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
Total Project Funding = $2,242,979
- Contractor Funding = $1,426,979
- DOE Funding = $800,000

Expenditures To Date = $822,242
- 2003 = $553,401
- 1st Quarter 2004 = $268,841
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
Hydrogen Storage and Handling
- Utilize Coaxial Containment System™

Power Park Component Testing
- Test Plans Include HAZOP Issues
- Qualify Test Personnel
PROJECT TIMELINE

- Power Park Business Case
- Power Park Model Conceptual Design
- Equipment Acquisition
- Equipment Testing
- Test Result Integration
- Vehicle (Fueling & Emissions)
KEY ELEMENTS OF THE POWER PARK

- Renewable Energy Source
- Hydrogen Production
- Vehicle Refueling
- Electric Generation
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
4 kg/day RAPS/UPS
1,500 kg/day GRID CONNECTED
150 kW MOBILE

Primary Objective:
To provide 100kW of electrical power

- Hybrid
- 480V 3Ø
- 208V 3Ø
- 240V 1Ø
- Average of 22 miles/day

ICE CUMMINS 8.3 L
GEN SET 150 KW
HP H₂ STORAGE 40kg

POWER TO GRID (UP TO 8 HOURS)
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, & H₂ Fuel
  ● 11 kW with propane and H₂ Fuel

Chiller
  ● Acquiring 5 ton chiller with waterless cooling

Line Truck
  ● Acquiring Class 8 Utility Line Truck

Renewable Energy
  ● 7 kW PV Array Installed
Hydrogen
- Production by Electrolysis (Proton)
- Commercial Delivery

Vehicle Refueling and H₂ 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
Currently, Arizona Public Service has photovoltaic generation capacity of over 5 megawatts. 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.

Hydrogen production from water electrolysis.
CONTROL SUB-PANELS
TESTING – DISTRIBUTED GENERATION
ICE Hydrogen & Blends

◆ Renewable Energy
  ● Solar Data Collection Underway

◆ Power Generation
  ● 5.4 L ICE – (H₂ & Blend) Complete
  ● 11 kW H₂ ICE & Propane - Complete
  ● 8.3L Cummins ICE – (H₂ & Blend) Underway
Hydrogen Fuel

High Efficiency Achieved

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

Sweep Efficiency Vs. Speed

- 2V Lambda 2.5
- 4V Lambda 3 to 2.2

Speed [RPM]
- **Hydrogen Fuel**

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

- DOE 2005 Target
- APS 2006 Target

Commercially Available

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<th>$/kW Out (hhv)</th>
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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
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
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