

Hydrogen and Fuel Cell Transit Bus Evaluations

**Joint Evaluation Plan for the U.S.
Department of Energy and the Federal
Transit Administration**

Technical Report
NREL/TP-560-42781-1
May 2008

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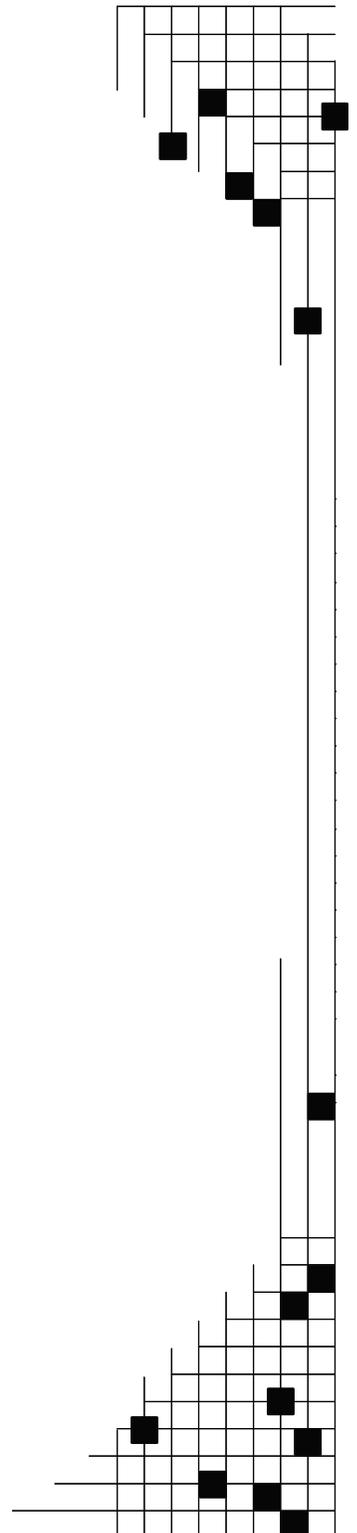
Joint Evaluation Plan for the U.S. Department of Energy and the Federal Transit Administration

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Purpose of this Document

This document describes the hydrogen transit bus evaluations performed by the National Renewable Energy Laboratory (NREL) and funded by the U.S. Department of Energy (DOE) and the U.S. Department of Transportation's Federal Transit Administration (FTA). For some projects, the entire evaluation is funded by either DOE or FTA, while in other cases individual activities within a specific evaluation are funded separately. This document provides a description of the demonstration sites, funding sources, and the data collection activities for hydrogen transit bus evaluations currently planned from FY08 through FY10.

Background

DOE and NREL have been evaluating alternative fuel transit buses with FTA since the early 1990s. In 1996, DOE and NREL completed an evaluation of transit buses at eight transit agencies that included six different alternative fuels. As part of this alternative fuel transit bus evaluation, NREL and Battelle (NREL's subcontractor for this effort) developed a customized data collection and evaluation protocol. This protocol has evolved over time, but it is still based on the original effort. Since the 1996 study of alternative fuels in transit, NREL has completed seven additional evaluations of natural gas and hybrid propulsion transit buses as well as several evaluations of truck applications (nine evaluations completed and three under way).

NREL's first evaluation of hydrogen-fueled transit buses was in 2000 working with SunLine Transit Agency in the Palm Springs, California area. The current hydrogen transit bus evaluations include four active projects and two that were completed in the last few years. Additional hydrogen transit bus evaluations are planned for DOE and for the FTA National Fuel Cell Bus Program. Table 1 provides an overview of the current and planned evaluations for both DOE and FTA. These evaluations will be discussed later in this section.

Table 1. Summary of Hydrogen Evaluations for DOE and FTA¹

Site/Locations	State	Eval. Funding	2007		2008				2009				2010					
			3	4	1	2	3	4	1	2	3	4	1	2	3	4		
AC Transit /Oakland	CA	DOE Tech. Validation	HyRoad															
AC Transit /Oakland	CA		AC Transit CA ZEB 2009															
SunLine /Thousand Palms	CA		FCB/HHICE															
SunLine /Thousand Palms	CA		FCB Ext. Service															
SunLine /Thousand Palms	CA		Advanced FCB Project															
CTTRANSIT /Hartford	CT		CTTRANSIT FCB Demo															
Hickam AFB /Honolulu	HI		Air Force FCV Demo															
VTA /San Jose	CA		VTA CA ZEB 2009															
AC Transit /Oakland	CA		Accelerated Testing															
SunLine /Thousand Palms	CA		American FCB Demo															
CTTRANSIT /Hartford	CT	CT Hybrid FCB Demo																
Columbia /Site 2/ CTTRANSIT	SC/CT	Dual Variable Output Hybrid FCB																
Logan Airport /Boston	MA	MA H2 FCB Fleet																
TBD/NY	NY	Lightweight FCB Demo																
TBD/NY	NY	Hydroelectric H2 Powered FCB																
SFMTA /San Francisco	CA	FC APU Hybrid																

Color coded by geographic area

* Detailed data collection and analysis funded by DOE

¹ For current version of the summary table, see link: http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html

DOE Hydrogen Vehicle and Infrastructure Evaluations

DOE has been researching hydrogen and fuel cells because of their potential to address several major challenges facing the United States today. These challenges include reducing dependence on petroleum imports, diversifying domestic energy sources, and decreasing pollution and greenhouse gas emissions. The Hydrogen, Fuel Cells & Infrastructure Technologies (HFCIT) Program at DOE² is working with partners to address the technical challenges and accelerate the development and successful market introduction of hydrogen technologies. Technology validation is one of the key elements of this program.³ Under NREL's Technology Validation activity, hydrogen and fuel cell vehicles are evaluated in parallel with hydrogen infrastructure to determine the current status of the technology and assess the progress toward technology readiness.

In 2003, DOE initiated the Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project, which is focused on validating light-duty fuel cell vehicles and the supporting fueling infrastructure. This project studies fuel cell vehicles in multiple geographic locations and climates using a variety of sources of hydrogen, including renewables. NREL's role in this six-year technology validation project, scheduled to continue until 2010, is to receive and analyze all of the technical data from both the fuel cell vehicles and the hydrogen fueling infrastructure. The raw data are protected in NREL's Hydrogen Secure Data Center. Public results are generated in the form of composite data products (CDPs).

Table 2 outlines the hydrogen and fuel cell transit bus evaluations conducted for DOE as part of NREL's Technology Validation⁴ activity. Collecting data on fuel cell systems in transit buses enables a more complete understanding of how the technology will perform in other transportation applications.

Table 2. DOE/NREL Heavy Vehicle Fuel Cell/Hydrogen Evaluations

Fleet	Vehicle/Technology	Number	Evaluation Status
Alameda-Contra Costa Transit District (Oakland, CA)	Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.	3	In process; results reported in Mar. 2007 and updated in Oct. 2007
SunLine Transit Agency (Thousand Palms, CA)	New Flyer/ISE Corp. hydrogen internal combustion engine transit bus	1	In process; results reported in Feb. 2007 and updated in Sep. 2007
	Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.	1	
Connecticut Transit (Hartford, CT)	Van Hool/UTC Power fuel cell hybrid transit bus integrated by ISE Corp.	1	Bus in operation; data collection started
U.S. Air Force/Hickam Air Force Base (Honolulu, HI)	Shuttle bus: Hydrogenics and Enova, battery-dominant fuel cell hybrid	1	Shuttle bus in operation; data collection started
	Delivery van: Hydrogenics and Enova, fuel cell hybrid	1	Van in operation; data collection started
Completed Evaluations			
Santa Clara VTA, (San Jose, CA) and San Mateo (San Carlos, CA)	Gillig/Ballard fuel cell transit bus	3	Complete and reported in 2006
SunLine Transit Agency (Thousand Palms, CA)	ISE Corp./ UTC Power ThunderPower hybrid fuel cell transit bus	1	Complete and reported in 2003

² DOE HFCIT website: www1.eere.energy.gov/hydrogenandfuelcells/

³ DOE Multi-Year Research, Development and Demonstration Plan, www1.eere.energy.gov/hydrogenandfuelcells/mypp/

⁴ NREL Technology Validation website: www.nrel.gov/hydrogen/proj_tech_validation.html

FTA Hydrogen Transit Bus Evaluations

The FTA is at the forefront of the research, development, and demonstration of fuel cell transit buses. The agency led early efforts to demonstrate fuel cell propulsion feasibility and proof-of-concept demonstrations in a liquid-fueled fuel cell transit bus development program with Georgetown University. The FTA also led a demonstration of three hydrogen fuel cell buses at the Chicago Transit Authority and another demonstration of three different types of fuel cell buses at SunLine Transit Agency.

Fuel cell technology is especially interesting to FTA because it holds the promise of greatly reduced emissions, quiet operation, and reduced fuel consumption for transit fleets. The early introduction of hydrogen fuel cell buses is expected to pave the way for later successful commercialization of fuel cells in other transportation applications. Current efforts focus on dramatically improving the energy efficiency, emissions, performance, and cost-effectiveness of the 40-ft heavy-duty transit bus, the most prevalent vehicle used by U.S. transit agencies.

The FTA's newest development program is the National Fuel Cell Bus Program (NFCBP)⁵, which was established as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: a Legacy for Users (SAFETEA-LU) transportation authorization. The NFCBP program designates \$49 million in funding for 2006 through 2009 to help develop commercially viable fuel cell buses and technologies.

The NFCBP awards were announced in November 2006. The FTA competitively selected three nonprofit organizations—the Center for Transportation and the Environment (CTE), the Northeast Advanced Vehicle Consortium (NAVC), and WestStart-CALSTART—to administer projects under the program. The FTA selected 14 separate projects in all (as shown in Table 3), including eight planned demonstration projects. These projects include both evolutionary and “clean sheet” approaches. They incorporate multiple drive technologies and configurations, fuel cell power plants in various sizes, and several energy storage technologies. Two component technology projects and four supporting and outreach projects were also selected.

The FTA is collaborating with DOE and NREL to ensure that data are collected on all fuel cell bus demonstrations under the program. The evaluations are coordinated with ongoing DOE evaluations. NREL uses the standard data collection and analysis protocol established for DOE heavy-duty vehicle evaluations as described in this plan. For the hydrogen-fueled transit bus evaluations described in this plan, funding is provided by DOE or FTA. Table 2 lists the evaluation sites funded solely by DOE. The eight NFCBP demonstration sites listed in Table 3 are funded by FTA. However, for the NFCBP evaluation sites, any detailed data collection and analysis of the fuel cell system or infrastructure will be funded by DOE. FTA is also considering additional funding for one or two sites beyond the NFCBP sites, but that has not been determined.

⁵ FTA Bus Research and Testing website: http://www.fta.dot.gov/assistance/technology/research_4578.html

Table 3. Summary of FTA NFCBP Projects

Demonstration Projects
Dual Variable Output Fuel Cell Hybrid Bus Validation and Testing —Develop battery-dominant 35-ft plug-in hybrid fuel cell bus (Hydrogenics) and demonstrate in Columbia, SC, and cities in CT (CTE)
UTC Power Hybrid Fuel Cell Bus Demonstration —Advanced bus development and in-service evaluation of hybrid 40-ft fuel cell buses; enhanced UTC Power 120 kW PEM fuel cell with upgraded seals, catalysts, bipolar plates, balance of plant (NAVC)
GE Lightweight Fuel Cell Hybrid Bus —Advanced propulsion system integrated with a lightweight bus platform for field evaluation focused on advanced battery technologies for lower cost (NAVC)
Massachusetts Hydrogen Fuel Cell Powered Bus Fleet —Advanced bus development and in-service demonstration; integrate Nuvera 82 kW fuel cell with drive system from ISE Corp. and advanced energy storage; demonstration effort includes Nuvera’s novel PowerTap fueling infrastructure (NAVC)
New York Power Authority Fuel Cell Bus Program —Develop and demonstrate two 40-ft buses for operation in upstate New York for up to 2 years; Next-generation Ballard HD6 fuel cell module (150 kW) in hybrid configuration with ISE drive and ultracapacitors or batteries (NAVC)
American Advanced Fuel Cell Bus Program —Design and demonstrate 40-ft fuel cell bus with design improvements; in-service evaluation in hot desert climate (WestStart-CALSTART)
Compound Fuel Cell Hybrid Bus for 2010 —Develop 40-ft hybrid bus with fuel cell auxiliary power unit coupled with diesel engine; demonstrate for one year at San Francisco MTA; small Hydrogenics PEM fuel cell (12 kW twin or 16 kW), BAE Systems drive, electrically driven accessories, advanced energy storage (WestStart-CALSTART)
AC Transit HyRoad: Commercialization of Fuel Cells for Public Transit —Accelerated testing to failure (partial phase 1) of existing fuel cell buses (WestStart-CALSTART)
Component Projects
Hybrid Fuel Cell Power Converter —Design and bench-test bidirectional, DC-DC converter for reduced cost, weight, and volume (WestStart-CALSTART)
Integrated Auxiliary Module for Fuel Cell Buses —Design, fabricate, and bench test Integrated Auxiliary Module (WestStart-CALSTART)
Supporting Projects
Survey and Analysis of Bus Demonstrations —Document and analyze bus demonstrations around the world from 2002-2007 (CTE)
FTA National Fuel Cell Bus Working Group —Support for FTA U.S. Fuel Cell Bus Working Groups and data collection efforts; two projects (NAVC)
International Fuel Cell Bus Working Group —Coordinate activities for International Fuel Cell Working Group and collaboration and outreach efforts for international fuel cell bus demonstration efforts (NAVC)
International Fuel Cell Bus Annual Workshop —Facilitation of the Annual Workshops in collaboration with the Working Group.

Overall Evaluation Objectives

The objectives of the DOE and FTA evaluations are to provide comprehensive, unbiased evaluation results of fuel cell and hydrogen bus development and performance compared to conventional baseline vehicles when available and appropriate. Baseline vehicles are typically diesel buses or occasionally compressed natural gas – CNG. These evaluations also include information on the development and performance of hydrogen infrastructure, and descriptions of the facility modifications required for safe operation of hydrogen-fueled vehicles.

The DOE and FTA demonstration and evaluation programs have two major goals:

- Provide credible data analysis results to the transit bus and fuel cell industries that go beyond “proof of concept” for fuel cell transit buses and infrastructure.

- Provide results focused on performance and use including progress over time and experience from integrating vehicle systems, operations, and facilities for the fuel cell transit buses and supporting infrastructure.

DOE and FTA have both cited the lack of data and analysis results in real-world service as a challenge for moving the technology forward. These evaluations have proved useful for a variety of groups including transit operators considering the technology for future procurements, manufacturers needing to understand the status of the technology for transit applications, and government agencies making policy decisions or determining future research needs.

To demonstrate that fuel cell propulsion systems can match the current technology, FTA has established specific objectives for fuel cell bus demonstration projects. As part of the NFCBP, FTA defined the following objectives:

- Develop and demonstrate fuel cell buses using innovative and improved fuel cell bus technologies.
- Develop and demonstrate innovative and improved components and technologies for fuel cell buses, including fuel cell technologies, energy storage, transit bus systems integration, and power electronics technologies.
- Advance different fuel cell technologies that may be viable for transit.
- Develop an understanding of the requirements for market introduction. This includes fuel supply, fueling infrastructure, supplier networks, maintenance, safety, insurance, education, performance, support, etc.
- Enhance the awareness of, and education about, fuel cell bus technologies.
- Collaborate in the development of design standards for fuel cell bus technologies.
- Compile and maintain information on the state of fuel cell bus technologies development and needs.

When available or possible, DOE and NREL will collect detailed propulsion system data that are considered proprietary by the manufacturers. These data will be protected using appropriate agreements and physical barriers as defined for other NREL Technology Validation activities for DOE. The detailed propulsion system data will be used to determine if the fuel cell systems will meet DOE performance targets, particularly for fuel cell stack durability.

Evaluation Selection and Coordination

As the interest in fuel cell technology has grown, more demonstration projects have been initiated around the United States. Because funding is limited, the evaluation team needed a way to select projects that would ensure the most value for the effort. NREL tracks all fuel cell and hydrogen bus demonstration projects that are on-going in the country, and recommends to DOE and FTA the projects that make the best candidates for evaluation.

Appendix A provides a summary of the hydrogen and fuel cell transit bus demonstration sites in the United States that are being considered for evaluation. The list includes a summary table which outlines the sites, funding agency (for selected sites), and vehicle demonstration schedule. The summary table is followed by a short description of each demonstration site listed. NREL will update this appendix on a quarterly basis to track progress. The update will be posted on the Web separately from this plan.

Site Selection Criteria

The criteria for site selection have been established as general guidelines. They are not intended to be rigid, but suggest a framework for selecting sites for participation in these projects. Criteria include:

1. Full-size transit buses (40-ft) are preferred, but others (such as shuttle buses) are allowed.
2. Propulsion systems should include fuel cell power systems, but could also have hydrogen internal combustion engines.
3. Baseline vehicles similar to the test vehicles in age and size are preferred (to ensure the best comparison).
4. Test and baseline vehicles must be used in a similar duty cycle (if baseline vehicles are available).
5. Host site must be motivated to participate in the evaluation program.
6. Host site must have good record-keeping.
7. Reliable, high-quality hydrogen fuel supply must be available.

Evaluation Type Selection

The evaluations described in this plan are focused on documenting the implementation experience for both the prototype hydrogen fuel cell transit buses and the related prototype infrastructure. This focus includes early experience related to the construction and operation of infrastructure as well as planning for and operation of the buses.

Because of the prototype nature of these technologies and the fact that current demonstrations employ a small number of buses at each site, there are two evaluation types planned – a full evaluation or a partial evaluation.

- A **Full Evaluation** is intended for a demonstration site that has standard, 40-ft fuel cell and baseline buses operating in similar duty cycles for at least one full year.

- A **Partial Evaluation** is intended for a demonstration site that uses buses smaller than 40-ft, does not have baseline buses in a similar duty cycle, has a specialized duty cycle planned (not typical of transit), or has the fuel cell buses operating in multiple locations for less than one year.

The data collection process for these two types of evaluations will essentially be the same. However, the evaluation period for the Partial Evaluation will be shorter and result in fewer analysis reports (as compared to the Full Evaluation).

Demonstration Site Coordination

Conducting an evaluation at each site requires the support and cooperation of several groups including the transit agency, manufacturers, other interested local, state, and federal government parties, as well as DOE and FTA. The roles of each project partner are detailed in the following:

- **Transit Agency** – Provide access to data as determined in this plan, host data collection and evaluation meetings on-site, provide insight into lessons learned, and provide input, review, and approval of all public products.
- **Manufacturers** – This group includes manufacturers of the fuel cell propulsion system, hybrid system, bus, and potentially others. Like the transit agency, the manufacturers provide input, review, and approval of all public products. For any detailed data collected, the manufacturer has the primary role of data collection and delivery to NREL.
- **Government partners** – There are many interested partners in these demonstrations. For some sites, local, state, or federal partners have provided the primary project funding and have been involved in the project design. In these cases, the project partners are required to provide limited access to ongoing evaluation results prior to public dissemination. These results are provided after approval by the transit agency and manufacturer partners.
- **DOE and FTA** – These two agencies provide funding to NREL for the evaluations and provide review of all evaluation products; both internal and for the public.
- **NREL** – NREL and its subcontractor (Battelle) complete the evaluation activities and provide results to the project team for review and approval. Evaluation activities include data collection, compilation, and analysis.

An evaluation is typically conducted in three stages: project initialization, data collection and analysis, and final reporting and wrap-up. During each stage, NREL and Battelle work closely with the transit agency and other project partners to ensure all data and experiences are captured accurately and completely.

- **Project initialization** – Once a specific fuel cell demonstration is selected for evaluation, NREL contacts the potential partners to determine their willingness to participate. In the beginning, there are phone conversations with the partners, followed by an on-site kick-off meeting. During this meeting, the evaluation team determines the primary contacts at the agency and the timing and methods for transferring the operational data on the buses and infrastructure. Establishing a good relationship with the transit agency is extremely important at this stage, because they are the primary source of data.

- **Data collection and analysis** – Once the buses (both hydrogen and baseline buses) have been selected and are in service, data collection begins. During the evaluation process, the transit agency and their manufacturer partners must address many questions. There is also a need to share results with those partners for input, comment, and review. This is accomplished through monthly presentations of selected data items. On-site meetings are held to discuss analysis results and demonstration activities, usually on a quarterly basis. Published reports are completed on a regular schedule, typically every 6 - 8 months. For all public reports or presentations, data analysis results are reviewed and approved by the appropriate evaluation partners.
- **Final reporting and wrap-up** – After the evaluation team collects operational data on the buses in service for the pre-determined time, a final report is published. This report covers the overall experience of the project partners, the final data analysis, and the summary of lessons learned.

Data Collection Approach

As discussed earlier, the objectives of the evaluation include:

- Provide credible data and evaluation results
- Provide results in context of the fact that these fuel cell buses and supporting infrastructure are *prototypes*
- Provide results that show progress and experience for fuel cell bus and infrastructure operation in transit service
- Provide results from multiple operating experiences and different transit agencies

Each evaluation is essentially a snapshot in time and technology. The results are extremely important for understanding the state of the technology and the work that still needs to be done. This information is also important for estimating what the future technology and costs of operation may look like based on the experiences of these agencies and expected advances in systems integration and developments.

To accomplish these objectives, two data collection and analysis activities are planned:

Standard Evaluation – The evaluation plan for this portion of the work is based on the protocol mentioned earlier. Non-proprietary data are collected on operation and maintenance of the bus and infrastructure. These data are collected primarily from the transit agency. The standard evaluation is described in the section ‘DOE/NREL Data Collection protocol’.

Detailed Technology Study – To support DOE’s Technology Validation activities, NREL is collecting additional data on the fuel cell buses and infrastructure that may be considered proprietary or commercially valuable. These data are intended to complement that of the light-duty Validation Project by adding detailed data on the fuel cell and systems in a heavy vehicle application. The primary contact for this effort is the manufacturers (rather than the fleet operators), because collecting second-by-second data on the fuel cell and system components requires their cooperation. These are considered sensitive and are protected accordingly. This detailed data collection is further explained in the section ‘Detailed Data Collection and Evaluation’.

The data collection and evaluation typically begins after the delivery of the fuel cell buses. Some work is planned to track the progress of facility modifications and fueling infrastructure implementation.

DOE/NREL Data Collection Protocol

Several levels of data are required to complete an evaluation.

1. The implementation story for the fuel cell buses and infrastructure
2. Descriptions of the vehicles used in the evaluation including the fuel cell buses and baseline comparison vehicles; these descriptions need to be as detailed as the manufacturers will allow and include system and component level information
3. The public awareness materials and public perception of the projects as available
4. Vehicle performance testing results from the manufacturers and transit agencies
5. Descriptions of the facilities built or used specifically for the demonstrations including fueling infrastructure and modifications to existing structures to accommodate the use of fuel cell buses
6. The capital costs for the vehicles, facilities, and training
7. The safety and training efforts conducted at each site
8. Descriptions of baseline operations for standard buses at the site using the newest standard bus operations for diesel or CNG buses as appropriate
9. Operations data collection – vehicle and fueling infrastructure, duty cycle/bus assignment, fueling, maintenance, and documentation of any configuration/design changes

The NREL data collection items are shown in Table 4. For each test fleet selected for evaluation, NREL collects all fueling, cost, and maintenance data for a period up to 24 months and reports this data to the project team. At the beginning of the data collection period, NREL also collects details on the fleet's operations including a description of facilities and services, capital costs, maintenance and fueling practices, and any other information needed to get a complete understanding of the fleet's experiences.

The data collection effort is intended to cause as little disruption as possible for the transit agencies. Visits to the site for information gathering, collection of costs, and facilities descriptions are planned. Telephone calls are made to verify data, investigate some details such as problems that arise with the vehicles or fueling infrastructure, and gather information on the overall experience using advanced technology vehicles at the site. Data collected and evaluations/analyses are distributed for review and input as required or as requested by the project partners.

For the full evaluation, the fuel cell buses are compared with diesel or CNG buses of a similar age, configuration, and operation. For each bus evaluation group (fuel cell and diesel/CNG), all maintenance and fueling data are collected. An evaluation period is selected based on a comparison of similar vehicle lifetimes of the fuel cell and diesel/CNG buses. The full evaluation period start date is specified by the site's determination that the fuel cell buses are ready to be compared to conventional vehicles. This requires NREL to collect significantly more data than are required and used for the actual evaluation.

Table 4. Data Collection Items

Type of Data	Frequency Recorded	Data Items
Vehicle Specification and Performance Expectations		
Vehicle System Descriptions	Start of data collection and changes as needed	Data items shown in Appendix B
Vehicle Performance Expectations	Start of data collection and changes as needed	Criteria and testing results for performance expectations
Vehicle Operation		
Vehicle Operating Cycle	Start of data collection and changes as needed	General description of daily use of vehicles
Special Service (Press events, public education, etc.)	Each time vehicle is used for atypical service	Description of event, time out of service.
Vehicle Usage in Service	At each time usage is measured	Odometer reading; hours of vehicle and fuel cell operation
		Daily vehicle assignment
		GPS data (if needed)
Fuel Consumption	Each time a vehicle is fueled	Amount of fuel
		Odometer reading
		Date
	Time for fueling	
	Each time the fuel price changes at a given site	Price per unit
Engine Oil Consumption and Changes (Baseline vehicles only)	Each time oil is added	Amount of Oil
		Odometer reading
		Date
	Each time oil is changed as recommended by the engine manufacturer	Price per quart
		Amount of oil
		Odometer reading
		Date
Maintenance	For each work order	Type of Maintenance: Scheduled, Unscheduled, Configuration Change
		Labor Hours
		Date of Repair
		Number of days out of service
		Odometer reading
		Parts replaced
		Parts cost
		Description of reported problem
		Description of repair performed
Road Call or Road Service	For each occurrence	Same as maintenance
Safety Incidents	Each occurrence	Description of each accident or incident involving the test or control vehicles, including collisions, and maintenance and fueling incidents
Facility Operating Costs		
Fueling Infrastructure	Each maintenance activity	Type of maintenance, labor, parts, costs, problems, configuration changes
Facilities (safety systems related to hydrogen and fuel cells)	Each maintenance activity	Type of maintenance, labor, parts, costs, problems, configuration changes
Facility Descriptions and Capital Costs		
Facility Descriptions	Start of data collection and as needed if and when changes are made	Fueling site equipment description
		Maintenance area description
		Vehicle storage area description
Facility Capital Costs	Start of data collection and as needed if and when changes are made	Facility modification capital costs by area (charging, maintenance, and vehicle storage)
Vehicle Capital Costs	Start of data collection	Vehicle capital cost for test vehicles

The data, shown in Table 4, are separated into four categories: vehicle specifications and performance expectations, bus operations, facility operating costs, and facility descriptions and capital costs. Each of these four categories is described in the following sections.

Vehicle Specifications and Performance Expectations

This category of data includes descriptions of the vehicle systems and vehicle performance expectations. Appendix B lists the specific information collected as part of the vehicle system descriptions. NREL collects these data at the beginning of the project, however, changes may be required if major systems are altered. The individual specification information is collected for both the fuel cell buses and baseline vehicles. The specifications are intended to describe the vehicle propulsion system and subsystems, as well as accessory equipment. This information documents that the baseline vehicles are similar in equipment to the demonstration buses. Also documented is any specific equipment that has the potential to affect the vehicles' fuel economy and overall reliability. The types of information that may be collected include:

- The fleet's specifications for their vehicles with an emphasis on the fleet's performance requirements such as length, weight, top speed, gradeability, acceleration, range, retardation (regenerative braking), noise, durability (vehicle life, battery pack life, etc.), emissions, fuel economy, special requirements such as low floor, and other useful information
- Interviews to document how the fleets typically measure vehicle performance when implementing a new technology
- Available performance information (such as first article acceptance testing data, independent fleet evaluations, etc.) on these vehicles
- Any other pertinent data to assist with the study

Vehicle Operation

Vehicle operation data items include the vehicle operating cycle, vehicle usage in service, fuel consumption, engine oil consumption (if an internal combustion engine is being used, typically only for the baseline vehicles), maintenance records, and any safety incidents. The vehicle operating cycle is described in text format for the general expected usage of the test vehicles. Data collection includes expected route descriptions, operating hours during a typical work day, number of days per week that the vehicle is operated, the amount of fuel and range (in miles) that are expected during a given work day and between fueling, and other information on how the vehicle is used.

The vehicle usage in service includes an analysis of how many miles each vehicle is used in service per day and month. The usage or duty cycle is described by the average speed, route assignments, and terrain information. GPS tracking information may also be used to understand speed and acceleration in service. The fuel cell buses may already electronically monitor some of the information needed to describe the in-service duty cycle of the vehicles. In those cases, the manufacturers and site may be asked to participate in collecting that onboard data, if available. Data are also to be collected for number of hours for fuel cell and vehicle operation for each fuel cell bus.

The other in-service data needed for this category include records of each fueling (amount of fuel, odometer reading, hour reading, date, and time required for fueling) and fuel prices (each fuel, each time the fuel price changes – price and date). Information is recorded from each engine oil addition (amount of oil, odometer reading, and date) and oil changes (amount of oil, odometer reading, and date are all collected as part of a maintenance action, usually preventive maintenance). Engine oil prices are also collected (the oil price and date each time the oil is changed). Details on the amounts of other fluids used in the fuel cell buses, such as de-ionized water, are also collected.

In the data collection, an odometer reading is usually replaced with a hubodometer reading. A hubodometer is a device placed on the wheel hub, usually the rear wheel facing the fueling side of the vehicle, which measures the revolutions of the wheel and converts those revolutions into miles traveled. Most fleets use a hubodometer to track usage in miles. This reading is usually the only measurement of vehicle usage in miles traveled used by the evaluation site.

Maintenance data includes each repair action—such as preventive maintenance, unscheduled maintenance, and road calls (date of repair, labor hours, number of days out of service, odometer reading, parts replaced, parts cost, and descriptions of problem reported and actual repair performed). Engine oil changes are included as part of preventive maintenance. The maintenance data are used to estimate operating costs (along with fuel and engine oil consumption costs) and for reliability and durability calculations.

Data on warranty repairs are collected in much the same way as data on normal maintenance actions. However, warranty cost data are not included in the operating cost calculation. Labor costs may be included depending on the mechanic who did the work (operator or manufacturer) and whether those hours were reimbursed under the warranty agreement. The warranty maintenance information is collected primarily for an indication of reliability and durability.

All roadcalls are marked in the maintenance data collected. A roadcall is defined as a maintenance call that occurs while the bus is in service and requires that the bus be replaced on the route or the repair results in a significant delay in returning to service. In this evaluation, each maintenance call in service is also tracked, even if a roadcall is not required.

Any safety incidents occurring with the vehicles, the fueling station, or in the maintenance facilities is described, including the nature of the incident or action and the vehicles or facilities involved. NREL also describes any changes in procedures or hardware required to ensure that the incident is not repeated.

Facility Operating Costs

During the evaluation, researchers collect the costs of operating the hydrogen fueling infrastructure and the safety systems for the facilities. For the hydrogen fueling infrastructure, the intent is to record all maintenance activities including descriptions of problems, labor used, parts used, costs, and any configuration changes after the initial installation. For the other facilities, the cost of maintaining the safety systems for hydrogen and fuel cells is tracked. This includes similar data items such as fueling infrastructure costs.

Facility Descriptions and Capital Costs

At the beginning of the data collection period, the team collects details on the fleet's operations including a description of facilities and services, capital costs, maintenance and fueling practices, and any other information needed to get a complete understanding of the fleet's experience with the fuel cell buses. Descriptions of facilities include fueling, maintenance, and vehicle storage facilities that may be associated with the vehicles in the study. These descriptions include systems in each facility that may be affected by the use of hydrogen and fuel cells or may affect how the vehicles are used. Data on capital costs include costs for any facility modifications that are required for safe operation of fuel cell buses. The vehicle capital costs include the costs for new vehicles and propulsion systems.

Implementation Experience

The experiences of a transit agency in implementing any new technology are an important part of fully understanding the current status of that technology. The fleet implementation experience is collected to document the background work needed for successful implementation of fuel cell buses, as well as some of the potential pitfalls and lessons learned. The types of information collected in support of this activity include:

- Documentation of the history that led to the fleet's decision to purchase fuel cell buses, i.e., the important influences (economic, environmental, legislative), their past experience with alternative fuels, incentives for advanced technology vehicles or disincentives for the other solutions that helped form their decision
- Documentation/understanding of where these vehicles fall in terms of current technology development, i.e., how is this technology different from other advanced technology vehicles on the market; why did the fleet select this particular vehicle technology?
- General information related to the manufacturers' commercialization efforts, i.e., how did they get to this point, where are they going from here, etc.?
- Description of the vehicles' duty service and overall fleet characteristics. What is the service application for the advanced technology vehicles and why was it chosen, what performance requirements are related to this application?
- Roles of important supporting organizations such as vehicle manufacturer and supplier, fuel suppliers, federal, state, or local government agencies.
- Specific incentives and regulations supporting the decision to purchase fuel cell buses.
- The driver, fleet personnel, and customer perceptions of the new technology vehicles. Does the fleet plan any special education activities for fleet personnel? Is the fleet planning any special public relations activities related to these vehicles?
- A description of the training implementation strategy including all employee orientation, operations and maintenance personnel, and the costs of this training. There is also an interest in plans to integrate this training into standard training programs.

- Special fleet needs such as mechanic, driver, or technician training requirements, special equipment, and safety issues. How did the fleet address these needs and were these approaches successful?
- What it took to bring these vehicles into revenue service, i.e., were there any technical/non-technical hurdles that had to be overcome?

Evaluation Results and Reporting

Each evaluation site completes similar results reporting, except for differences between the full and partial evaluations.

- **Monthly analysis results** – each site receives a monthly presentation of selected results for its bus operation. These results provide an opportunity for the project partners to review data and results to date and respond with changes. For DOE and FTA as well as other government partners, this is an opportunity to keep up to date with current results. Monthly reports are completed by the end of the following month. These data are not shared with government partners outside of DOE and FTA until after the transit agency and manufacturer partners have given approval. This report is for the internal project team only, and not for public dissemination.
- **Project Description Handout** – a two-page fact sheet is developed for each evaluation site soon after the fuel cell buses are placed into service. This fact sheet provides a description of the transit agency's program and the buses being tested. The primary purpose of this fact sheet is to provide the project partners with a response to requests for information about their project.
- **Evaluation Results Reports** – two to four evaluation results reports are planned for each site, depending on the type of evaluation (full or partial) and the duration of the evaluation (six, 12, or 24 months of operation). These reports provide a summary of the transit agency's program, descriptions of the vehicles and infrastructure, and document the implementation experience and operation at the site. These reports are typically planned at 6-8 month increments and also show results from the start of operation with a focus on the newest data in the report.

Results from the projects also are reported at appropriate conferences such as the American Public Transportation Association (APTA) Bus conference, the National Hydrogen Association Conference, the Fuel Cell Seminar, and the DOE Annual Program Review. Participation in a conference typically requires the production of a formal presentation.

Each report, including the data, is made available for review and editing by the respective agency and its project partners before results are published. We expect that each site and their project partners will be involved with the presentation and publishing of the results.

Reports are posted on the following Web pages:

http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/ca_transit_agencies.html

http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html

Detailed Data Collection and Evaluation

NREL is working toward collecting additional categories of data outside of the established evaluation protocol described above. This includes data on the fuel cell vehicles and hydrogen infrastructure that may be considered proprietary by the manufacturers. These data are intended to complement the light-duty DOE Validation Project by adding detailed data on fuel cells and systems in a heavy vehicle application.

Detailed Fuel Cell System Technology Data Collection and Analysis

NREL is working with the various fuel cell bus manufacturers to collect detailed data on the fuel cell systems. The additional data needed for DOE include:

- On-road performance data on the propulsion system and components, such as voltage and current on the fuel cell stack, traction motor, energy storage, power control system, and parasitic loads
- Vehicle performance test results (if available) such as track testing (acceleration, range, top speed, cold start time, etc.) and fuel cell system efficiency
- Fuel cell stack durability data such as total hours at end of life and cause of failure

These items are considered proprietary by each manufacturer, and NREL will take appropriate measures to protect that data. NREL will follow data protection procedures similar to those developed for the light-duty DOE Validation Project.

The approach to collecting sensitive data is quite different from collecting the data described in Table 4. The primary contact for this effort must be the manufacturers (rather than the fleet operators), because collecting second-by-second data on the fuel cell and system components requires their cooperation. If necessary, NREL will formalize an agreement with each bus/fuel cell system manufacturer to collect this additional detailed data. Any confidentiality agreements would apply specifically to this detailed data.

As part of the light-duty DOE Validation Project, NREL has developed some advanced tools to automate the data processing and analysis of every single trip that each fleet vehicle drives. These tools are used to process any detailed data that are collected on the fuel cell buses. As with the light-duty DOE Validation Project, NREL may share processed data on a specific vehicle system with the originating manufacturer to obtain feedback and a review of results. Only approved composite data products that mask the identity of individual participants will be shared publicly. If the data collected from the different manufacturer teams are not sufficient to adequately mask the identity of individual data points, no composite data products can be published.

Detailed Study of Hydrogen Infrastructure Performance and Operation

DOE/NREL are also interested in collecting more detailed data on hydrogen fueling infrastructure. Understanding the entire picture for a fleet integrating fuel cell buses into their operation is not possible without taking infrastructure operational costs into account. Collecting this detailed data on hydrogen production, delivery, and use also supplements the DOE

Validation Project, by adding to the existing data on fueling sites. The fuel providers at each site need to be willing to participate in this effort. Data collected for this effort include:

- Hydrogen production efficiency
- Hydrogen quality
- Hydrogen production cost
- Infrastructure maintenance
- Infrastructure safety incidents

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