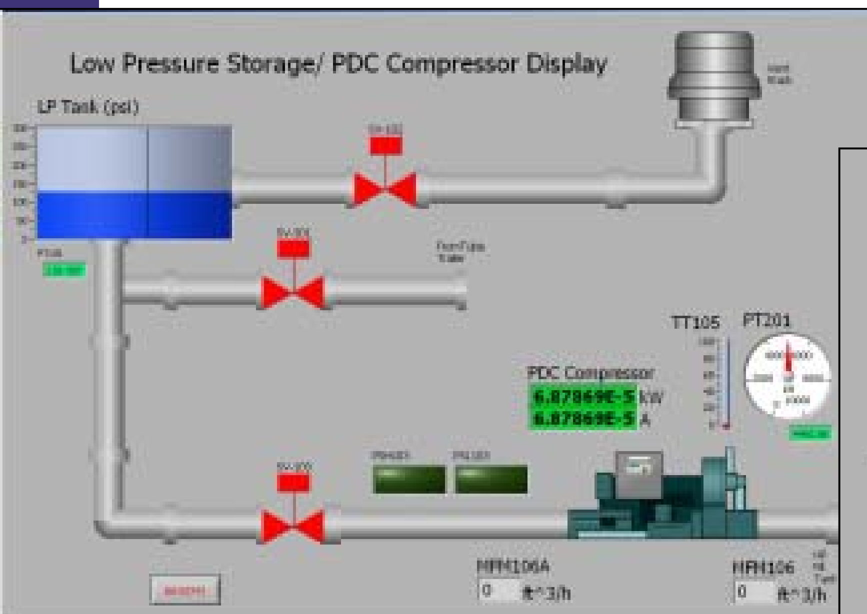


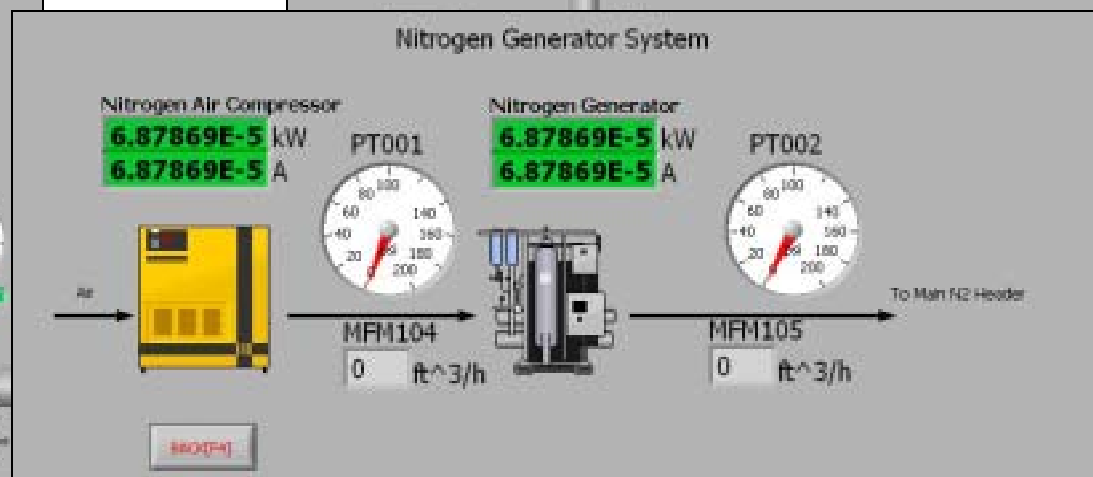
CONTROL SUB-PANELS











TESTING – DISTRIBUTED GENERATION
ICE Hydrogen & Blends

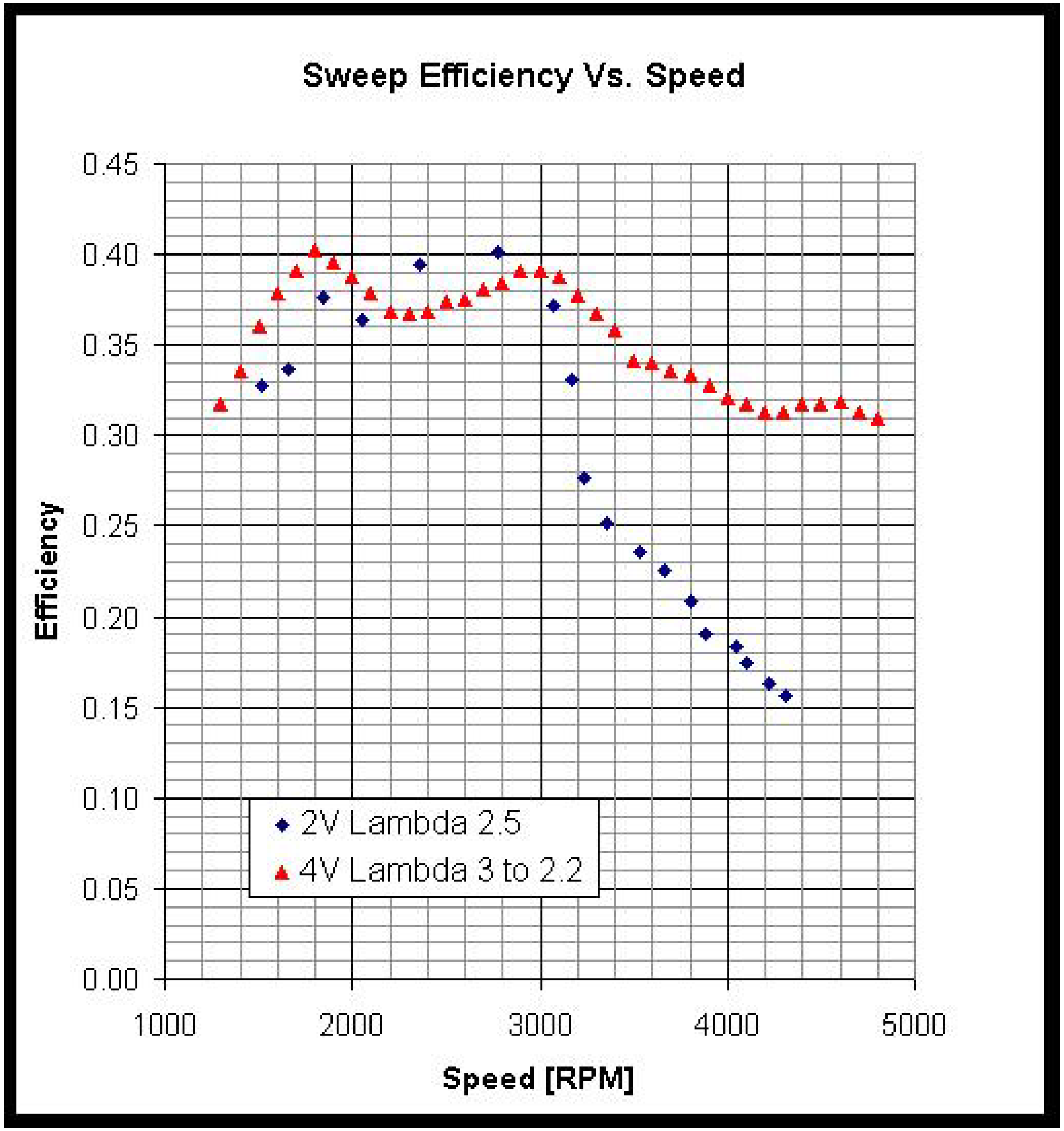
- **Renewable Energy**
  - **Solar Data Collection Underway**

- **Power Generation**
  - **5.4 L ICE – (H_2 & Blend) Complete**
  - **11 kW H_2 ICE & Propane - Complete**
  - **8.3L Cummins ICE – (H_2 & Blend) Underway**

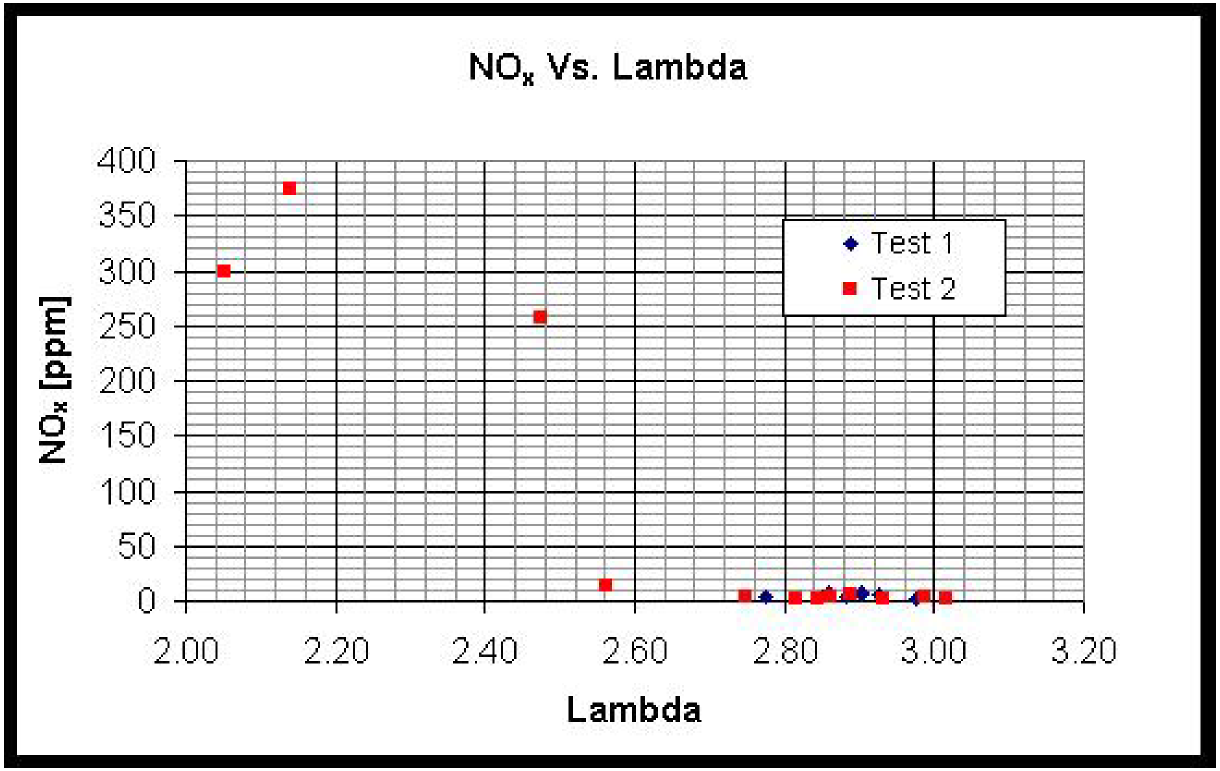
TESTING - ICE

ENGINE PERFORMANCE 5.4 L - Complete

- Hydrogen Fuel
- High Efficiency Achieved
  - High Compression Ratio
  - Fuel Ratio & Spark Timing Critical
  - Tradeoff With Power & Emissions



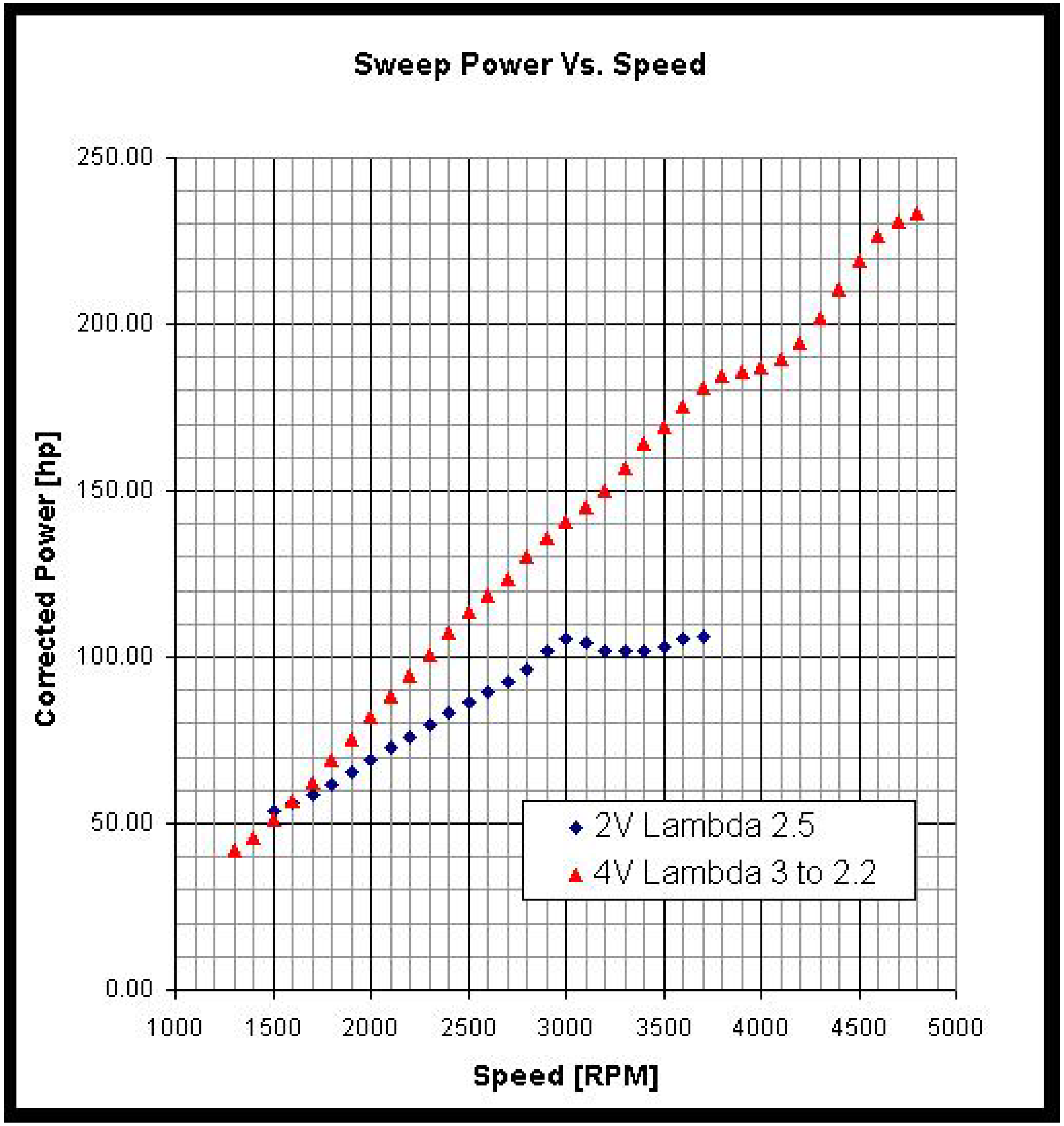
ENGINE PERFORMANCE
5.4 L (continued)



- **Hydrogen Fuel**
- **Emissions Sensitive To Fuel Air Ratio**
  - **Tradeoff With Power**
  - **Forced Induction Replaces Lost Power**
  - **Insignificant Emitter**

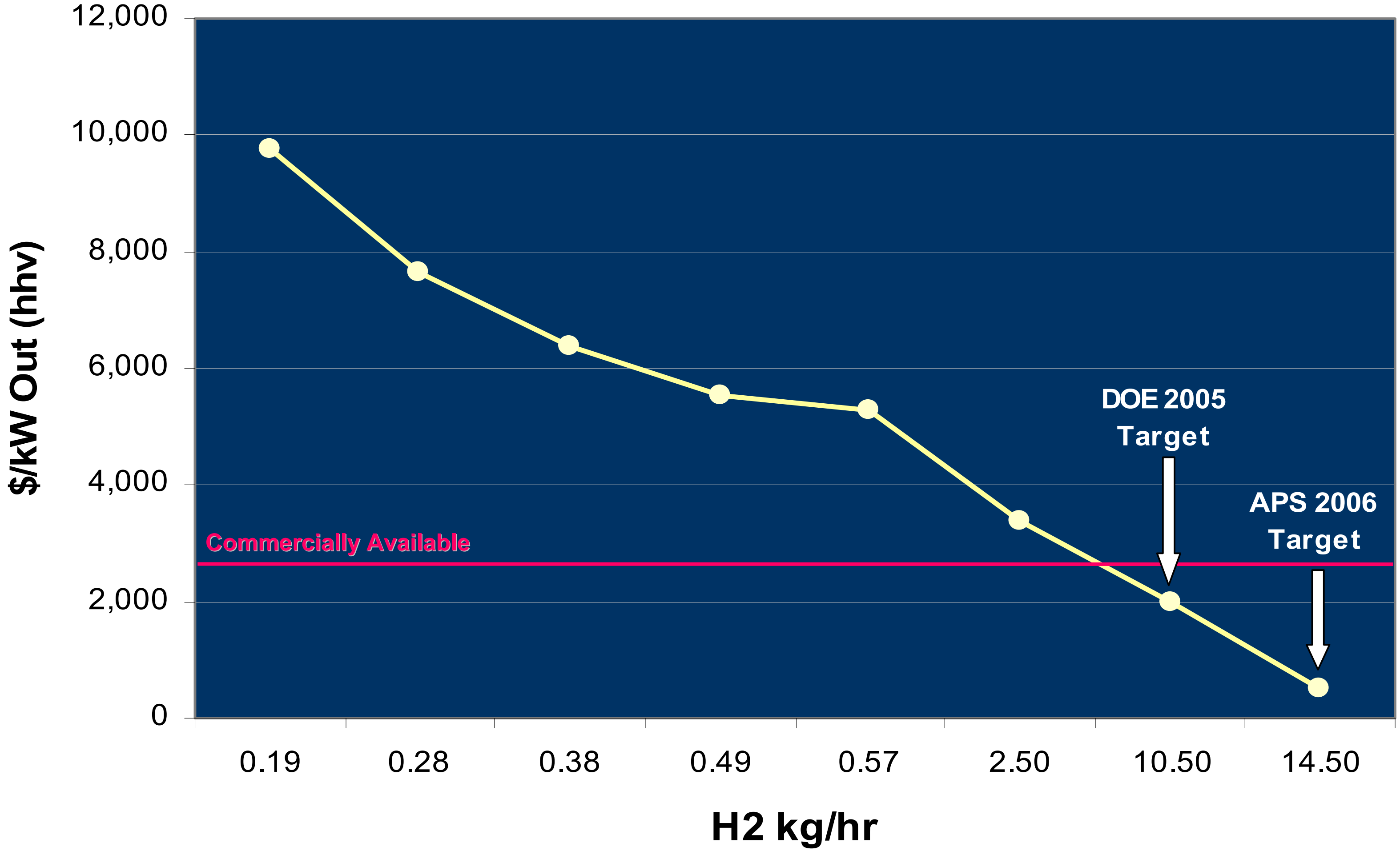
ENGINE PERFORMANCE
5.4 L (continued)

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



Electrolyzer Equipment Costs

Hydrogen Production Rate vs. Electrolyzer Cost



INTERACTIONS & COLLABORATIONS

- **BC Hydro, Canada**
  Power Park Models, High Pressure Storage
- **Southern California Edison, California**
  Battery Systems, Hybrid Power Train
- **General Electric, New York**
  Hydrogen Production
- **Publications**
  Hobbs, R.S., "Development of Hydrogen Fuel Based Power Park": Proceedings of the 15th Annual National Hydrogen Association Conference, April 26-30, 2004, Hollywood, California.

REVIEWER COMMENTS

- **Comments**
  - **Project Not Started**
  - **No Accomplishments Noted**
  - **Need Additional Detail**
- **Resolution**
  - **Contract Executed Through The State Of Arizona**
  - **Measurable Progress Presented**

FUTURE WORK

- **Complete Equipment Testing**
  - **Electrolysis Unit**
    - **Electrolyzer**
  - **Fuel Cell**
    - **UNIGEN PEM (1 kW)**
    - **Plug Power (5 kW)**
  - **Engine Generators**
    - **8.3L Hydrogen 100 kW**
    - **8.3L Natural Gas/Hydrogen Blend 100 kW**
  - **Absorptive Chiller**
    - **5 ton**
    - **Engine Waste Heat Recovery**

FUTURE WORK (continued)

- **Evaluate Power Park Models**
  - **Integrate Test Results With Models**
    - **Determine Efficiency & Cost Based On Component Test Results**
  - **Compare Costs To Alternatives**
  - **Prepare Energy & Mass Balance for each model**
  - **Finalize Conceptual Designs for Models**
  - **Evaluate Business Case**
    - **Analyze Current Competitiveness**
    - **Evaluate Improvements Required To Achieve Competitiveness**
    - **Identify Equipment Cost & Operation Envelope**
    - **Identify Customer Value Proposition**