DOE Hydrogen Program
Technology Validation Sub-Program

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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

<table>
<thead>
<tr>
<th>Task</th>
<th>DOE</th>
<th>Cost Shares</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>EW&amp;D</td>
<td>Interior</td>
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<tr>
<td>1</td>
<td>$6,359,761</td>
<td>$16,713,129</td>
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<tr>
<td>2</td>
<td>$720,000</td>
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<tr>
<td>3</td>
<td>$1,178,355</td>
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</tr>
<tr>
<td>4</td>
<td>$350,000</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>$250,000</td>
<td>$351,000</td>
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<tr>
<td>1&amp;4</td>
<td>$5,059,000</td>
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## Congressionally Directed Projects

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Budget</th>
<th>Tasks</th>
<th>Project Details</th>
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<tbody>
<tr>
<td>California Infrastructure</td>
<td>$4,960,000 (2005)</td>
<td>Tasks 1 &amp; 4</td>
<td>Develop, build, and test hydrogen infrastructure</td>
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<tr>
<td>Locomotive fuel cell</td>
<td>$300,000 (2005)</td>
<td>Task 1</td>
<td>Develop, build &amp; test underground H2 mine loader</td>
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<tr>
<td>Bus Evaluation</td>
<td>$99,000 (2005)</td>
<td>Task 1</td>
<td>Analyze zero emissions bus – Santa Clara, CA</td>
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<tr>
<td>Univ. of Alabama Birmingham</td>
<td>$963,372 (2003)</td>
<td>Task 1</td>
<td>Test stationary and vehicle hydrogen systems</td>
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<tr>
<td>Hawaii Energy Center</td>
<td>$992,000 (2005)</td>
<td>Task 2</td>
<td>Develop fuel cell test center</td>
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<td>$2,982,000 (2004)</td>
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<td>Hawaii Power Park</td>
<td>$490,539 (2004)</td>
<td>Task 2</td>
<td>Build and test power parks</td>
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<tr>
<td></td>
<td>Amount</td>
<td>Task</td>
<td>Description</td>
</tr>
<tr>
<td>----------------</td>
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<td>-------</td>
<td>-----------------------------------------------------------------</td>
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<tr>
<td>NEXT Energy</td>
<td>$793,096 (2003)</td>
<td>2</td>
<td>Build and test refueling station</td>
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<tr>
<td>Chattanooga</td>
<td>$2,485,250 (2004)</td>
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<td>Develop, build and test solid oxide fuel cell coproduction system</td>
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<td>Washoe County</td>
<td>$1,962,155 (2004)</td>
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<td>Develop, build &amp; test geothermal/electrolyzer refueling station</td>
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<td>$992,000 (2005)</td>
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<td></td>
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<tr>
<td>UNLV</td>
<td>$963,372 (2003)</td>
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<td>Build and test photovoltaic refueling station</td>
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## Barriers

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
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</thead>
</table>
| **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)  
• vehicle drivability, operation and maintenance |
| **B** Storage | • driving range  
• cost  
• composite tank operating cycle life and failure |
| **C** \(H_2\) Refueling Infrastructure | • capital costs to build and install  
• footprints  
• system availability |
| **D** Hydrogen and Electricity Coproduction | • statistical data on cost and durability of hydrogen fuel cells and reformer systems  
• development of safety procedures  
• codes & standards development  
• availability, operation and maintenance experience |
| **E** Maintenance & Training Facilities | • limited certified procedures  
• limited trained personnel  
• lack of data on operation and maintenance costs |
| **F** Codes & Standards | • statistical data for codes and standards development  
• need development of safety procedures (i.e., HAZOP and FMEA)  
• global standards need to be established |
| **G** Hydrogen from Renewable Resources | • durability, cost and efficiency for integrated renewable electrolysis systems  
• biomass feed system, catalyst lifetimes |
Balanced Program is Being Implemented

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

- Basic & Applied Research
- H₂ Production
- H₂ Delivery
- H₂ Storage
- Fuel Cells
- Safety, Codes & Standards Education
- Systems Analysis & Integration
- Technology Development
- 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

California Fuel Cell Bus Demonstration Sites

- Hickam Air Force Base
- 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.

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 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**

<table>
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<tr>
<th>Performance Measure</th>
<th>2009*</th>
<th>2015**</th>
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<tbody>
<tr>
<td>Fuel Cell Stack Durability</td>
<td>2000 hours</td>
<td>5000 hours</td>
</tr>
<tr>
<td>Vehicle Range</td>
<td>250+ miles</td>
<td>300+ miles</td>
</tr>
<tr>
<td>Hydrogen Cost at Station</td>
<td>$3.00/gge</td>
<td>$1.50/gge</td>
</tr>
</tbody>
</table>

* To verify progress toward 2015 targets
** Subsequent projects to validate 2015 target
Cooperative Agreements Have Begun

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

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

Composite Data Products

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

![Graph showing Fuel Cell Durability: Actual vs. DOE Targets, All OEM's, All Fuel Cell Stacks](image)

- Median
- 90% Prediction Interval
- Target

Not real data

- Durability (Operating Hours)
Analysis Example: Stack Degradation

Fuel Cell Stack VI Animation for Simulation

\[ V_{\text{pred}} = 426.6 - 16.10 \times \log(\text{current}) - 0.3285 \times \text{current} \]
11.7 hours of data per curve fit
6000 data points per curve fit

Time (oper hrs) = 344

Predicted (Curve Fit) Voltage vs. time for Simulation

- @Current = 50A
- @Current = 100A
- @Current = 150A
- @Current = 200A
- @Current = 250A

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

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
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

<table>
<thead>
<tr>
<th>Refueling Events</th>
<th>Hydrogen</th>
<th>CHyNG</th>
<th>CNG</th>
<th>Total</th>
<th>Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>236</td>
<td>717</td>
<td>2,938</td>
<td>3,891</td>
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</table>

<table>
<thead>
<tr>
<th>Fuel Dispensed*</th>
<th>Hydrogen</th>
<th>CHyNG</th>
<th>CNG</th>
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</thead>
<tbody>
<tr>
<td>dispensed</td>
<td>259 kg</td>
<td>2,378 gge</td>
<td>14,218 gge</td>
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</table>

* 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-\( \text{H}_2 \) 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 \( \text{H}_2 \) produced including station operation and maintenance
- Disseminate data from refueling sites to verify component performance
Task 3 – Natural Gas-to-H₂ 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 H₂ & 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
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 H₂ 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 H₂ 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

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