# DOE Hydrogen Program
# Technology Validation Sub-Program

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

# Congressionally Directed Projects
## Continued

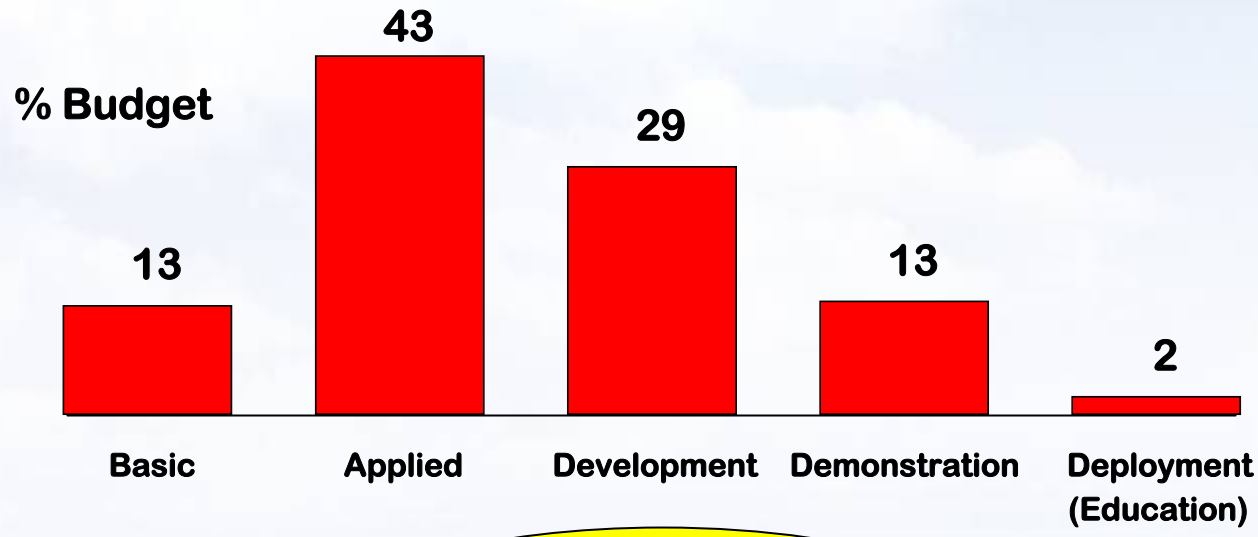
| | | | |
|---|---|---|---|
| NEXT Energy | $793,096 (2003) | Task 2 | Build and test refueling station |
| Chattanooga | $2,485,250 (2004) | Task 4 | Develop, build and test solid oxide fuel cell coproduction system |
| Washoe County | $1,962,155 (2004)<br>$992,000 (2005) | Task 5 | Develop, build &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

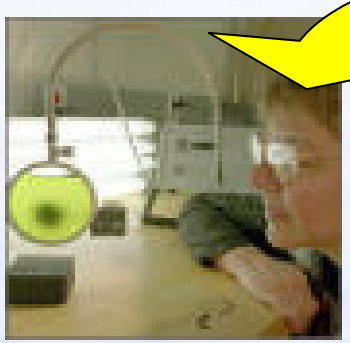
| | | | |
|---|---|---|---|
| A | Vehicles | • statistical data for vehicles that are operated under controlled, real-world conditions (i.e., fuel economy, cold start efficiency, stack degradation, system durability)<br>• vehicle drivability, operation and maintenance | |
| B | Storage | • driving range<br>• cost | • composite tank operating cycle life and failure |
| C | $H_2$ Refueling Infrastructure | • capital costs to build and install | • footprints<br>• system availability |
| D | Hydrogen and Electricity Coproduction | • statistical data on cost and durability of hydrogen fuel cells and reformer systems<br>• development of safety procedures<br>• codes & standards development<br>• availability, operation and maintenance experience | |
| E | Maintenance & Training Facilities | • limited certified procedures<br>• limited trained personnel<br>• lack of data on operation and maintenance costs | |
| F | Codes & Standards | • statistical data for codes and standards development<br>• need development of safety procedures (i.e., HAZOP and FMEA)<br>• global standards need to be established | |
| G | Hydrogen from Renewable Resources | • durability, cost and efficiency for integrated renewable electrolysis systems<br>• biomass feed system, catalyst lifetimes | |

# Balanced Program is Being Implemented

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




- $H_2$ Production
- $H_2$ Delivery
- $H_2$ 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

California Fuel Cell Bus Demonstration Sites



SunLine Transit Agency


Santa Clara Valley
Transportation Authority


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.

<u>Major Objectives</u>

- 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 2nd generation
- Renewable feedstock for H2 generation included
- Codes, Standards and Education integral to the success of the project
- Stationary facilities that co-produce electricity and hydrogen are included

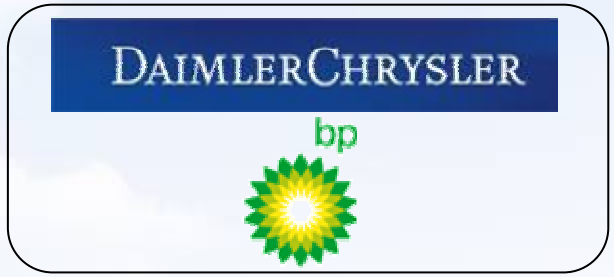
**Key Targets**

| 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

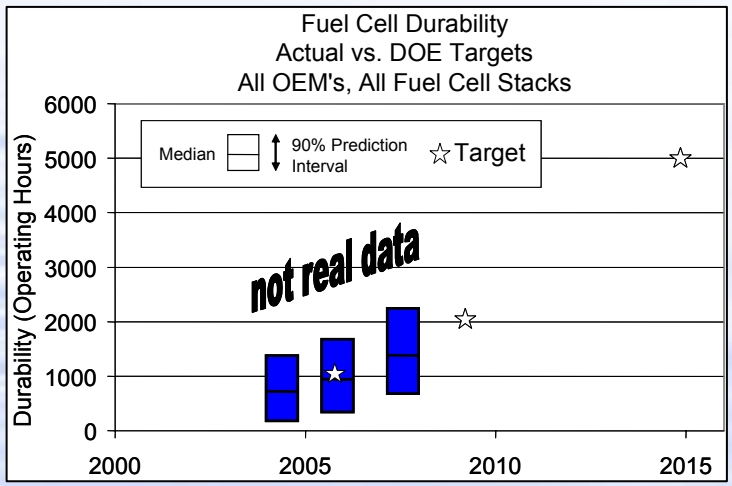
## Developed Secure Data Center and composite data products

**Raw Data, Reports**

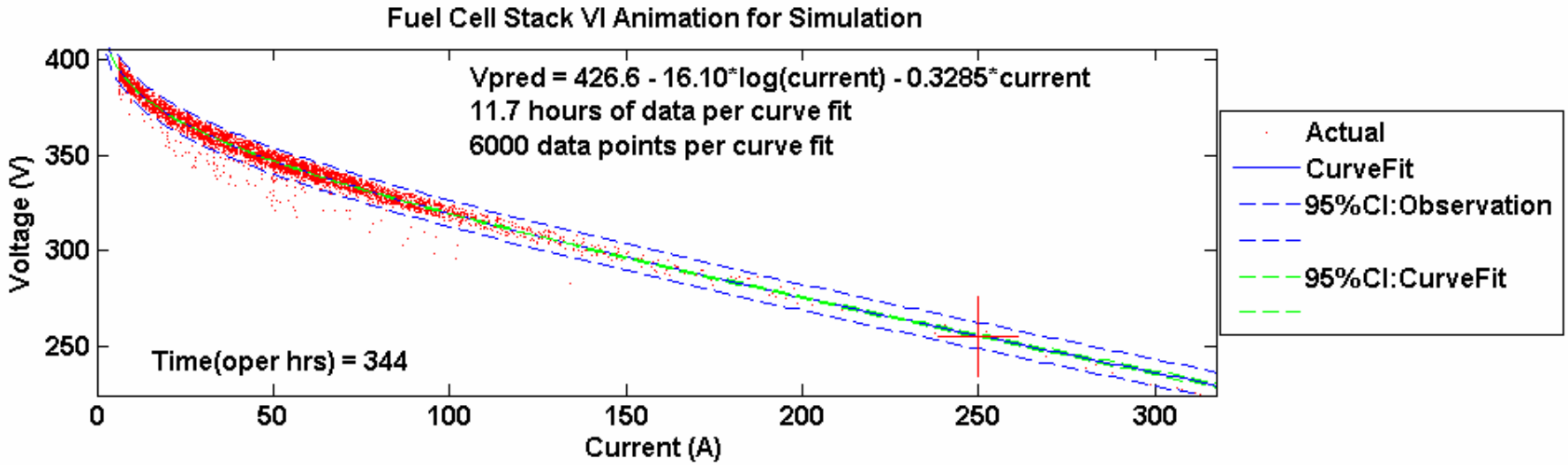
- @ NREL: Strictly Controlled Access
- Detailed Analyses, Data Products, Internal Reports
- HSDC ADVISOR

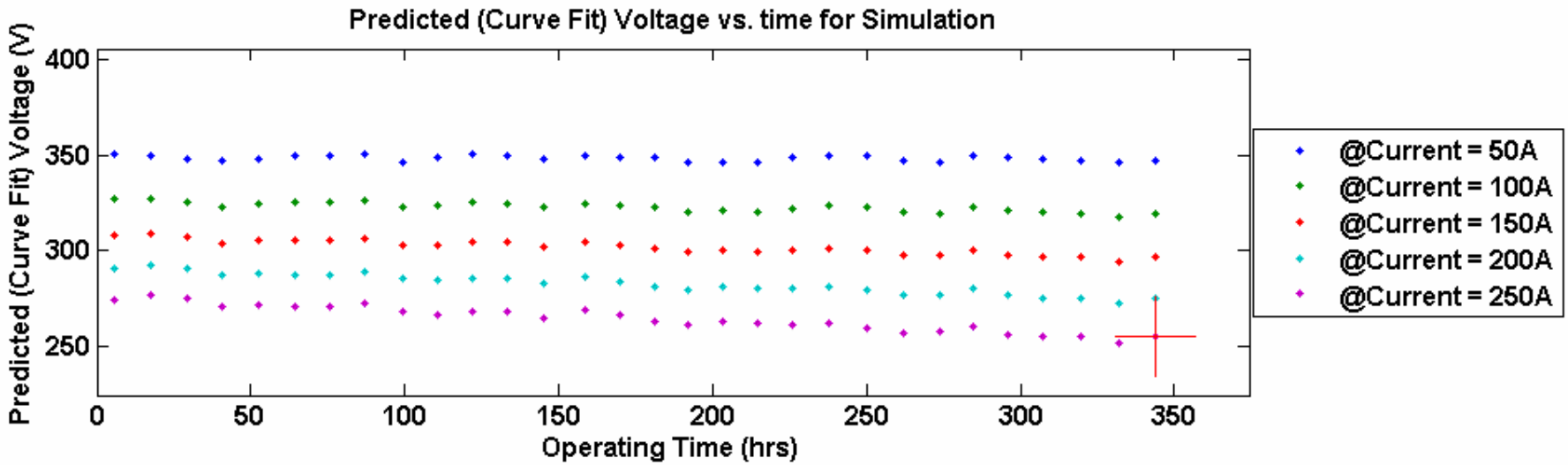
**Composite Data Products**

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



# Analysis Example: Stack Degradation




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

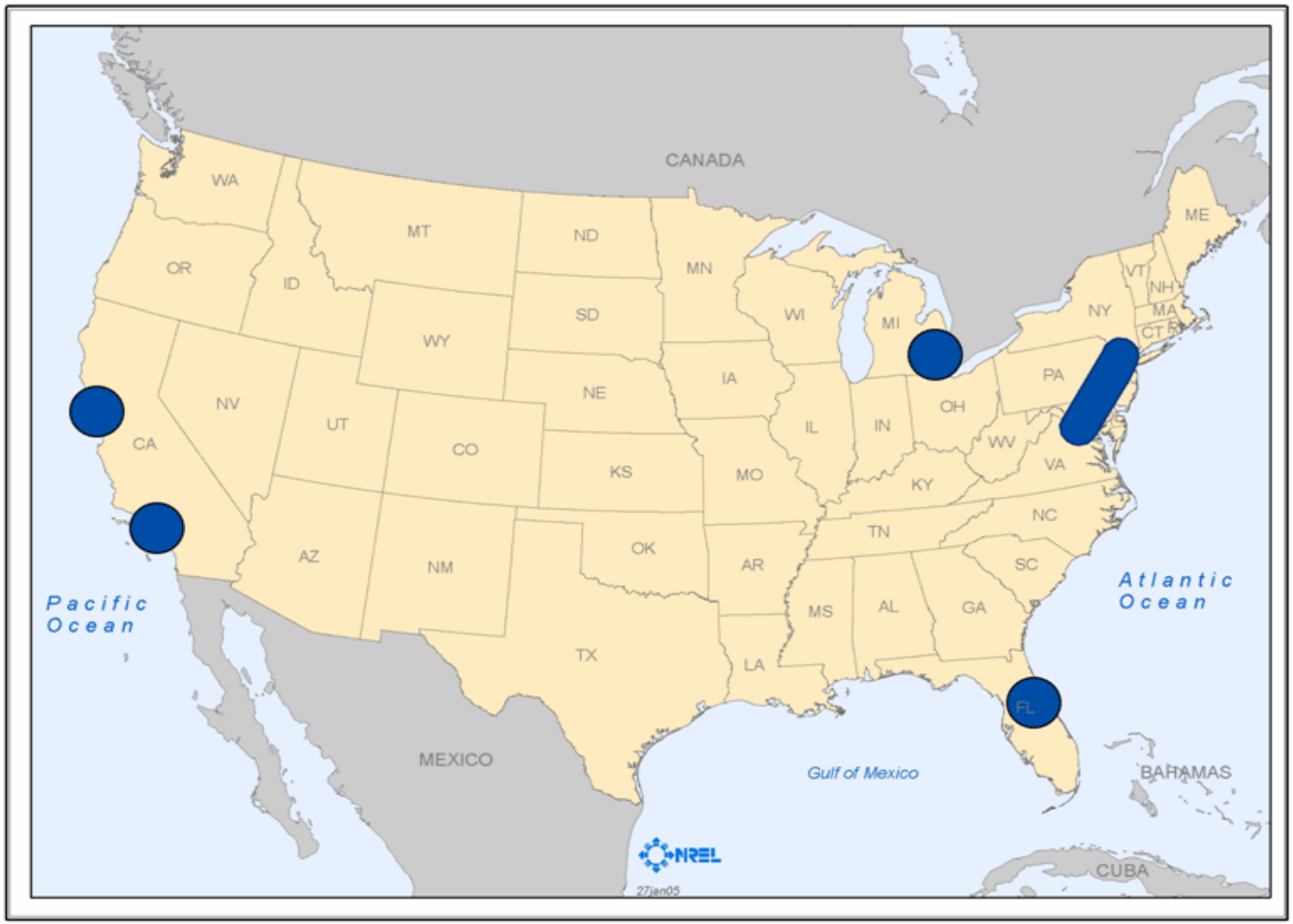

Chino, CA

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

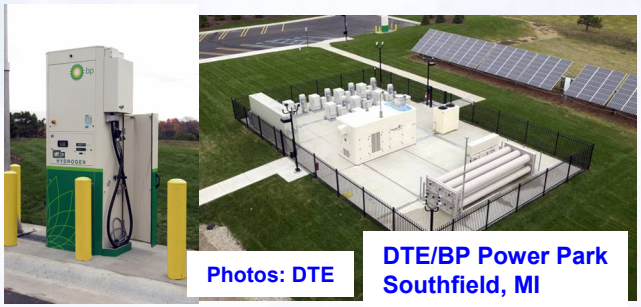
By 2008, 20,000 hour fuel-cell durability (stationary), 32% efficiency, $1500/kW
By 2008, 68% efficiency (electrolyzer stack) and $600/kW

## 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



Photos: DTE

DTE/BP Power Park
Southfield, MI

## 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.*

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-$H_2$ 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 $H_2$ produced including station operation and maintenance
- Disseminate data from refueling sites to verify component performance

# Task 3 – Natural Gas-to-$H_2$ 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 $H_2$ & 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 $H_2$ & 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 $H_2$ 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

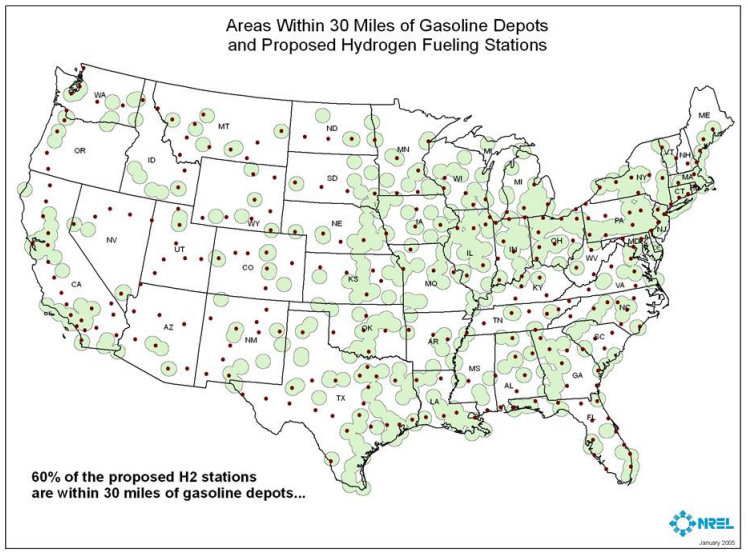
# Task 5 – Renewable $H_2$ Production Systems

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

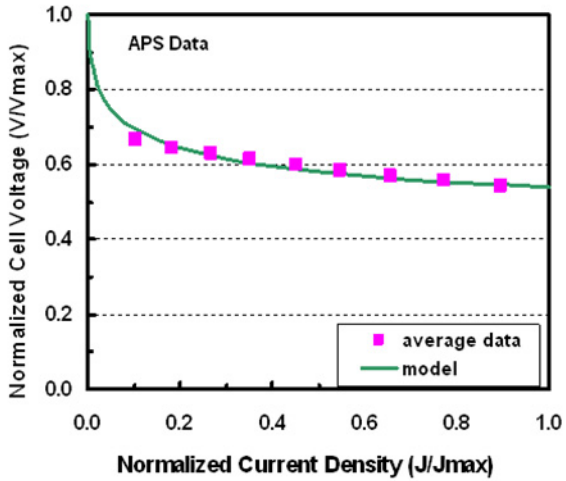
Accomplishments:

- 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 |