A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

2004 DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

Controlled Hydrogen Fleet & Infrastructure Analysis

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May 26, 2004

This presentation does not contain any proprietary or confidential information

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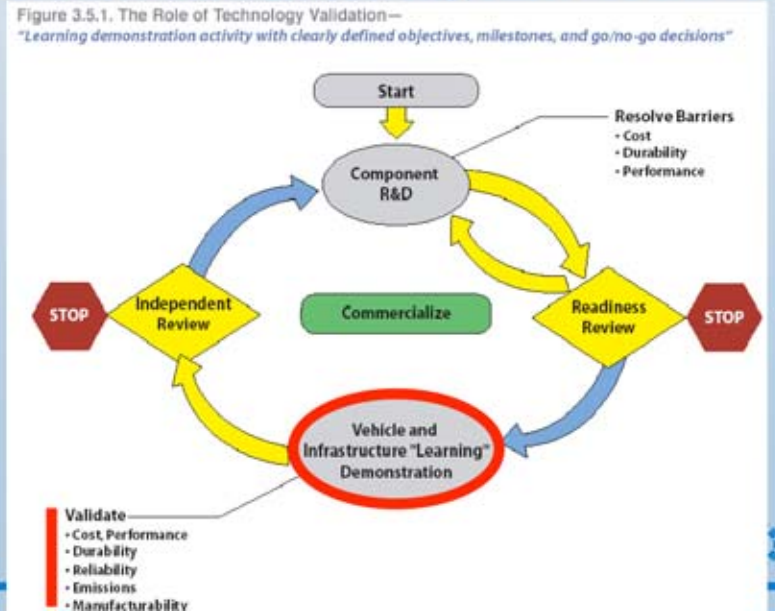
Project Objectives

- **5-year technology validation objective (MYPP):** By 2008, validate H2 vehicles with:
  - greater than 300-mile range
  - 2,000-hour FC durability
  - $3/kg H2 production cost
- **Objective** of this validation project is assist DOE in demonstrating use of FC vehicles and H2 infrastructure under real-world conditions, using
  - Multiple sites, varying climates, variety of sources for hydrogen, including renewables
- **Primary activity over last year** was to support DOE solicitation process and prepare for post-award work
- **Future activities** will include analyzing data from vehicles and infrastructure to obtain maximum value for DOE and industry from this "learning demonstration"

Definition and Role of Technology Validation

- **Definition:**
  - Confirmation that component technical targets for a given technology have been incorporated into a complete system solution, and
  - that system performance and operation are met under **realistic operating scenarios**

Figure 3.5.1. The Role of Technology Validation—
"Learning demonstration activity with clearly defined objectives, milestones, and go/no-go decisions"



Budget

- Current FY04 funding: **$630 K total**
  - $15K subcontract with Battelle for data analysis planning support

Responses to Previous Year Reviewer's Comments

- This is the first year this project is being reviewed
- No reviewers comments from previous year

Technical Barriers and Targets

- **Key DOE Technology Validation Technical Barriers** addressed by this project:
  - A. Vehicles – lack of sufficient H2 vehicle data
  - B. Storage – not yet providing necessary 300+ mile range
  - C. Hydrogen Refueling Infrastructure – cost and availability
  - E. Codes and Standards – lack of adoption/standardization
  - F, G, H. Hydrogen Production from fossil, nuclear, renewable – cost is major barrier
- **Technical Targets**: Technology Validation does not have its own component technology targets
  - Component technical targets are verified under real-life conditions as part of an integrated system
  - After they've already been verified at the component level in laboratory
  - However, solicitation does have performance targets…

Controlled Fleet Performance Targets
(From solicitation RFP, Appendix C)

- 2008 Performance Targets
  - FC Stack Durability: 2000 hours
  - Vehicle Range: 250+ miles
  - H2 cost at station: $3.00/kg

To verify progress toward 2015 targets

- 2015 Performance Targets
  - FC Stack Durability: 5000 hours
  - Vehicle Range: 300+ miles
  - H2 cost at station: $1.50/kg

Subject of subsequent projects to validate 2015 targets

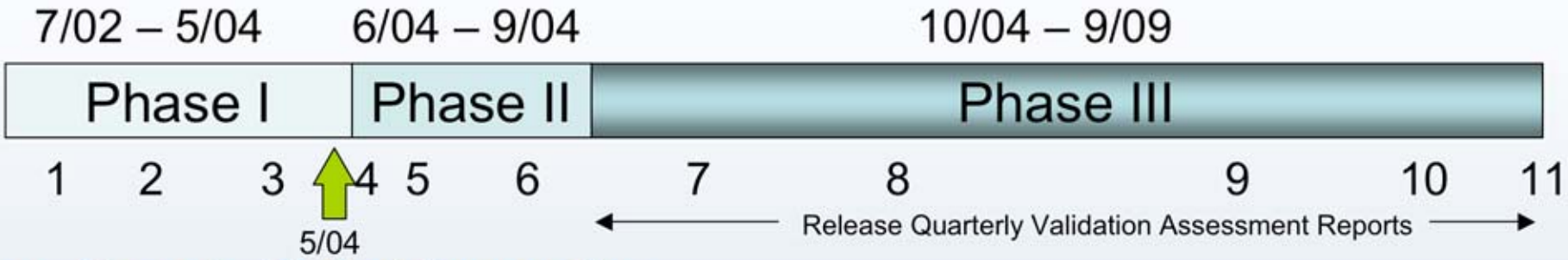
Overall Approach

- Provide technical support to DOE for solicitation RFP process:
  - "Controlled Hydrogen Fleet & Infrastructure Demonstration and Validation Project"
- Plan NREL/DOE data analysis activities
- Investigate hydrogen infrastructure transition pathways through analysis

Project Safety

- Solicitation bidders required to include in their proposal:
  - Preliminary Failure Modes and Effects Analysis (FMEA) on the project
  - Brief example of safety assessment
  - Detailed outline of Risk Mitigation Plan
  - Description of how safety performance will be measured and monitored
  - Detailed outline for Communication Plan, including reportable accidents, management response, and independent reviews
- Safety accounted for 20% of proposal evaluation score
- RFP included “Guidance for Safety Aspects of Hydrogen Projects” for reference

Project Timeline



- **Phase I – Project Preparation**
  - 1 Support Development of RFP, Statement of Objectives (Appendix C)
  - 2 Bidder's meeting in Detroit – launch of RFP
  - 3 Create data analysis plan and presentation for discussion with industry
- **Phase II – Project Launch**
  - 4 Announcement of successful bidders (timing TBD)
  - 5 Kick-off meetings and cooperative agreement awards
  - 6 Preliminary data collection, analysis, and first quarterly assessment report
- **Phase III – Data Analysis and Feedback to R&D activities (partial list)**
  - 7 Demonstrate FCVs that achieve 50% higher fuel economy that gasoline vehicles
  - 8 Go/No-Go: Decision for purchase of additional vehicles based on perf., durability, cost
  - 9 Validation on a vehicle 2.0 kWh/kg, 1.2 kWh/L compressed gas tank, $10/kWh
  - 10 Validate $2.50/kg hydrogen cost
  - 11 Demonstrate FCVs with 300-mile range, 2,000 hour durability, and $125/kW (based on volume production)

Overview of Technical Accomplishments/Progress

- Helped formulate plans for solicitation
- Assisted in preparation of technical details of RFP Statement of Objectives (Appendix C)
- Performed technical review of solicitation proposals (AOP milestone)
- Completed draft validation project technical *data analysis plan* and sample data flows
- Performed preliminary infrastructure analysis

Accomplishments

Provided Content/Review for RFP Statement of Objectives

- 8 tables
- Footnotes to clarify

DRAFT
FINAL CONTENT SUBJECT TO CHANGE

APPENDIX A

Statement of Objectives
Controlled Hydrogen Fleet and Infrastructure Demonstration

A.1.0 Background

The use of fuel cell technology with hydrogen as the energy carrier of
viable option to reduce dependence on imported petroleum, develop d
improve fuel efficiency while reducing greenhouse gas emissions, and
a diverse source of energy feedstocks. It also offers the opportunity to
embrace both transportation and electric generation sectors.

In November of 2002, Energy Secretary, Spencer Abraham, announce
Energy Roadmap, a document designed to ensure a more secure and cl
America. The Roadmap provides a blueprint for the coordinated, long-term, public and priva
efforts required for hydrogen energy development. These requirements include:

- Improved fuel cell durability
- Decreased cost of fuel cell stack
- Enhanced infrastructure/vehicle systems integration
- Focused demonstrations to showcase vehicle/infrastructure capabilities
- Accelerated development of codes and standards
- Public policies to educate the public about hydrogen as a fuel

A.3.0 Project performance measures

Applicants shall provide summaries of the vehicle, site, and energy parameters, as well as energy production (optional) test plans. Tables 1 - 6 below and the accompanying narrative summarize the performance measures.

A.3.1 Performance Measures

Table 1. Vehicle Performance Measures

Category	Performance Measure	Units	Baseline Benchmark (Current)	2006 Performance Targets	2008 Performance Targets	Comments
Operations	Fuel Economy (a)	MPGGE *	50 (fuel cell vehicle)	50	60	Use draft SAE J2572 and draft EPA fuel economy test procedures. Overall testing may include FTP75, HWYFE,
	R					

Table 6. –Data for Modeling and Evaluation of Component Development Program at DOE

Vehicle Component	Required Data	Comments
Dynamometer Testing (a)		
Fuel Cell Stack	1. Stack voltage, current 2. Anode inlet and outlet temperature and pressure 3. Cathode inlet and outlet temperature and pressure 4. Hydrogen feed and recirculation rates 5. Cathode air feed rate 6. Humidification levels for cathode and anode feed gases	Data to be obtained on a continuous basis.
Fuel Cell System Balance-of-	1. Power consumption by – air compressor or blower – radiator/condenser fan(s)	Same as above

Accomplishments
Controlled Fleet Solicitation

- Reviewed all "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project" Proposals in October
- Provided detailed feedback on proposals
- Created maps of existing H2 infrastructure used in discussion of proposed refueling stations

SOLICITATION FOR SUBMISSION OF FINANCIAL ASSISTANCE APPLICATIONS

OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

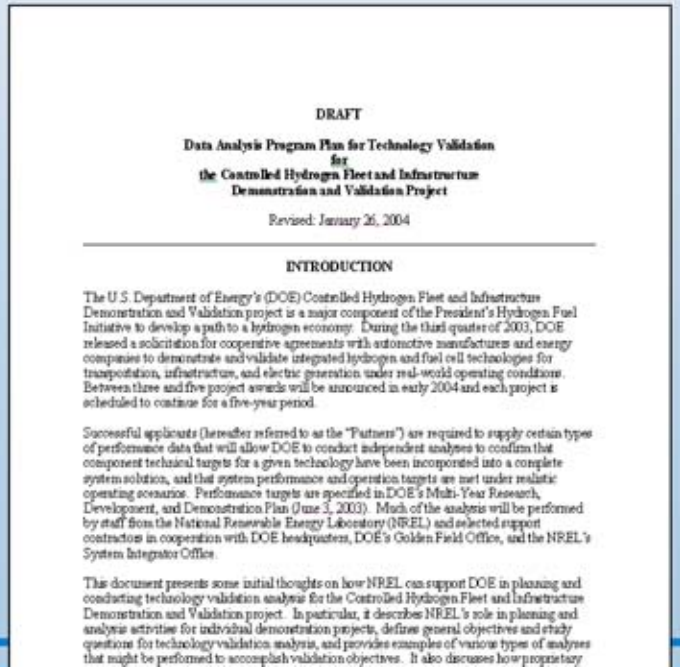
SOLICITATION NUMBER
DE-PS36-03GO93010

CONTROLLED HYDROGEN FLEET AND INFRASTRUCTURE DEMONSTRATION AND VALIDATION PROJECT

Accomplishments

Completion of Draft Data Analysis Plan

- Prepared draft NREL document "**Data Analysis Plan** for Technology Validation for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project"
- Served as starting point for discussion about how the data being collected by industry will be used to provide significant value to the HFCIT program



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Data Analysis Program Plan for Technology Validation for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project

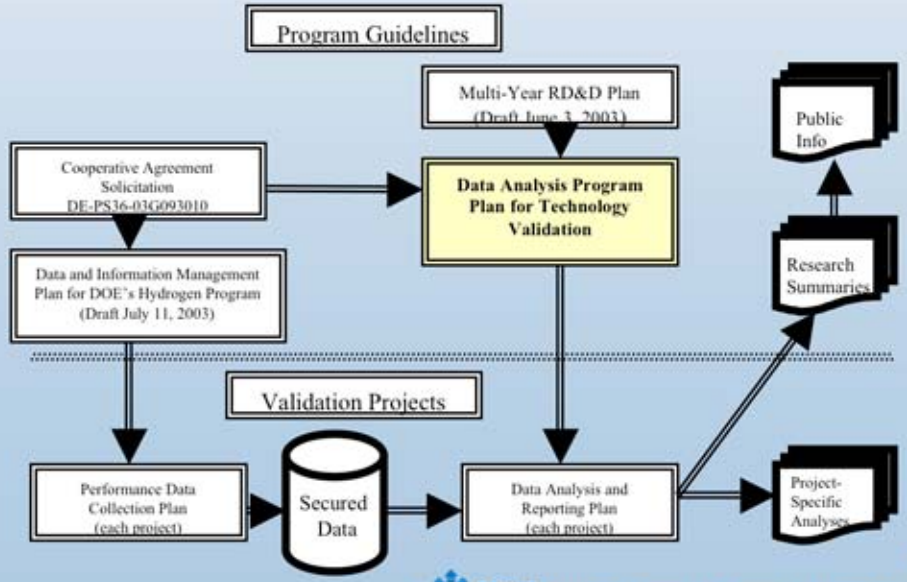
Revised: January 26, 2004

INTRODUCTION

The U.S. Department of Energy's (DOE) Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation project is a major component of the President's Hydrogen Fuel Initiative to develop a path to a hydrogen economy. During the third quarter of 2003, DOE released a solicitation for cooperative agreements with automotive manufacturers and energy companies to demonstrate and validate integrated hydrogen and fuel cell technologies for transportation, infrastructure, and electric generation under real-world operating conditions. Between three and five project awards will be announced in early 2004 and each project is scheduled to continue for a five-year period.

Successful applicants (hereafter referred to as the "Partners") are required to supply certain types of performance data that will allow DOE to conduct independent analyses to confirm that component technical targets for a given technology have been incorporated into a complete system solution, and that system performance and operation targets are met under realistic operating scenarios. Performance targets are specified in DOE's Multi-Year Research, Development, and Demonstration Plan (June 3, 2003). Much of the analysis will be performed by staff from the National Renewable Energy Laboratory (NREL) and selected support contractors in cooperation with DOE headquarters, DOE's Golden Field Office, and the NREL's System Integrator Office.

This document presents some initial thoughts on how NREL can support DOE in planning and conducting technology validation analysis for the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation project. In particular, it describes NREL's role in planning and analysis activities for individual demonstration projects, defines general objectives and study questions for technology validation analysis, and provides examples of various types of analyses that might be performed to accomplish validation objectives. It also discusses how proprietary



Data Analysis Approach (Fuel Cell Vehicles)

A. Identify significant factors affecting vehicle performance from collected data
B. Provide processed data for development/verification of codes and standards
C. Measure progress compared to research technical targets (MYPP, solicitation targets)
D. Identify possible technical areas of future research within Program from results -- *technology gaps and research opportunities*

Overview of Technology Validation Hydrogen Fuel Cell Vehicle Performance Analysis

Performance at multiple temperatures

Performance at multiple elevations

Acceleration & Gradeability

FC Component Efficiencies

Dyno Fuel Economy

On-Road Fuel Economy

Driving Range

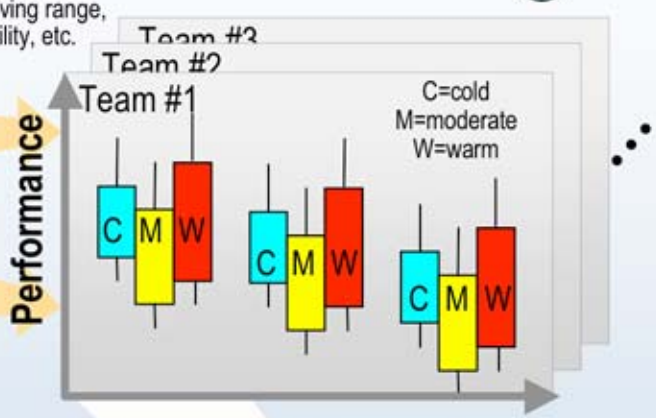
In-Use Data Acquisition System

Data Collected by Auto Teams

Performance measures include vehicle fuel economy, driving range, acceleration, gradeability, etc.

Compare Results from Multiple Climates & Technologies

A



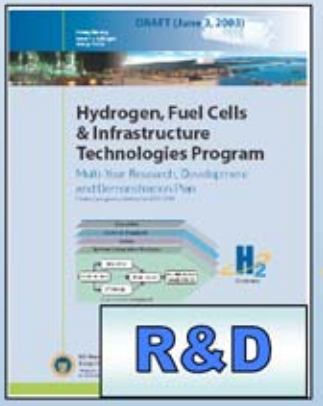
metal vs. carbon bi-polar plates, pressurized vs. non-pressurized stack, H2 ICE vs. FC, etc.

Firewall

Summarize Results by Technology & Climate

Results to Codes & Standards Groups

B



Re-Focus R&D as Appropriate

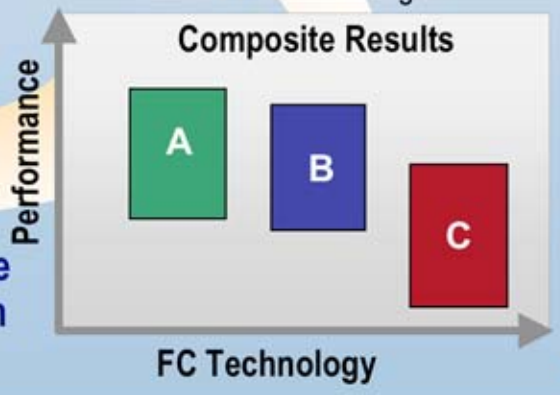
D

ADVISOR 2003 Advanced Vehicle Simulator

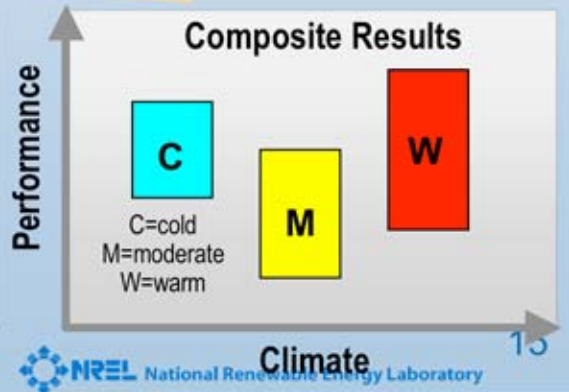
Compare Performance Against DOE Program Technical Targets

C

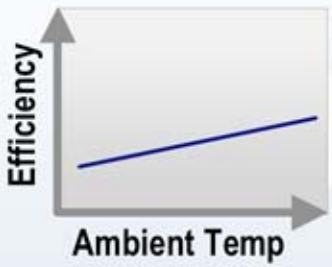
Range of Performance for Various FC Technologies



Range of Performance for 3 climates



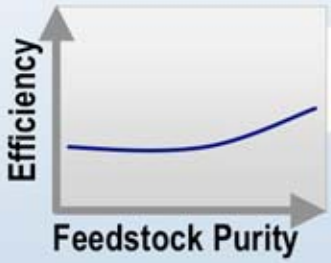
Overview of Technology Validation Hydrogen Production Analysis



Detailed analyses of production data determine what factors affect productive efficiencies

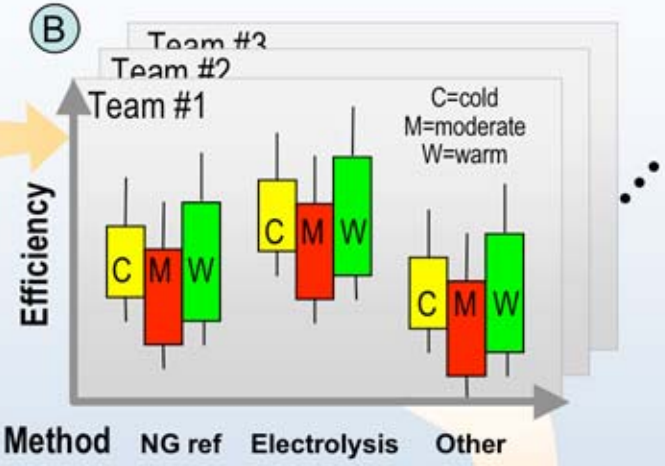
A

Identify Factors Affecting Performance



Compare Results from Multiple Sites and Methods

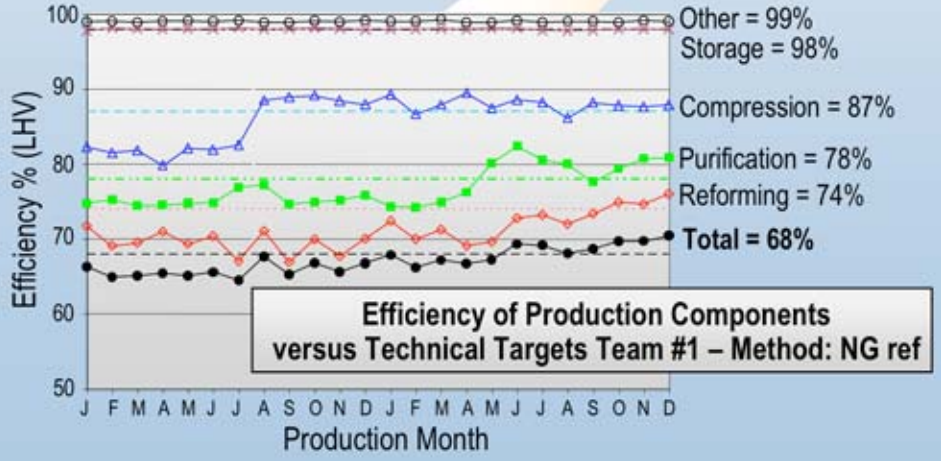
B



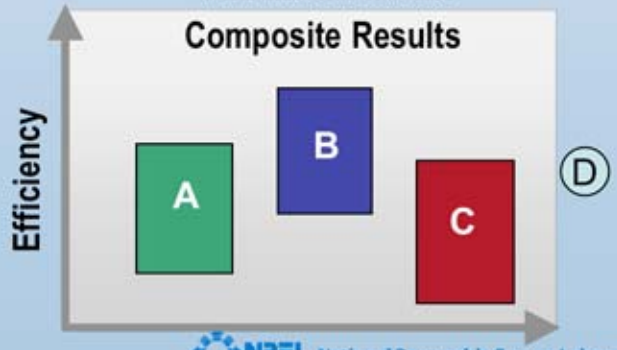
Map Performance Against Program Technical Targets

C

Summarize Results by Method



Range of Efficiency Achieved by Different Productive Methods



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Specific Data Analysis Example

Fuel Cell Component and System Efficiency Evaluation

Data Collected by Auto Teams

Detailed fuel cell system component behavior in real vehicle environment

- Dyno Data → Component voltage/current RFP, App. C, Table 7
- On-Road Data → On-Board DAS RFP, App. C, Table 4
- Lab-Bench Testing of Fuel Cell Systems → Efficiency at 25% load RFP, App. C, Table 2

H2 Consumption

Fuel Cell Stack

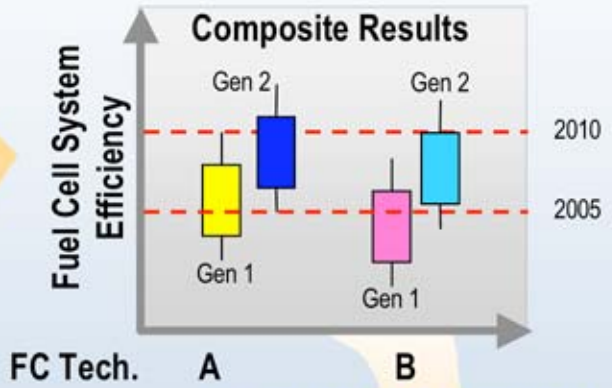
Air Compressors or Blowers

Coolant Pumps

Other Electrical Parasitics

Data Used to Validate DOE Fuel Cell Vehicle Models

ADVISOR 2003
Advanced Vehicle Simulator



Compare Performance Against DOE Program Technical Targets

Re-Focus R&D as Appropriate

R&D

50-kWe (net) Integrated FC Power Systems Operating on Direct H2 (MYPP Table 3.3.2)

Accomplishments
Infrastructure Transition Analysis

Goal: Identify near term strategies for developing an H2 infrastructure

- Estimate refueling station requirements and costs to facilitate vehicle deployment
- Identify number and optimal locations for stations using GIS capabilities
- Coordinating efforts with H2 analysis activities:
  - H2A
  - Systems Integration

Accomplishments
Infrastructure Transition Analysis

- Performed spreadsheet analysis to allow rough calculations for the range of infrastructure needs based upon various assumptions (extension of GM work)
- Conducted literature search on infrastructure activities
- Identified most traveled interstate routes based on GIS data

Urban Analysis - GM Methodology

	Percentage Of Population	Number of MSA	Mega - 240 Stations	Large - 120 stations	Mid - 60 Stations	Small - 50 Statior
GM	68	100	2	9	49	40
NREL A	57	50	2	9	39	0
NREL B	71	125	2	9	49	65
NREL C	50	32	2	9	21	0
Alternate	Input	Input	Input	Input	Input	Input

Urban Analysis - MSA Specific DOE Analysis

	Percentage Of Population	Number of MSA	Urban Stations
Clean Cities - 10	61	82	4659
Clean Cities - 3	61	82	61347

Station Analysis

	Highway Stations	Urban Stations	**Total Stations**
GM	5200	6500	**11700**
NREL 1A	1300	3900	**5200**
NREL 2C	2600	2820	**5420**
NREL 1B	1300	7750	**9050**
NREL 1; CC10	1300	4659	**5959**
NREL 1; CC3	1300	61347	**62647**
Alternate	Input	Input	**0**

Accomplishments
Infrastructure Transition Analysis

Interim Results:

- Based upon spreadsheet analysis, supported by U. of Michigan paper, strategy of placing refueling stations along major traffic routes is best
- GIS is necessary to identify strategic placement of stations to provide best coverage

Interactions and Collaborations

- Met with all major auto OEMs and energy companies in helping DOE to craft objectives and scope of controlled fleet solicitation
- Open discussion with industry on solicitation facilitated by bidder's meeting in Detroit (3/03)
- Interactions on transition analysis with UC Davis and University of Michigan

Interactions and Collaborations

Project Planning Input Gathered from Multiple Organizations

Auto Manufacturers

Ford
DCX
GM
Toyota
Hyundai
USCAR

Collaborations

CA Fuel Cell Partnership
NEXT Energy
Building Owners and Managers Assoc.
Altarum
Teamworks
CUTE Europe
SCAQMD
NYSERDA
Albany- Nanotech

Fuel/Storage/FC Suppliers

Chevron-Texaco
PDVSA Citgo
Exxon Mobil
Phillips
Union Oil
BP
Shell Hydrogen
Stuart Energy
PraxAir
General Atomics Corp
MTI-Micro Fuel Cells Inc.
UTC Fuel Cells
H-Power Corp
Plug Power Corp
Ovonics

Learning Facilities

Virginia Technical Institute
SUNY-Albany

Military

TARDEC/NAC

Future Work
Controlled H2 Fleet & Infrastructure Project

- Remainder of FY04
  - Wrap-up transition analysis work and document findings in report (mapping and vehicle simulation)
  - Enter Phase II of project (post announcement)
  - Actively participate in industry team kick-off meetings, discussions on data collection methods, and early applications/analyses of data
  - Begin quarterly Validation Assessment Reports
- FY05 and beyond (Phase III):
  - Compare technical progress to program objectives
  - Actively feed findings from project back into HFCIT program R&D activities ("learning demonstration")
  - Provide quarterly Validation Assessment Reports to report on technology and project progress

Team Acknowledgements

- Aaron Brooker (vehicle simulation)
- Sig Gronich (DOE program mgr)
- Deborah Kielian (FY03 project lead)
- Margo Melendez (transition analysis)
- John Orban (Battelle, analysis plans)
- Liz Brady Sabeff (GIS/mapping)
- Holly Thomas (codes and standards)