



# DOE Hydrogen Program Technology Validation Sub-Program

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Technologies

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Project #: TV1



# Objectives



Validate integrated hydrogen and fuel cell technologies for transportation, infrastructure, and electric generation in a systems context under real-world operating conditions.

- By 2005, \$3.60/gge and 8¢/kWh.
- By 2008, 20,000 hour fuel-cell durability (stationary), 32% efficiency, \$1,500/kW
- By 2009, 250+ mile range, 2000 hour fuel-cell durability (vehicle), \$3.00/gge hydrogen (untaxed)
- By 2011, biomass/wind or geothermal electrolyzer-to-hydrogen system to produce hydrogen for \$2.85/gge at the plant gate



# Tasks



- Task 1 Vehicle Field Evaluations
- Task 2 Hydrogen Infrastructure – Power Parks
- Task 3 Natural Gas-to-Hydrogen Refueling Stations
- Task 4 Co-Production of Hydrogen and Electricity
- Task 5 Renewable Hydrogen Production Systems
- Task 6 Technical Analyses



# Budget



| Task |                                      | DOE         |              | Cost Shares  |
|------|--------------------------------------|-------------|--------------|--------------|
|      |                                      | EW&D        | Interior     |              |
| 1    | Fleet & Infrastructure               | \$6,359,761 | \$16,713,129 | \$21,781,890 |
| 2    | Power Parks                          | \$720,000   |              | \$720,000    |
| 3    | Natural Gas to H2 Refueling Stations | \$1,178,355 |              | \$878,355    |
| 4    | Energy Station                       | \$350,000   |              | \$350,000    |
| 5    | Renewable                            | \$0         |              | \$0          |
| 6    | Analyses                             | \$250,000   | \$351,000    | \$0          |
| 1&4  | Earmarks                             | \$5,059,000 |              | \$5,059,000  |



# Congressionally Directed Projects



|                             |  |                |  |
|-----------------------------|--|----------------|--|
| California Infrastructure   | \$4,960,000<br>(2005)                        | Tasks<br>1 & 4 | Develop, build, and test hydrogen infrastructure |
| Locomotive fuel cell        | \$300,000<br>(2005)                          | Task<br>1      | Develop, build & test underground H2 mine loader |
| Bus Evaluation              | \$99,000<br>(2005)                           | Task<br>1      | Analyze zero emissions bus – Santa Clara, CA     |
| Univ. of Alabama Birmingham | \$963,372<br>(2003)                          | Task<br>1      | Test stationary and vehicle hydrogen systems     |
| Hawaii Energy Center        | \$992,000<br>(2005)<br>\$2,982,000<br>(2004) | Task<br>2      | Develop fuel cell test center                    |
| Hawaii Power Park           | \$490,539<br>(2004)                          | Task<br>2      | Build and test power parks                       |



# Congressionally Directed Projects

Continued



|                              |  |        |   |
|------------------------------|--|--------|---|
| NEXT Energy                  | \$793,096 (2003)                       | Task 2 | Build and test refueling station                                    |
| Chattanooga                  | \$2,485,250 (2004)                     | Task 4 | Develop, build and test solid oxide fuel cell coproduction system   |
| Washoe County                | \$1,962,155 (2004)<br>\$992,000 (2005) | Task 5 | Develop, build & test geothermal/<br>electrolyzer refueling station |
| UNLV                         | \$963,372 (2003)                       | Task 5 | Build and test photovoltaic refueling station                       |
| Florida Hydrogen Partnership | \$1,962,155 (2004)                     |        | Hydrogen research and development                                   |



# Barriers



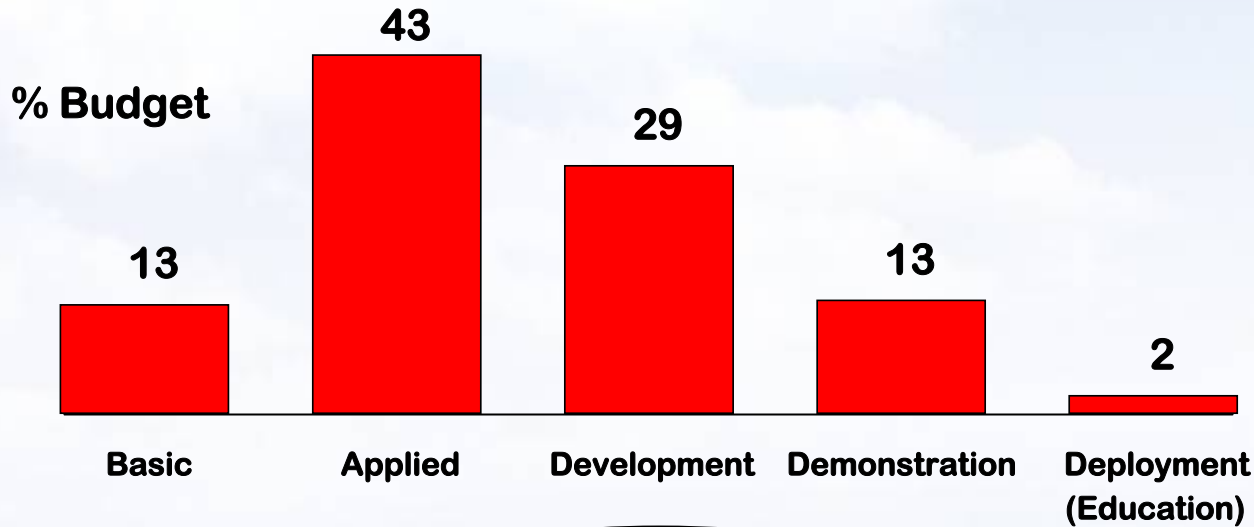
|   |   |   |
|---|---|---|
| A | Vehicles                                | <ul style="list-style-type: none"><li>• statistical data for vehicles that are operated under controlled, real-world conditions (i.e., fuel economy, cold start efficiency, stack degradation, system durability)</li><li>• vehicle drivability, operation and maintenance</li></ul>      |
| B | Storage                                 | <ul style="list-style-type: none"><li>• driving range</li><li>• cost</li><li>• composite tank operating cycle life and failure</li></ul>  |
| C | H <sub>2</sub> Refueling Infrastructure | <ul style="list-style-type: none"><li>• capital costs to build and install</li><li>• footprints</li><li>• system availability</li></ul>   |
| D | Hydrogen and Electricity Coproduction   | <ul style="list-style-type: none"><li>• statistical data on cost and durability of hydrogen fuel cells and reformer systems</li><li>• development of safety procedures</li><li>• codes &amp; standards development</li><li>• availability, operation and maintenance experience</li></ul> |
| E | Maintenance & Training Facilities       | <ul style="list-style-type: none"><li>• limited certified procedures</li><li>• limited trained personnel</li><li>• lack of data on operation and maintenance costs</li></ul>  |
| F | Codes & Standards                       | <ul style="list-style-type: none"><li>• statistical data for codes and standards development</li><li>• need development of safety procedures (i.e., HAZOP and FMEA)</li><li>• global standards need to be established</li></ul>   |
| G | Hydrogen from Renewable Resources       | <ul style="list-style-type: none"><li>• durability, cost and efficiency for integrated renewable electrolysis systems</li><li>• biomass feed system, catalyst lifetimes</li></ul>   |



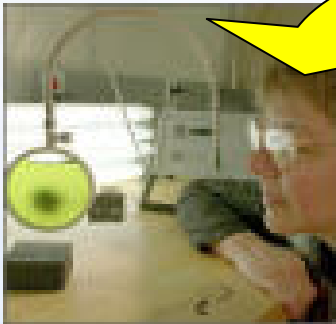
# Balanced Program is Being Implemented



FY 2005: Requested DOE Hydrogen Program Budget, by Category (\$227M)



H<sub>2</sub> Production  
H<sub>2</sub> Delivery  
H<sub>2</sub> Storage  
Fuel Cells



Basic & Applied Research

Technology Development

Systems Analysis & Integration

Safety, Codes & Standards  
Education



Technology Validation through "Learning Demonstrations"





# Task 1 – Vehicle Field Evaluation “Learning Demonstration”



## Description

- Support CaFCP vehicle and bus demonstration
- Support Controlled Fleet demonstrations (collect vehicle operating experience from different geographic regions)
- Design, build and test hydrogen locomotive and front-end loader vehicles



# CaFCP Bus Demonstration



Hickam Air Force Base



Santa Clara Valley Transportation Authority

## California Fuel Cell Bus Demonstration Sites



SunLine Transit Agency



Alameda Contra-Costa Transit Agency

- Completed evaluation of ThunderPower bus at SunLine
- Data collection in progress at Santa Clara VTA and Hickam AFB
- Infrastructure in place for the Alameda Contra-Costa Transit Agency



# Technology Validation Strategy



- Conduct learning demonstrations of hydrogen infrastructure in parallel with hydrogen fuel cell-powered vehicles to enable and assess technology readiness for a 2015 commercialization decision.

## Major Objectives

- Obtain detailed component data under real-world conditions (climatic, geographic etc.) to re-focus the Department's hydrogen and fuel cell component and materials research
- Validate the technology against time-phased performance-based targets



# Learning Demonstration Description and Performance Targets



- FY 2004 – 2009 Project Period
- Government/industry cost shared co-operative agreement
- \$190M Government share subject to the appropriations process
- 2 Generations of vehicles
- Cold climates to be included by 2<sup>nd</sup> generation
- Renewable feedstock for H<sub>2</sub> generation included
- Codes, Standards and Education integral to the success of the project
- Stationary facilities that co-produce electricity and hydrogen are included

## Key Targets

| Performance Measure        | 2009*      | 2015**     |
|----------------------------|------------|------------|
| Fuel Cell Stack Durability | 2000 hours | 5000 hours |
| Vehicle Range              | 250+ miles | 300+ miles |
| Hydrogen Cost at Station   | \$3.00/gge | \$1.50/gge |

\* To verify progress toward 2015 targets

\*\* Subsequent projects to validate 2015 target



# Cooperative Agreements Have Begun



(1)



(1)



Awarded 4 cooperative agreements  
1 project in negotiation

(1) Fuel cells supplied by Ballard



# Data Collection & Analysis Process



## Developed Secure Data Center and composite data products

Raw Data, Reports

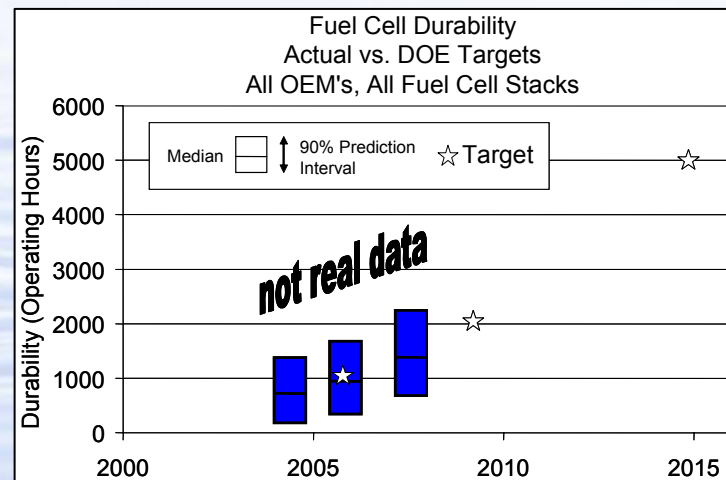


- @ NREL: Strictly Controlled Access
- Detailed Analyses, Data Products, Internal Reports
- HSDC ADVISOR



## Composite Data Products

- Pre-Agreed Upon Aggregate Data Products
- No Confidential Information

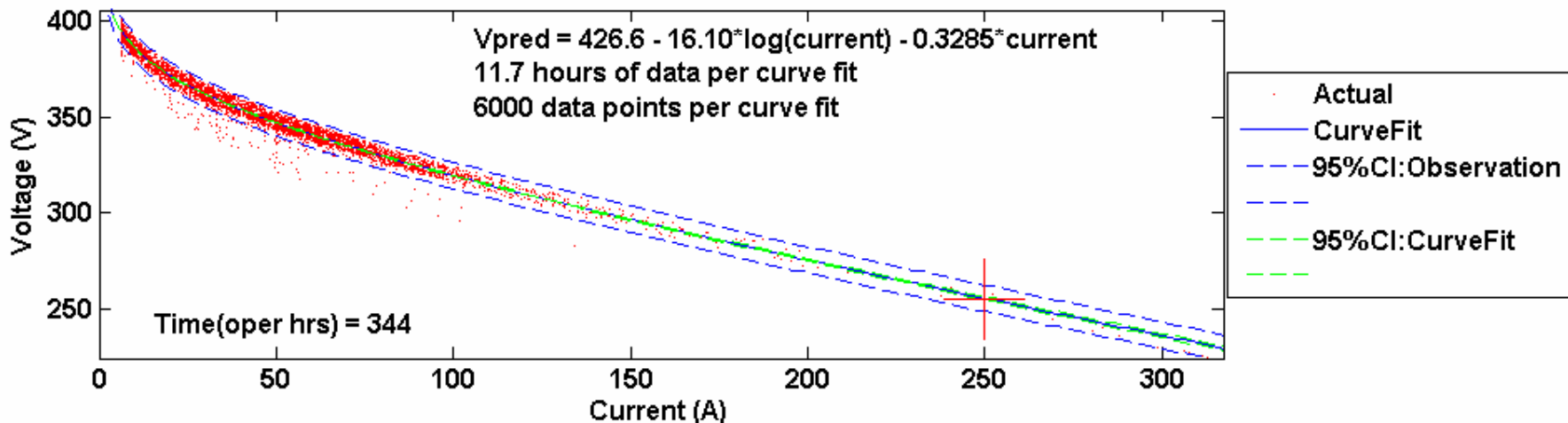




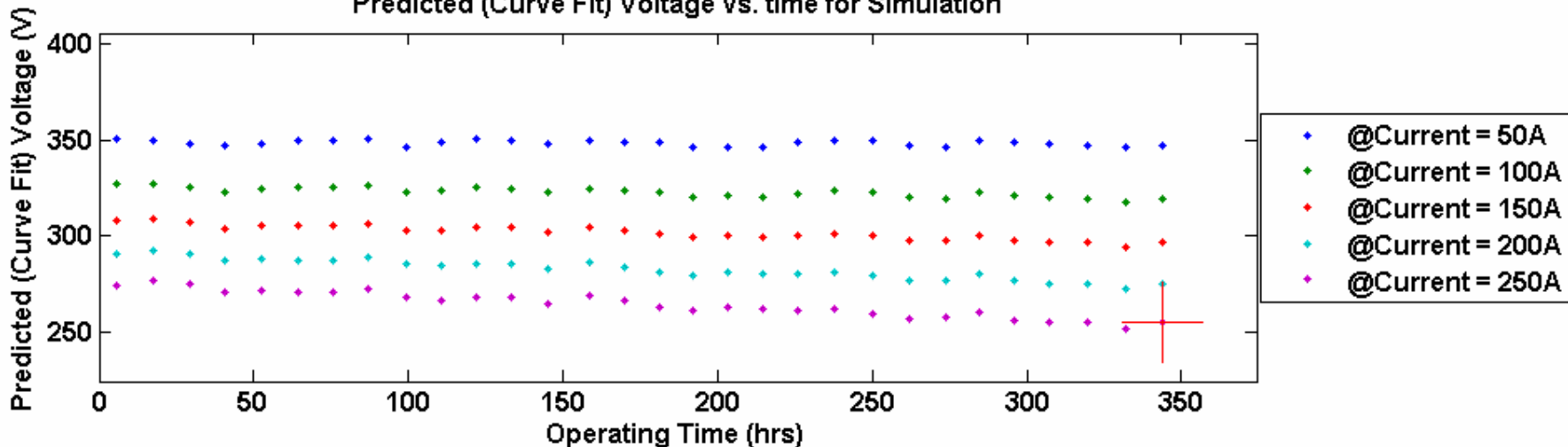
# Analysis Example: Stack Degradation



Fuel Cell Stack VI Animation for Simulation



Predicted (Curve Fit) Voltage vs. time for Simulation



not real data



# Hydrogen Vehicles



By 2009, 250+ mile range, 2000 hour fuel cell durability



Vehicles have been delivered and data collection has begun





# Hydrogen Refueling Infrastructure



By 2009, <\$3.00/gge hydrogen, untaxed



Photos: DTE

DTE/BP Power Park,  
Southfield, MI



LAX refueling station



Hydrogen and gasoline  
station, WA DC

Photo:Shell Hydrogen



Chino, CA

Photo: H2CarsBiz

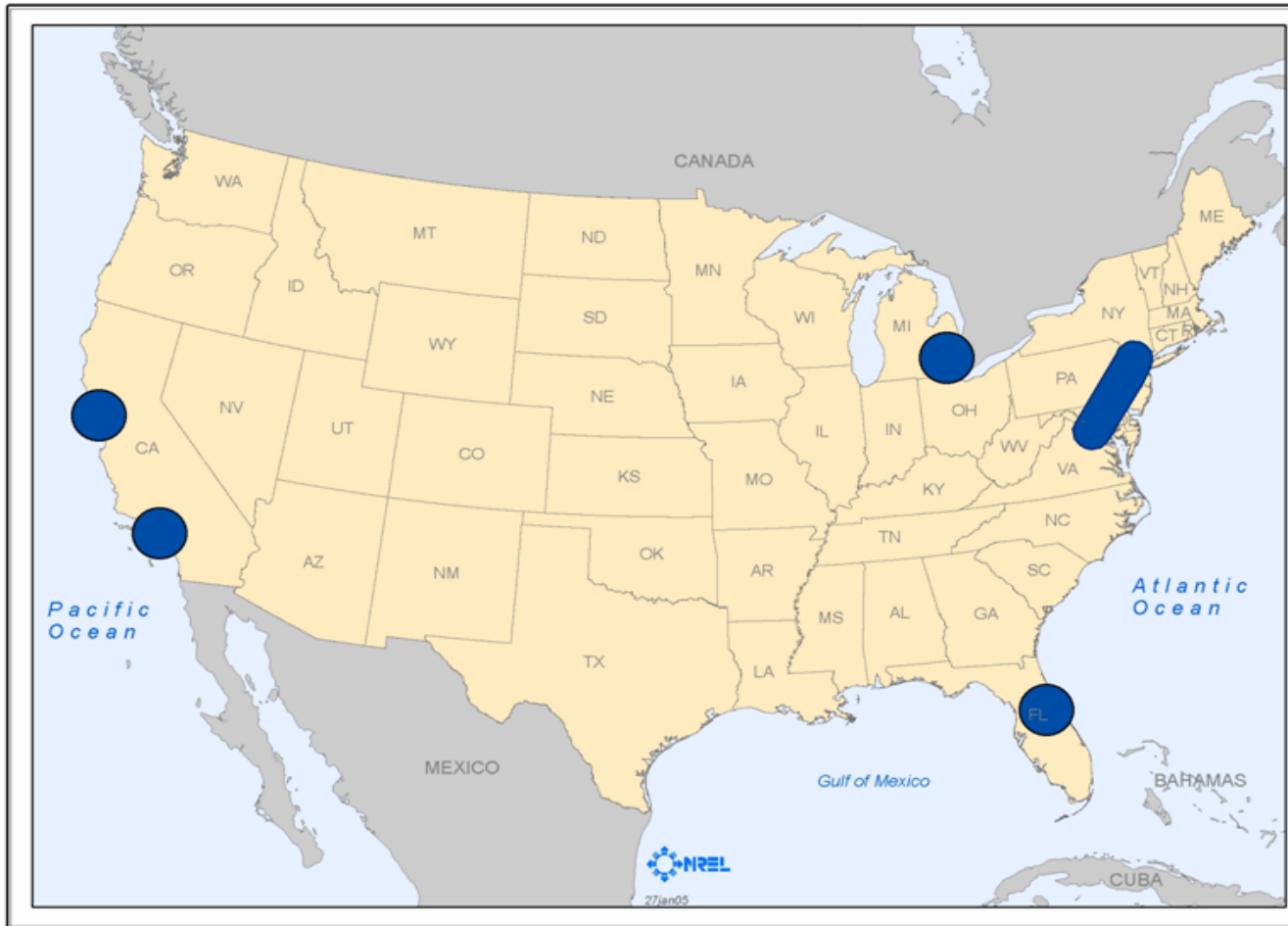
Hydrogen Refueling Stations Opened  
in California, Michigan and Washington D.C.



# Data Collection



Diverse Geography Addresses Four Key U.S. Climates



Cold, Moderate, Hot/Humid, Hot/Arid Climates



# Hydrogen Locomotive and Front End Loader Vehicles Accomplishments



## Accomplishments:

- Completed testing of hydrogen locomotive
- Completed detailed engineering design, review and risk assessment for front end loader
- Completed fabrication and testing of fuel cell power plant for front end loader
- Other subassembly fabrication in progress including metal hydride storage for front end loader



# Task 2 – Hydrogen Infrastructure Power Parks



By 2008, 20,000 hour fuel-cell durability (stationary),  
32% efficiency, \$1500/kW

By 2008, 68% efficiency (electrolyzer stack) and \$600/kW

## Description

- Design and construct early refueling facilities on integrated renewable/fossil systems
- Document permitting requirements, lessons learned and safety plans
- Collect and disseminate operating data from different geographic regions

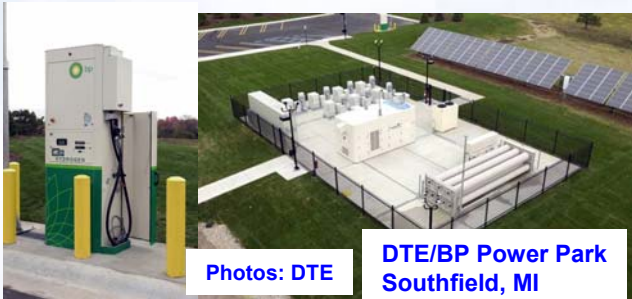


# Task 2 – Hydrogen Infrastructure Power Parks



By 2008, 20,000 hour fuel-cell durability (stationary),  
32% efficiency, \$1500/kW

## Motor Vehicle Refueling



Photos: DTE

DTE/BP Power Park  
Southfield, MI

### 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.

## Accomplishments:

- Power Park installed and operated that is capable of producing 60 kg/day and 400 kwhr/day. Utilize solar and biomass electrolysis systems. Dispense 5000 psi hydrogen at 99.995% (DTE)
- The hydrogen side of pilot park has a 99.33% availability during 26,000 calendar hours of operation and 8500 hours of electrolyser operation (APS)
- Fuel cell and ICE gen sets operating produced 9.6 MWH of power (APS)
- Pearson 5 tpd gasifier using bagasse tested (Hawaii)
- Initiated testing on Ballard and GM fuel cells (Hawaii)



# Task 3 – Natural Gas-to-H<sub>2</sub> Refueling Stations



By 2006, validate \$3.00/gge

## Description

- Build and operate natural gas-to-hydrogen refueling station to collect data on reformer performance and reliability
- Validate the cost of H<sub>2</sub> produced including station operation and maintenance
- Disseminate data from refueling sites to verify component performance



# Task 3 – Natural Gas-to-H<sub>2</sub> Refueling Stations



By 2006, validate \$3.00/gge

## Accomplishments:

- Completed Phase 2 subsystem development for all components of an advanced SMR. Final system design efforts and equipment procurement initiated. Liquid hydrogen tank and blend and dispenser systems installed. (APCI)
- Completed subsystem and system designs. Second generation fuel processor built and tested. Developed hydrogen dispenser fill control algorithm. (GTI)
- Completed Phase 2 development of an autothermal cyclic reformer pilot scale reformer and PSA subsystem. Both systems have been operated to finalize Phase 3 system design. (GE)
- Autothermal reformer tested at SunLine to supply hydrogen for demonstration buses in revenue service. (Hydradix)
- Design and component testing completed on isothermal compressor. (APCI)





# Task 4 – Co-Production of H<sub>2</sub> & Electricity



By 2005, validate 8¢/kWh and \$3.60/gge

## Description

- Collect data on reformer and fuel cell performance, reliability and cost
- Identify the operation and maintenance requirements for the Energy Station
- Determine the economics for a large co-production refueling station





# Task 4 – Co-Production of H<sub>2</sub> & Electricity



By 2005, validate 8¢/kWh and \$3.60/gge

## Accomplishments:

- Successfully demonstrated 2,000 hour run on hydrogen generator (Las Vegas)
- Installed and initiated operation of commercial fuel cell system (DTE)
- Designed and initiated procurement of second generation hydrogen generator (Penn. State)
- Go decision made to proceed with engineering development and preliminary design of high temperature fuel cell concept (APCI)
- 5 kW solid oxide fuel cell system design completed. Component assembly and testing initiated. (Chattanooga)
- Bus successfully operated on 30%/70% hydrogen/natural gas blend (Las Vegas)





# Task 5 – Renewable H<sub>2</sub> Production Systems



By 2011, validate \$2.85/gge at the plant gate from biomass/wind or geothermal resource

## Description

- Validate integrated systems and their ability to deliver hydrogen
- Collect data to verify component performance



# Task 5 – Renewable H<sub>2</sub> Production Systems



By 2011, validate \$2.85/gge at the plant gate from biomass/wind or geothermal resource

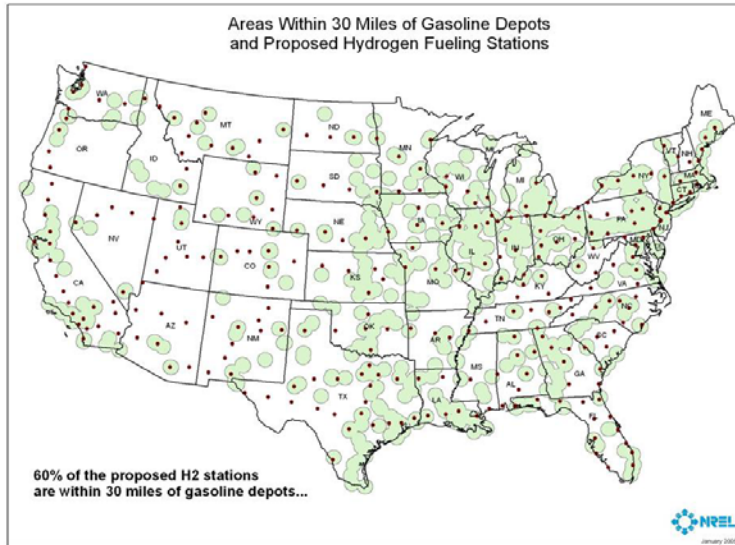


## Accomplishments:

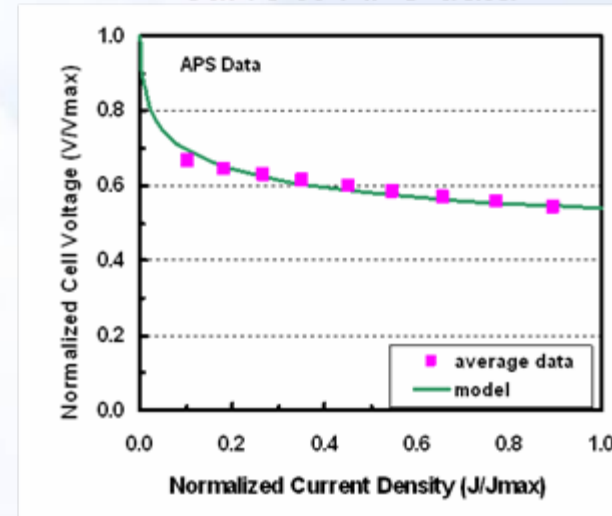
- Completed construction and preliminary testing of biomass-to-hydrogen pyrolysis-reformer pilot plant (Clark Atlanta University)
- Identified potential co-products option (University of Georgia)
- Safety and component performance review completed (University of Georgia)
- PV hydrogen station design completed (UNLV)



# Task 6 – Technical Analyses



Calibration of FC polarization curve to APS data



## Description

- Analyze early infrastructure deployment options
- Analyze advanced Power Parks for production of hydrogen and electricity

## Accomplishments

- Early hydrogen infrastructure analysis completed for several scenarios
- Power Park validation analyses for several stations is completed



# Future Work



Task 1 Complete testing and analysis of generation 1 vehicles and operation and analysis of infrastructure

Continue data collection on VTA, Hickam, AC Transit and SunLine buses

Complete front end loader test program

Task 2 Complete the installation and operation of 3 power park projects

Task 3 Complete validation of 3 natural gas to hydrogen refueling stations projected to produce hydrogen at less than \$3.00/gge



# Future Work Continued



- Task 4 Complete validation of energy station projected to produce hydrogen at less than \$3.60/gge and 8¢/kWh
- Continue with high temperature coproduction systems
- Task 5 Complete 1000 hour durability and performance tests of biomass pyrolysis system
- Complete construction and testing of PV hydrogen refueling station
- Task 6 Complete analysis of power park systems and define market applicability
- Continue development of early infrastructure scenarios