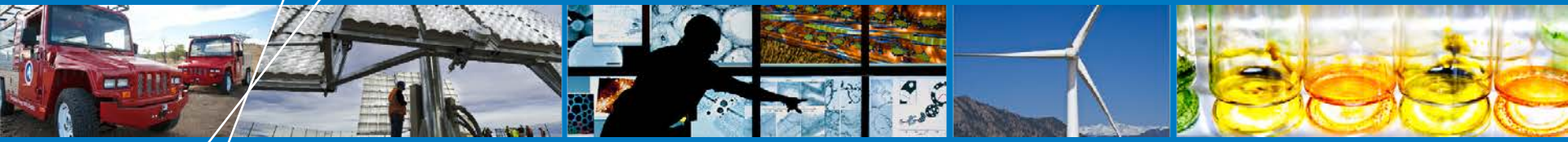
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell Electric Vehicle Evaluation



2013 DOE Annual Merit Review and Peer Evaluation Meeting

Jennifer Kurtz, Keith Wipke, Sam Sprik, Chris Ainscough, Genevieve Saur

Project ID# TV001

May 16, 2013: Washington, DC

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

Project start date: October 2012

Project end date: September 2013*

Percent complete: On-going

Barriers

Lack of current controlled and on-road hydrogen fuel cell vehicle data

Budget

Total project funding

DOE share: $485k

Contractor share: $0

Funding received in FY13: $485k

Partners

Several fuel cell vehicle OEMs (data providers)

*Project continuation and direction determined annually by DOE

Project Objectives, Relevance, and Targets
Fuel Cell Electric Vehicle Evaluation

- **Objectives**
  - Validate H_2 FC vehicles in real-world setting
  - Identify current status and evolution of the technology
- **Relevance**
  - Objectively assess progress toward targets and market needs
  - Provide feedback to H_2 research and development
  - Publish results for key stakeholder use and investment decisions

Key Targets

Performance Measure	Status*	Ultimate (2020)
Fuel Cell Stack Durability	2,500 hours	5,000 hours
Vehicle Range	254+ miles	300+ miles
Fill Rate	0.77 kg/min	1.0 kg/min
Efficiency	59% at 25% Power	60% at 25% Power

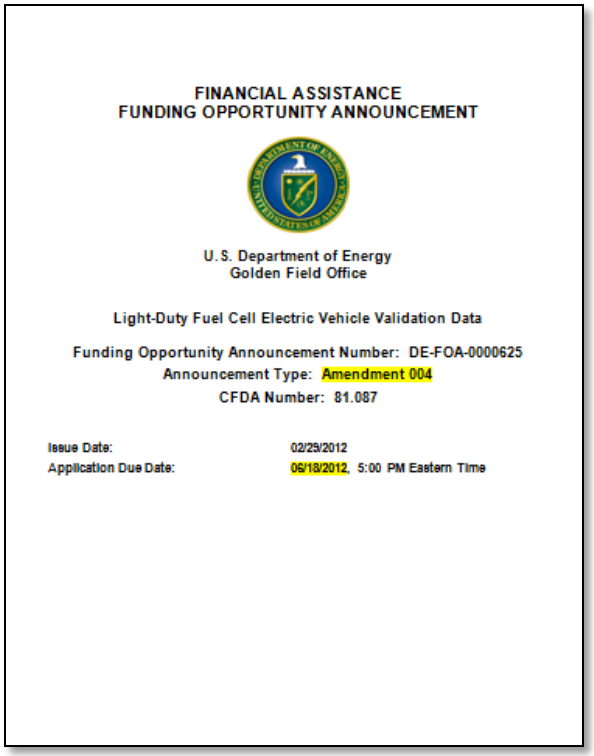
*As reported in previous Learning Demonstration results

APC/Shell Pipeline station, Torrance, CA. Photo: NREL

Objective: FOA-625 Status (FCEV Data)

- **Proposals were submitted June 18**
- **Objectives of FOA**
  - Provide FCEV vehicle data to NREL's HSDC for analysis and aggregation
  - Seek to validate improved performance and longer durability from comprehensive set of early FCEVS, including first production vehicles
  - 5-year project duration; 2 phases

    "…to collect and submit dynamometer and real-world vehicle performance data to a DOE-sponsored third-party collection and analysis provider to provide statistically valid projections on key metrics including durability of fuel cell system"
- **DOE negotiations in progress with OEM teams**



FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

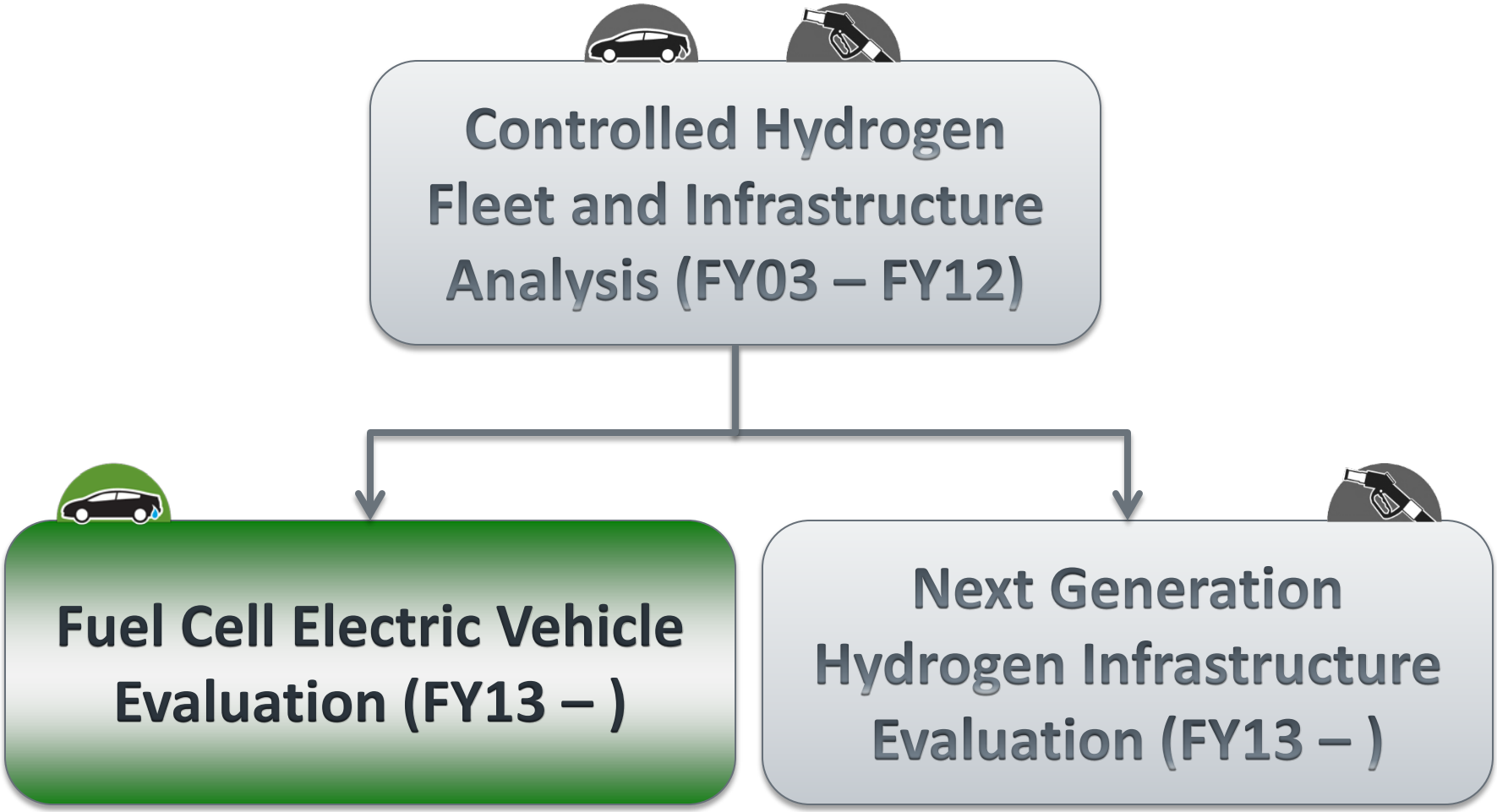
U.S. Department of Energy
Golden Field Office

Light-Duty Fuel Cell Electric Vehicle Validation Data

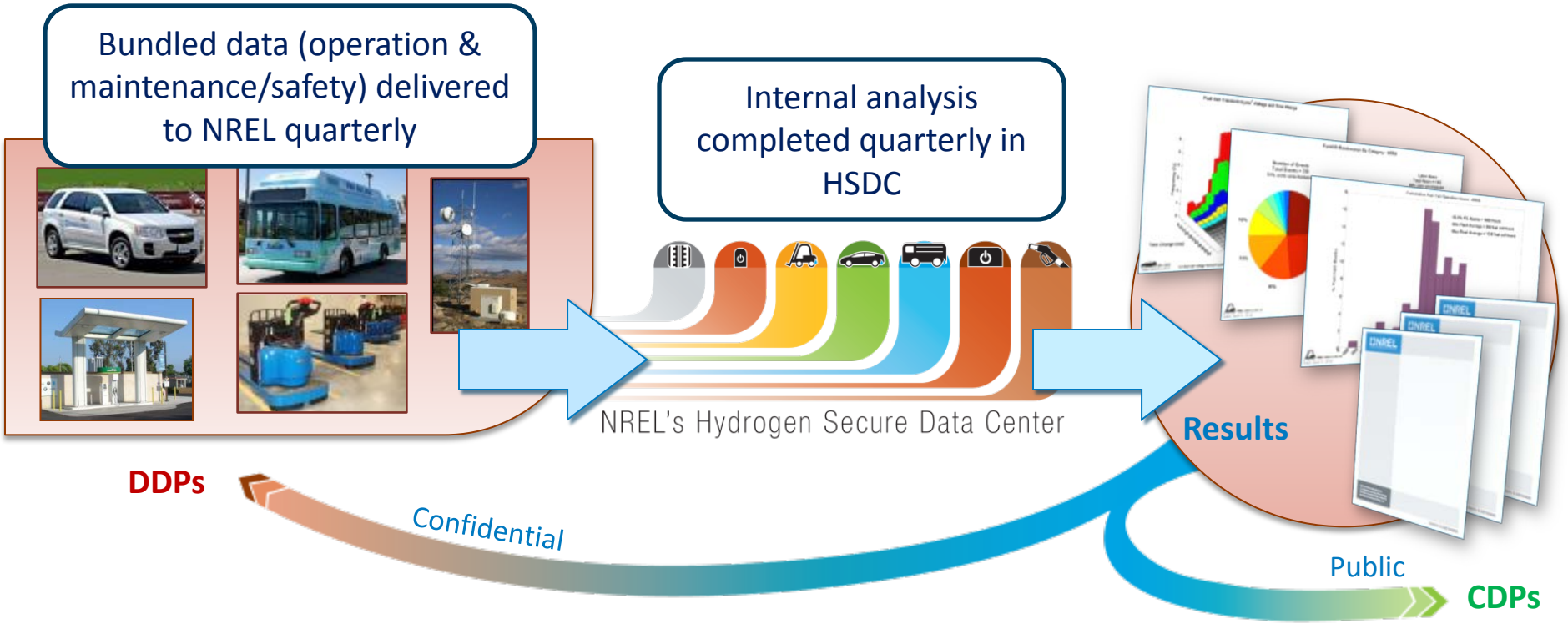
Funding Opportunity Announcement Number: DE-FOA-0000625
Announcement Type: Amendment 004
CFDA Number: 81.087

Issue Date: 02/29/2012
Application Due Date: 06/18/2012, 5:00 PM Eastern Time

Approach: Leverage Learning Demonstration Activity



Approach: Analysis and Reporting of Real-World Operation Data



Detailed Data Products (DDPs)

- Individual data analyses
- Identify individual contribution to CDPs
- Shared every six months only with the partner who supplied the data[1]

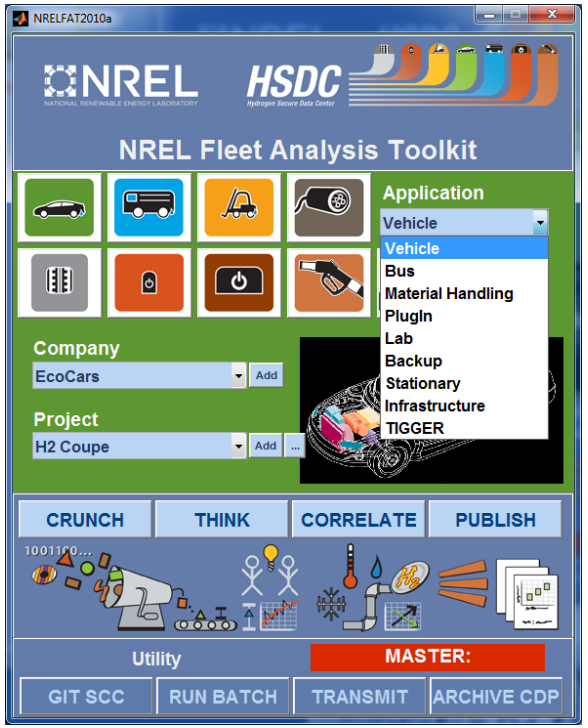
Composite Data Products (CDPs)

- Aggregated data across multiple systems, sites, and teams
- Publish analysis results every six months without revealing proprietary data[2]

1) Data exchange may happen more frequently based on data, analysis, and collaboration
2) Results published via NREL technology validation website, conferences, and reports (http://www.nrel.gov/hydrogen/proj_learning_demo.html)

Approach: Analysis

- **NREL Fleet Analysis Toolkit (NRELFAT)**
  - Developed first under fuel cell vehicle Learning Demonstration
  - Expanded to include material handling, backup power, and stationary power
  - Restructured architecture and interface to effectively handle new applications and projects and for flexible analysis



- **Publish results**
  - Detailed and composite results
  - Target key stakeholders such as fuel cell and hydrogen developers and end users

Approach and Accomplishments: Milestones

1. Finalize data collection and analysis plans through communications with DOE and industry partners
2. Move HSDC to Energy Systems Integration Facility
3. ◆ Quarterly analysis of operation and maintenance data for fuel cell systems and hydrogen infrastructure
4. ✦ Bi-annual technical composite data products
5. ⬟ Site visits and project kick-offs

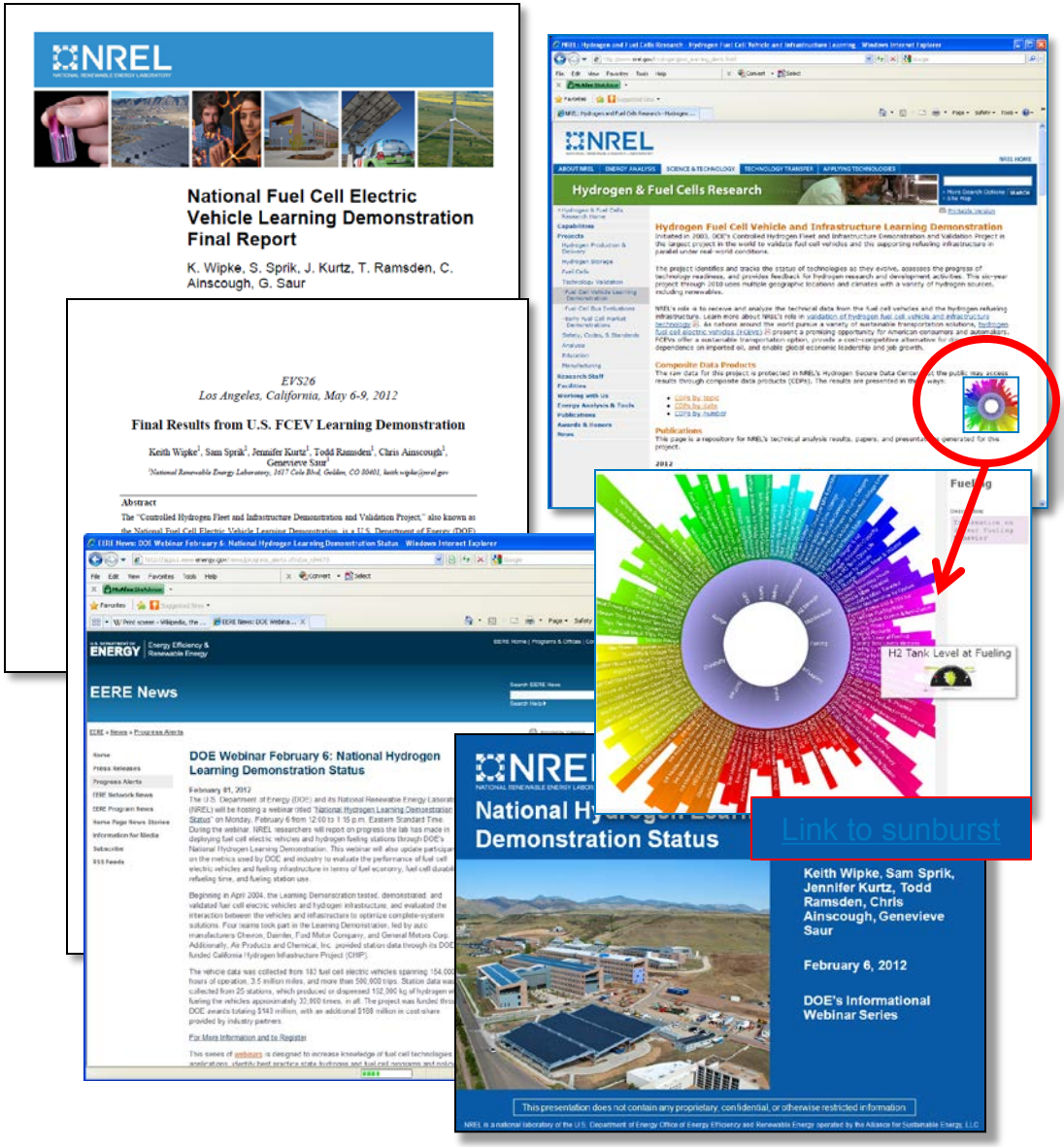
New 5 year project planned

Approach: CDPs Published from Learning Demonstration available for benchmarking current FCEV performance

Total of 99 CDPs published for vehicles and infrastructure

Approach: Communicate Results to Broad Audience

- Presentations
- Webinars
- Interactive way to access CDP results from website



Approach: Tracking Future Progress Against Previous Demonstration Results

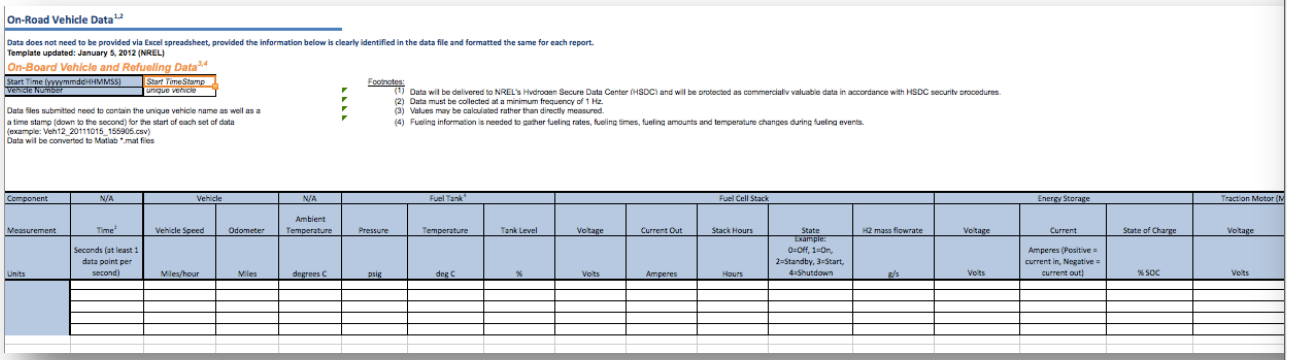
Vehicle Performance Metrics	Gen 1 Vehicle	Gen 2 Vehicle	2009 Target	After 2009Q4
Fuel Cell Stack Durability			**2,000 hours**	
Max Team Projected Hours to 10% Voltage Degradation	**1,807 hours**	**2,521 hours**		--
Average Fuel Cell Durability Projection	821 hours	1,062 hours		1,748 hours
Max Hours of Operation by a Single FC Stack to Date	2,375 hours	1,261 hours		1,582 hours
Driving Range			**250 miles**	
Adjusted Dyno (Window Sticker) Range	**103-190 miles**	**196-254 miles**		--
Median On-Road Distance Between Fuelings	56 miles	81 miles		98 miles
Fuel Economy (Window Sticker)	42 – 57 mi/kg	43 – 58 mi/kg	no target	--
Fuel Cell Efficiency at ¼ Power	51% – 58%	53% – 59%	60%	--
Fuel Cell Efficiency at Full Power	30% – 54%	42% – 53%	50%	--

Infrastructure Performance Metrics			2009 Target	After 2009Q4
H_2 Cost at Station (early market)	On-Site Natural Gas Reformation **$7.70 – $10.30/kg**	On-Site Electrolysis **$10.00 – $12.90/kg**	**$3/gge**	--
Average H_2 Fueling Rate	0.77 kg/min		1.0 kg/min	0.65 kg/min

Outside of this project, DOE independent panels concluded at 500 replicate stations/year:
Distributed natural gas reformation at 1,500 kg/day: **$2.75-$3.50/kg** (2006)
Distributed electrolysis at 1,500kg/day: **$4.90-$5.70** (2009)

Outside review panel

Accomplishment: Data Templates and Security Procedure Updated



On-Road Vehicle Data[1,2]

Data does not need to be provided via Excel spreadsheet, provided the information below is clearly identified in the data file and formatted the same for each report.
Template updated: January 5, 2012 (NREL)

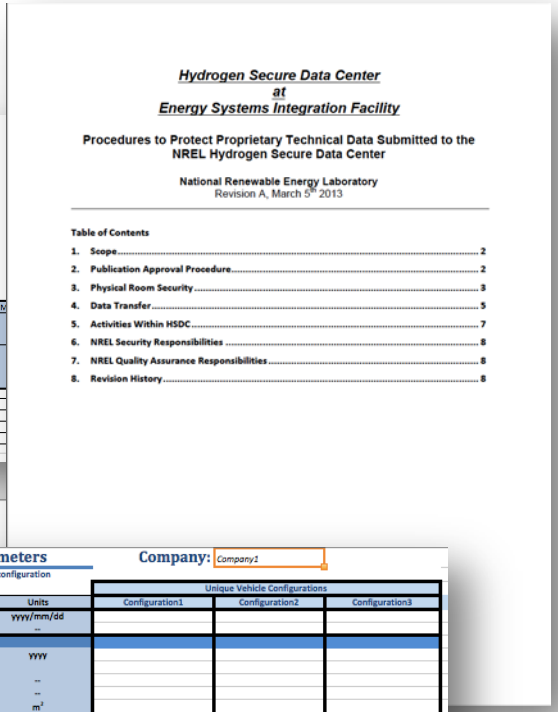
On-Board Vehicle and Refueling Data[3,4]

Start Time (yyyymmddHHMMSS) — Start TimeStamp
Vehicle Number — unique vehicle

Data files submitted need to contain the unique vehicle name as well as a time stamp (down to the second) for the start of each set of data (example: Veh12_20111015_155905.csv)
Data will be converted to Matlab *.mat files

Footnotes:
(1) Data will be delivered to NREL's Hydrogen Secure Data Center (HSDC) and will be protected as commercially valuable data in accordance with HSDC security procedures.
(2) Data must be collected at a minimum frequency of 1 Hz.
(3) Values may be calculated rather than directly measured.
(4) Fueling information is needed to gather fueling rates, fueling times, fueling amounts and temperature changes during fueling events.

Component	N/A	Vehicle		N/A	Fuel Tank[4]			Fuel Cell Stack					Energy Storage			Traction Motor (M
Measurement	Time[2]	Vehicle Speed	Odometer	Ambient Temperature	Pressure	Temperature	Tank Level	Voltage	Current Out	Stack Hours	State (example: 0=Off, 1=On, 2=Standby, 3=Start, 4=Shutdown	H2 mass flowrate	Voltage	Current	State of Charge	Voltage
Units	Seconds (at least 1 data point per second)	Miles/hour	Miles	degrees C	psig	deg C	%	Volts	Amperes	Hours		g/s	Volts	Amperes (Positive = current in, Negative = current out)	% SOC	Volts



Hydrogen Secure Data Center
at
Energy Systems Integration Facility

Procedures to Protect Proprietary Technical Data Submitted to the NREL Hydrogen Secure Data Center

National Renewable Energy Laboratory
Revision A, March 5th 2013

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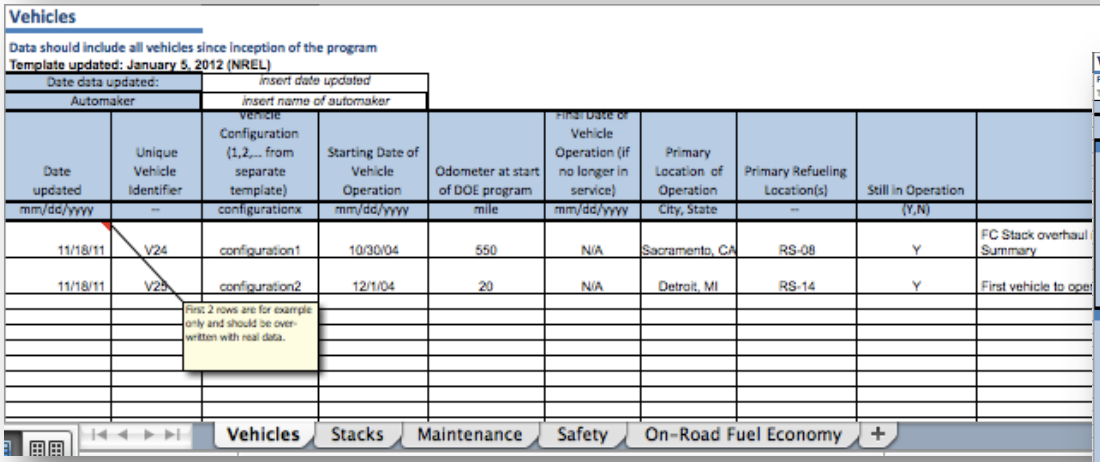


Vehicles

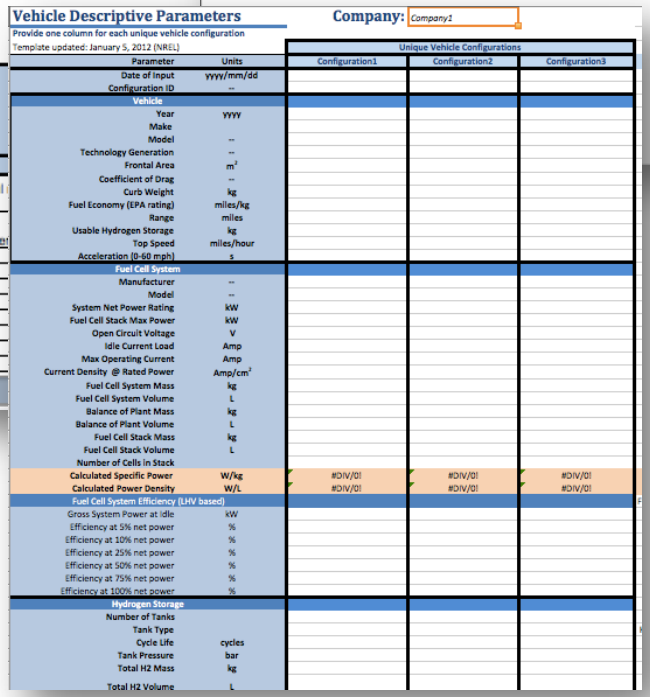
Data should include all vehicles since inception of the program
Template updated: January 5, 2012 (NREL)

Date data updated: *insert date updated*
Automaker: *insert name of automaker*

Date updated	Unique Vehicle Identifier	Vehicle Configuration (1,2,... from separate template)	Starting Date of Vehicle Operation	Odometer at start of DOE program	First Date of Vehicle Operation (if no longer in service)	Primary Location of Operation	Primary Refueling Location(s)	Still in Operation	
mm/dd/yyyy	--	configurationx	mm/dd/yyyy	mile	mm/dd/yyyy	City, State	--	(Y,N)	
11/18/11	V24	configuration1	10/30/04	550	N/A	Sacramento, CA	RS-08	Y	FC Stack overhaul Summary
11/18/11	V25	configuration2	12/1/04	20	N/A	Detroit, MI	RS-14	Y	First vehicle to oper

First 2 rows are for example only and should be over-written with real data.

Vehicles | Stacks | Maintenance | Safety | On-Road Fuel Economy | +



Vehicle Descriptive Parameters — Company: Company1

Provide one column for each unique vehicle configuration
Template updated: January 5, 2012 (NREL)

Parameter	Units	Unique Vehicle Configurations: Configuration1	Configuration2	Configuration3
Date of Input	yyyy/mm/dd			
Configuration ID	--			
Vehicle				
Year	yyyy			
Make				
Model	--			
Technology Generation	--			
Frontal Area	m^2			
Coefficient of Drag	--			
Curb Weight	kg			
Fuel Economy (EPA rating)	miles/kg			
Range	miles			
Usable Hydrogen Storage	kg			
Top Speed	miles/hour			
Acceleration (0-60 mph)	s			
Fuel Cell System				
Manufacturer	--			
Model	--			
System Net Power Rating	kW			
Fuel Cell Stack Max Power	kW			
Open Circuit Voltage	V			
Idle Current Load	Amp			
Max Operating Current	Amp			
Current Density @ Rated Power	Amp/cm^2			
Fuel Cell System Mass	kg			
Fuel Cell System Volume	L			
Balance of Plant Mass	kg			
Balance of Plant Volume	L			
Fuel Cell Stack Mass	kg			
Fuel Cell Stack Volume	L			
Number of Cells in Stack				
Calculated Specific Power	W/kg	#DIV/0!	#DIV/0!	#DIV/0!
Calculated Power Density	W/L	#DIV/0!	#DIV/0!	#DIV/0!
Fuel Cell System Efficiency (LHV based)				
Gross System Power at Idle	kW			
Efficiency at 5% net power	%			
Efficiency at 10% net power	%			
Efficiency at 25% net power	%			
Efficiency at 50% net power	%			
Efficiency at 75% net power	%			
Efficiency at 100% net power	%			
Hydrogen Storage				
Number of Tanks				
Tank Type				
Cycle Life	cycles			
Tank Pressure	bar			
Total H2 Mass	kg			
Total H2 Volume	L			

Vehicle operation, maintenance, safety, and specification templates were all updated based on previous templates, discussions with stakeholders, and validation topic priorities.

Accomplishment: Key Analysis Topics Identified

Critical

- FC durability
- Vehicle operation (hours, miles)
- Specs (power density, specific power)
- Range, fuel economy, and efficiency
- Fill performance
- Reliability

Important

- Drive behaviors
- Fill behaviors
- Power management
- Energy
- Transients
- Comparisons to conventional vehicles

These key topics were selected based on review of past CDPs, targets, most common referenced topics, and DOE feedback.

Highlights of Interactions and Collaborations

- **Auto Industry Partners**
  - Detailed discussion of NREL HSDC procedures
  - Discussion of data priorities, templates, and methods
  - Review of all results prior to publication
- **U.S. DRIVE Technical Teams**
  - Provide annual briefing of FCEV performance results to the Hydrogen Storage and Fuel Cell Tech Team
- **FCHEA Technical Working Groups**
  - Participate in Transportation Working Group
  - Participate in Joint H_2 Quality Task Force
- **California Organizations**
  - CaFCP and CHBC: NREL actively participating as member
  - CARB and CEC: New stations offer potential to provide future data to NREL

Future Work

- **Support DOE in launching the new validation project**
  - "Light-Duty Fuel Cell Electric Vehicle Validation Data" (**FOA 625**)
- **Perform quarterly analysis of initial data**
- **Identify first set of FCEV CDPs for publication scheduled at the end of FY13**
- **Identify new opportunities to document FC and H_2 progress publicly**

Summary

- **Relevance**
  - Validate FCEV performance against DOE and industry targets
- **Approach**
  - Collaborate with industry partners
  - Continue to develop core HSDC and analysis capability and tools
  - Leverage 7+ years of analysis and experience from the Learning Demonstration
- **Technical Accomplishments and Progress**
  - Completed data templates and HSDC security procedures
  - Prioritized key analysis topics
  - Interactions with auto OEMs on priorities, data sharing, and methods
- **Collaborations**
  - Work closely with industry partners to validate methodology, and with other key stakeholders to ensure relevance of results
- **Future Work**
  - Complete quarterly analysis of initial data
  - Identify first set of FCEV CDPs for publication scheduled at the end of FY13
  - Identify new opportunities to document FC and H_2 progress publically

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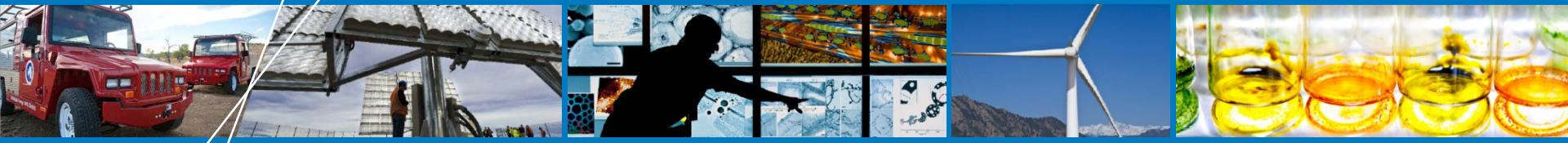
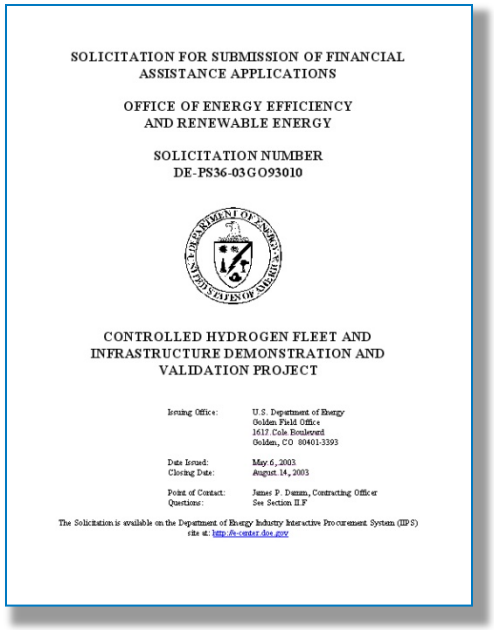


Technical Backup Slides

History: 4 OEM/Energy Teams Selected Competitively through DOE FOA in 2004



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

Issuing Office: U.S. Department of Energy
Golden Field Office
1617 Cole Boulevard
Golden, CO 80401-3393

Date Issued: May 6, 2003
Closing Date: August 14, 2003

Point of Contact: James P. Dumm, Contracting Officer
Questions: See Section II.F

The Solicitation is available on the Department of Energy Industry Interactive Procurement System (IIPS) site at: http://e-center.doe.gov

ChevronTexaco*
HYUNDAI
KIA
UTC Fuel Cells **
A United Technologies Company

Ford
bp

DAIMLERCHRYSLER ***
bp

GM
Shell

DOE funding: $170M
Industry cost share: $189M
Total: $359M

NREL received $6.6M from DOE for analysis and support of this project since FY03

* now Chevron ** now ClearEdge *** now DAIMLER

Industry Partners: Collaborative Relationship, Working through Details of Analysis, was Critical to Success

FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
RFP	Startup	Operation, Data Collection, and Analysis							

- Ford/BP and Chevron/Hyundai-Kia Concluded in 2009

Daimler, GM, and Air Products (CHIP) demonstrated vehicles/stations within project through Sept. 2011

2nd Generation Vehicles Demonstrated Technology Improvements Over 1st Generation

Generation 1 Vehicles

- FC not freeze-capable
- ~2003 stack technology
- Storage: liquid H_2 and 350 and 700 bar
- Range: 100-200 miles
- Efficiency: 51%-58% at ¼ power

Generation 2 Vehicles

- FC freeze-capable
- ~2007-2009 stack tech.
- Storage: All 700 bar
- Range: 200-250 miles
- Efficiency: 53%-59% at ¼ power
- Longer FC durability