Fleet Test & Evaluation

National Renewable Energy Laboratory
U.S. Department of Energy

General Evaluation Plan

Fleet Test & Evaluation Projects

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Background

The National Renewable Energy Laboratory (NREL) Fleet Test & Evaluation (FT&E) team was formed to accomplish the objectives of U.S. Department of Energy's (DOE) current and emerging programs. Composed of NREL and Battelle personnel, the team supports vehicle test projects initiated by DOE's Office of FreedomCAR and Vehicle Technologies (OFCVT) and the Office of Hydrogen, Fuel Cells, and Infrastructure Technologies (OHFCIT).

FT&E projects help fleet owners and operators facilitate purchase decisions by providing them with comprehensive laboratory and fleet test data on viable alternative fuel vehicles (AFVs) and advanced technology vehicles (ATVs). ATVs include hybrid electric and fuel cell vehicles.

NREL has evaluated many light- and heavy-duty alternative fuel fleets of trucks and transit buses. FT&E projects are generally intended to follow the data collection protocol developed for evaluations previously performed at NREL. However, the protocol has been enhanced. For example, the vehicle technology being evaluated is no longer required to be a commercial product. The new evaluation projects now focus on the commercialization process and progress—in other words, a technology assessment. One extremely important change from previous evaluations is control vehicles for comparison, which are no longer required. Some of the new technology vehicles will not have comparable vehicles for comparison. This places more focus on understanding the duty cycle (actual use pattern) of the vehicles' intended use. The reporting is intended to be more responsive, faster, and compact for quick access, but the numbers will still be available for those who wish to have them.

NREL and Battelle are working together to establish and execute the evaluations, which include interfacing directly with the fleets and other project partners; collecting, processing, and evaluating the data gathered from the vehicle operators; and providing reports on these activities. FT&E projects at NREL have been designed to include six to nine evaluation sites or fleets over the next four years. Two or three fleets per year are expected to be evaluated in parallel. Each site is planned to have as many as 12 months of data collected from study and control vehicles (if available) for an evaluation of cost, operations, and performance. Final reports of the results are planned for publication. The vehicles to be evaluated may include those using alternative fuels, such as compressed or liquefied natural gas, and advanced technology propulsion systems, such as hybrid electric and fuel cell.

The objective of DOE/NREL projects is to provide comprehensive, unbiased evaluations of currently available advanced technologies. These evaluations include economic, technical, emissions, and safety factors. Data are collected on the operation, maintenance, performance, and, sometimes, the emissions characteristics of advanced technology fleets and comparable diesel fleets (if available) operating at the same site. Operators considering the use of these ATVs comprise the primary intended audience for this information.

Selection of Technology, Site, and Type of Evaluation

Many U.S. fleet sites are considering the use and implementation of new technology vehicles—all of which are considered potential candidates for FT&E projects. Although the team would like to test all available technologies, resources are limited, so only a few sites can be selected. Participants are selected by the type of technologies they offer, the operational characteristics of the sites they have, and the scope of evaluation strategies the FT&E team have developed.

To conserve project resources, selected sites may be designated "potential evaluation sites," but activities will not start until the test vehicles are delivered and put into operation. Experience shows that the delivery of ATVs can be delayed six to 12 months from the original expected delivery date. Other potential delays in the startup of vehicle operation and testing arise from problems with initial vehicle reliability and support infrastructure availability at the site.

Technology

ATV technologies being considered for these evaluation projects include:

- Those using alternative fuel such as natural gas (liquefied and compressed), propane (single fuel or dual-fuel), biodiesel, E-diesel, and hydrogen or hydrogen/natural gas mixtures.
- Hybrid electric with various power plants such as internal combustion engine, turbine, or fuel cell using diesel, gasoline, hydrogen or other alternative fuel.
- Clean diesel fuel formulations with aftertreatment devices.
- Other technologies as they emerge and start testing.

The point at which vehicle technologies become candidates for FT&E evaluation projects depends on the status of a technology's development. New vehicle propulsion technologies (or any new technology) are usually introduced in six phases:

1. Concept development.
2. Technology research and development.
3. Vehicle development, design, and integration.
4. Manufacturing and assembly integration.
5. Vehicle demonstration, testing, and production.
6. Deployment, marketing, and support.

These evaluation projects will most likely begin with vehicle propulsion technologies that are in phases 5 or 6. The most important vehicle propulsion technologies for consideration are those that appear to have a significant chance of commercialization.

Site

Since resources are limited for evaluation projects, the FT&E team looks for certain criteria when considering sites. These criteria, listed below, are not rigid, but suggest a framework for selecting sites.

- Vehicles must be medium- or heavy-duty trucks or buses (however, automobiles and light-duty trucks are sometimes also considered).
- Test vehicles must run on alternative fuels or advanced technology propulsion systems, such as natural gas, propane, electricity, hybrid electric, turbine, fuel cell, fly wheel, and clean diesel with aftertreatment.

- Engines must be emissions-certified technology (or nearing certification).
- Test and control vehicles must be used in similar duty cycle (if control vehicles are available).
- Host site must have good record keeping.
- Host site must be willing to allow and support vehicle emissions testing (if required/needed).
- Reliable, high-quality fuel supply must be available.
- Host site must be interested in and motivated to participate in the evaluation program.

Additionally:

- Engines from original equipment manufacturers are preferred.
- Vehicles and propulsion system combinations offered as a package from a reputable manufacturer are preferred.
- A minimum of five alternative fuel or advanced technology propulsion system vehicles are preferred.
- Control vehicles similar to the test vehicles in age and use (duty cycle) are preferred.

Types of Evaluations

The commercialization of advanced vehicle propulsion systems is assumed to require three to five years once the vehicles are in the prototype stage (phase 5). The evaluation strategy has been designed to reflect the point at which the vehicle propulsion technology has progressed toward commercialization at the time of selection. There are three types of evaluation strategies–early, limited, and full. Reporting strategies will be slightly different depending on the type of evaluation.

- **Early Demonstration**: This type of evaluation would occur at a site with very early implementation of new technology in limited numbers. This demonstration would be with prototype vehicles. Future evaluation activities may be desired at a later date but only cursory data collection is planned at this time.

- **Limited Evaluation**: This type of evaluation would be focused on an on-road prototype demonstration beyond the one or two vehicle demonstration. These vehicles may be on their way to becoming commercial products. The information collected here would include vehicle usage (mileage and duty cycle), implementation experience, fuel economy, infrastructure implementation experience, and description of maintenance/performance issues and progress. Future evaluation activities may be desired at a later date. The limited evaluation might be four to six months for the data collection period.

- **Full Evaluation**: This type of evaluation would be concentrated on commercial or nearly commercial vehicles. The evaluation would include at least five of the advanced technology propulsion vehicles and possibly three or more conventional propulsion vehicles matched in operation and vehicle type (as close as possible and if available). The data collection period would include at least 12 months of operation and maintenance.

Data Collection and Reporting

Once sites are identified, the first challenge is to find suitable conventional vehicles to use as a baseline (control vehicles). Many advanced propulsion technologies that are being considered may not have vehicles suitable for comparison. In such cases, special efforts will be made to completely describe the duty cycle (or use pattern) of the ATVs. The second challenge will be to collect, analyze, and report the evaluation data as quickly as possible. For these projects, the evaluation strategy will be adjusted based on the progress the technology has made toward commercialization. In the early stages of development, the evaluation strategy will be cursory and provide only general technical information. As the technology advances, the evaluation will be more detailed. For the three designated types of evaluations, the data collection strategies are summarized below:

- **Early Demonstration**: This will include cursory data collection focused on vehicle system descriptions and how the implementation and operation are progressing. The time required is as long as three months, including the report.

- **Limited Evaluation**: This will include vehicle system descriptions, the implementation process, duty cycle, and four to six months of operations data, including fueling and maintenance. The time required is nine to 12 months, including reports.

- **Full Evaluation**: This will include vehicle system descriptions, the implementation process, duty cycle, and at least 12 months of operations data, including fueling and maintenance. The time required is 15 to 18 months, including reports.

The strategy for all potential data collection is planned to be consistent with the established NREL protocol (see Table 1). The highest priority activities at the beginning of the evaluation are to gain the confidence of the fleet and establish efficient data collection procedures. For each test fleet, the team will collect the appropriate data items as defined by the three types of evaluations and the data items in Table 1. The data collection strategy for the implementation experience and reporting are described after the descriptions of the data items from Table 1.

Vehicle Specifications and Performance Expectations

This group of data collection items includes vehicle system descriptions and vehicle performance expectations (see Appendix A for specific information). The vehicle systems are described at the beginning of the data collection; changes may be required if major systems are altered. For these evaluations, the descriptions consist of specification information for the ATVs and control vehicles (if available and part of the evaluation). The specifications are intended to describe the main systems of the vehicle propulsion system as well as accessory equipment. This information documents the equipment similarity of the evaluation vehicles and describes specific equipment that may affect the performance of the vehicles' fuel economy and overall reliability. Some future changes to the vehicle system description data collection form are expected based on the ATV systems encountered.

Table 1. 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	Shown in Appendix A
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, more detailed information if available
Vehicle Usage in Service	At each time usage is measured	Odometer reading
		GPS data (if needed)
Fuel Consumption	Each time a vehicle is fueled	Amount of fuel
		Odometer reading
		Date
	Each time the fuel price changes at a given site	Price per unit
Engine Oil Consumption and Changes	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, road call, 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
Safety Incidents	Each occurrence	Description of each accident or incident involving the test or control vehicles, including collisions, and maintenance and fueling incidents
Emissions Testing		
Emissions Testing	Once during the data collection period	As required
Emissions Certification Descriptions	As needed	Emissions certification data
Facility and Capital Costs		
Facility Descriptions	Start of data collection and as needed if and when changes are made	Refueling 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 fleet's specific performance expectations for the ATVs are collected and evaluated according to those expectations. Other information may be available from the fleet, the vehicle manufacturer, and the system integrator that allow for a direct assessment of how well these vehicles meet the fleet's performance expectations. The types of information that may be collected include:

- The fleet's vehicle specifications, with an emphasis on performance requirements such as length, weight, top speed, gradeability, acceleration, range, retardation (regenerative braking), noise, durability (e.g., vehicle life, battery pack life), emissions, fuel economy, special requirements such as low floor, and other useful available information.

- Documented interviews to define how the fleets typically measure vehicle performance when implementing a new technology.

- Available performance information (e.g., first article acceptance testing data, independent fleet evaluations).

- Other pertinent data.

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 used), maintenance, and 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, average speeds, typical operating hours, number of days per week the vehicle is operated, and the amount of fuel and range (in miles) expected during a given work day and between fuelings.

The vehicle usage in service includes an analysis for each vehicle of how many miles it is used in service per day and month. If there is no baseline to compare the advanced vehicle technologies, more attention is given to the vehicle usage or duty cycle, which is described by the average speed, route assignments, terrain information, and possibly global positioning system tracking information to understand speed and acceleration in service. These ATVs may already electronically monitor some of the information needed to describe their in-service duty cycle. In those cases, the manufacturers and site are asked to help collect the onboard data, if available.

The other in-service data needed for this category include data collection at each fuel fill (amount of fuel, odometer reading, and date) and fuel prices (each fuel, each time the fuel price changes – price and date). Data collection also includes engine oil consumption (if an internal combustion engine is used) and engine oil changes. 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 as part of a maintenance action). Engine oil prices are also to be collected (the oil price and date each time it changes).

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) that measures the revolutions of the wheel and converts those revolutions into miles traveled. The hubodometer reading is usually the only measurement of vehicle usage in miles traveled used by the site.

Maintenance data include 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 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.

For the full vehicle evaluations, data on warranty repairs are collected in a similar manner as data on normal maintenance actions. However, the cost data are not included in the operating cost calculation. Labor costs may be included depending on the mechanic (operator or manufacturer) and whether those hours were reimbursed under the warranty agreement. (Warranty maintenance information is collected primarily for an indication of reliability and durability.)

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

Emissions Testing

Emissions testing may be available for these projects. The zero emissions technologies that may be evaluated will not need chassis dynamometer testing; however, some testing of the control vehicles may be desired. In the case of zero emissions technologies, documenting the life cycle emissions of the vehicle based on the fuel used (such as hydrogen) may be desired. Any available emissions certification data and information are collected for the test vehicles.

For sites where chassis dynamometer emissions testing may be considered, West Virginia University (WVU) will generally perform that testing. The WVU mobile laboratory can measure particulate matter (PM), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_X), methane (CH_4), methanol (CH_3OH), and formaldehyde (HCHO). Other measurements can be added. All results from emissions testing are available to the participating site as soon as the information is available. To reduce disruptions, WVU contacts the host site to schedule testing and to get permission to use approximately 10,000 square feet of space at the site or at a nearby location. If more convenient or already planned by the site, emissions testing results from other testing laboratories may be used.

Facility and Capital Costs

At the beginning of the data collection period, the team will collect 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 ATVs. Descriptions include refueling, maintenance, and vehicle storage facilities, and systems that may be affected by the use of the advanced technologies or that may affect how the vehicles are used. Data on capital costs include those for facility modifications required to operate ATVs. The vehicle capital costs include the costs for new vehicles and engines.

Implementation Experience

Collecting information on a fleet’s implementation experience documents the background work needed to successfully implement AFVs and ATVs, as well as 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 AFVs and ATVs—the important influences (economic, environmental, legislative); their past experience with alternative fuels; incentives for AFVs and ATVs; or disincentives for the other solutions that helped form a decision.

- Documentation and understanding of where these vehicles fall in terms of current technology development: How is this technology different from other AFVs or ATVs on the market? Why did the fleet select this particular vehicle technology?

- General information related to the manufacturers' commercialization efforts: How did they get to this point? Where are they going from here?

- Description of the vehicles' duty service and overall fleet characteristics: What is the service application for the AFVs and ATVs, and why was it chosen? What performance requirements are related to this application?

- Roles of important supporting organizations such as vehicle manufacturers and suppliers; fuel suppliers; and federal, state, and local government agencies.

- Specific incentives and regulations supporting the decision to purchase AFVs and ATVs.

- 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 strategy, including all employee orientation, operations and maintenance personnel, and the costs of this training; also interested in plans to integrate this training into standard training programs.

- Special fleet needs such as mechanic, driver, or technician training requirements, special equipment, safety issues: How did the fleet address these needs? Were these approaches successful?

- What did it take to bring these vehicles into revenue service? Were there technical or nontechnical hurdles that had to be overcome?

Reporting

Three types of reports will be prepared for evaluation sites:

- **Advanced Technology Vehicles in Service:** This is a two-page handout that describes the site and its ATV program. A description of the advanced vehicle technology and a summary of the vehicle systems are included. Appendices B and C provide examples of this type of report from the New York City Transit and Tempe Transportation Division hybrid electric bus programs. The documents are produced as soon as possible after at least one ATV is on site and ready for operation. For examples, see Appendices B and C.

- **Early Experience and Results:** This is an eight- to 12-page report describing the results of a limited evaluation site or interim results from a full evaluation site. It includes information about the performance of the ATVs and the results of some of the evaluations of vehicle operations such as fuel economy and any maintenance issues and resolutions available. This report also includes a description of the implementation experience and provides information about the status of the technology development. The report is produced four to six months into the evaluation of the site. For an example, visit www.ott.doe.gov/otu/field_ops/pdfs/nyc_transit.pdf.

- **Full Evaluation Final Report:** This is a 16- to 24-page report describing the final results of a full evaluation site. It includes all analyses and results from the evaluation. An appendix of the final analysis results is provided on the CD-ROM attached to the back cover of the report. The final report for the site is produced some time after the 12-month data collection has been completed (15 to 18 months after the start).

Other technical papers and presentations may be produced for conferences, such as the Society of Automotive Engineers (SAE) Truck and Bus conference or American Public Transportation Association (APTA) Bus Conference. All reports and technical papers are available for review and editing by the site and others participating in the evaluation before results are published. The results of these evaluations are much stronger and useful with interest and support from the site and the manufacturers. A few technical papers covering overarching issues, such as general guidelines for implementing new technologies, are planned.

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Appendix A

Advanced Technology Vehicle Specification Form

NREL
ADVANCED TECHNOLOGY VEHICLE SPECIFICATION FORM

Operating Company	
Vehicle Number	
Vehicle Manufacturer	
Model	
Vehicle Identification Number (VIN)	
Date of Purchase	
Accumulated Mileage at Start of Operation	

Vehicle Dimensions	
Length, ft.	
Width, in.	
Height, in.	
Ground clearance, in.	
Wheel Base	
Front overhang (axle to vehicle front), in.	
Number of axles	
Number of driven axles	
Gross Vehicle Weight Rating, lb.	
Front Axle	
Rear Axle	
Total	
Curb Weight, lb.	
Front Axle	
Rear Axle	
Total	
Seated Load Weight	
Front Axle	
Rear Axle	
Total	

Passenger Seats	
Number of Passenger Seats with no Wheelchairs on Board	
Number of Wheelchair Positions	
Number of Passenger Seats with all Wheelchair Positions Occupied	
Maximum Number of Standees	
Fuel	
Type(s)	
Necessary Additives	
Hybrid Configuration	
Series or Parallel?	
Charge Sustaining or Charge Depleting?	
Multiple operating modes? (Yes/No)	
Number of operating modes	
Driver controlled or automatic?	
Regenerative Braking?	
Power Plant	
OEM or Retrofit?	
Power Plant Type (engine, turbine, fuel cell)	
Manufacturer	
Model Number	
Year of Manufacture	
2 Cycle or 4 Cycle?	
Compression Ratio	
Ignition Aids Used? (Yes/No)	
Type of Ignition Aid (Spark Plug, Glow Plug, Pilot Ignition, Other)	
EPA Certified? (Yes/No)	
CARB Certified? (Yes/No)	
Power Rating	
Max. bhp	
RPM of Max. bhp	

Max. Torque (ft. lbs.)	
RPM of Max. Torque	
Displacement (L)	
Engine Oil	
Type(s) Used	
Necessary Additives	
Oil Capacity (qts.)	
Blower? (Yes/No)	
Turbocharger? (Yes/No)	
Liquid Fuel Delivery Systems	
Mechanical or Electronic Fuel Injectors?	
Injector Manufacturer	
Injector Model Number	
Number of Fuel Filters	
Fuel Filter Manufacturer	
Fuel Filter Model	
Gaseous Fuel Delivery Systems	
Direct Injection or Fumigation?	
Throttle for Intake Air? (Yes/No)	
OEM or Retrofit?	
Power Plant Accessories	
Mechanical or Electric Drive Accessories?	
Generator	
Output at Normal Idle	
Maximum Rating	
Starter Type (Electrical/Air)?	
Manufacturer	
Model	
Hydraulic Pump	
Manufacturer	
Model	
Output (gpm @ psi)	

Heating	
Heating System Type	
Capacity, BTU/hr	
Air Conditioning	
Manufacturer	
Model	
Capacity, BTU/hr	
Air Compressor	
Manufacturer	
Model Number	
Capacity, Cubic Ft./Min.	
Drivetrain	
Transmission/Gearbox	
Manufacturer	
Model Number	
Model Year	
Manual or Automatic?	
Number of forward speeds	
Gear Ratios	
Torque conversion ratio	
Additional features	
Retarder	
Manufacturer	
Model Number	
Drive Axle	
Manufacturer	
Model Number	
Axle ratio(s)	
Tires	
Manufacturer	
Model Number	
Size	

Torque converter	
Manufacturer	
Model Number	
Type (hydraulic, other)	
Electric Propulsion Generator	
Manufacturer	
Model Number	
Type	
Nominal output power, kW	
Peak output power, kW	
Rated speed, rpm	
Rated torque, Nm or ft-lb	
Maximum current, amps	
Minimum voltage	
Electric Propulsion Energy Storage	
Energy Storage Device (battery, ultra-capacitor)	
Manufacturer	
Model Number	
Energy Storage Type	
Number of cells or modules	
Nominal pack voltage	
Total capacity, Ah	
Source (measured, manufacturer, etc.)	
Total energy, kWh	
Source (measured, manufacturer, etc.)	
Placement in vehicle (roof, under floor, rear engine compartment, etc.)	

Electric Propulsion Motor(s)	
Manufacturer	
Model Number	
Type	
Number of motors	
Total nominal power output, kW	
Total peak power output, kW	
Rated speed, rpm	
Rated torque, Nm or ft-lb	
Maximum current, amps	
Minimum voltage	
Location of motors (hub mounted, between torque coupler and final drive, etc.)	
Electric Propulsion Energy Storage On-Board Charger	
Manufacturer	
Model Number	
Type	
Power, kW	
Fuel Storage System	
Number of Tanks	
Maximum Working Pressure (Gaseous Fuels Only)	
Total Useful Amount of Fuel	
Tank Manufacturer	
Tank Model(s)	
Total Empty Weight of Tank(s)	
Safety Equipment	
Fire Detection (Y/N)?	
Manufacturer	
Model Number	
Year of Manufacture	
Sensor Type	
Number of Sensors	

Fire Suppression (Y/N)?	
Manufacturer	
Model Number	
Year of Manufacture	
Amount of Agent	
Type of Agent	
Number of Discharge Points	
Vapor Detection (Y/N)?	
Manufacturer	
Model Number	
Year of Manufacture	
Sensor Type	
Number of Sensors	
Alarm Threshold (% LEL)	
Other Attributes or Features (Wheelchair lifts, wheelchair position, bicycle racks, any items that make this bus different from the other test or control buses)	
Emission Control	
Catalytic Converter (Y/N)?	
Manufacturer	
Model Number	
Type	
Length of pipe from engine to catalyst	
Diesel Particulate Control Device (Y/N)?	
Manufacturer	
Model Number	
Type	
Special Requirements (Low sulfur diesel, specific regeneration temperatures, etc.)	
Power Plant Emissions Certification Data	

Additional Information

Appendix B

Advanced Technology Vehicles in Service: New York City Transit Diesel Hybrid Electric Buses

Advanced Technology Vehicles in Service

Field Operations Program
U.S. Department of Energy
Office of Technology Utilization

New York City Transit

Diesel Hybrid Electric Buses

NEW YORK CITY TRANSIT is the largest public transportation system in the United States. The 235 bus routes carry more than 2 million passengers daily. The agency has 4,489 buses operating from 18 depots, with an average of 1,871 miles of routes each day. Since 1992, NYC Transit has tested and evaluated a variety of clean fuel buses in revenue service. NYC Transit introduces new bus technologies through a three-step process of demonstrating the new technology by (1) operating a single bus prototype in non-revenue service, (2) operating a small pilot fleet of buses in revenue service, and then (3) expanding the fleet for full-scale implementation. The department now has 221 buses powered by compressed natural gas (CNG) and a pilot fleet of 10 Orion model VI diesel hybrid electric buses, which started testing in revenue service in 1998.

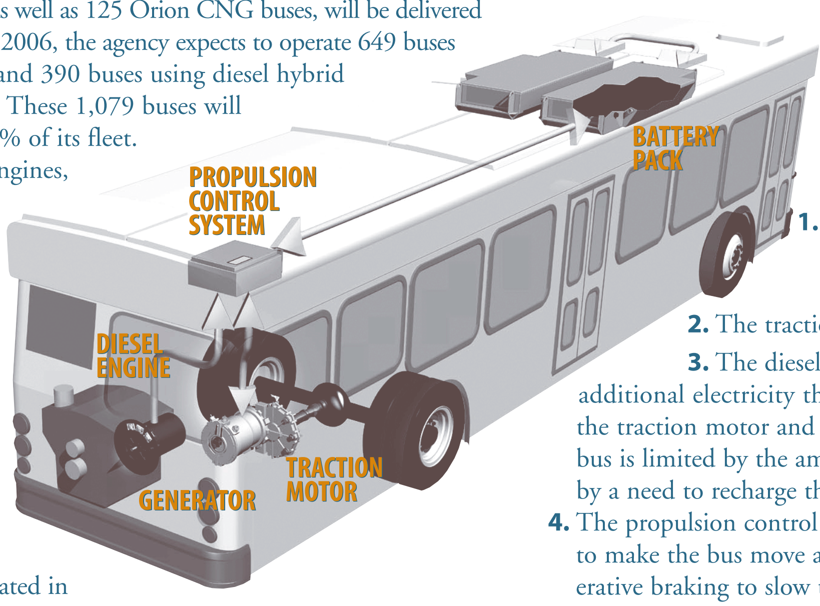
THESE CLEAN FUEL BUSES represent about 5% of NYC Transit's fleet. By early 2002, 125 more Orion diesel hybrid electric buses (model VII), as well as 125 Orion CNG buses, will be delivered to NYC Transit. By 2006, the agency expects to operate 649 buses powered by CNG and 390 buses using diesel hybrid electric propulsion. These 1,079 buses will represent nearly 24% of its fleet. All the diesel bus engines, including the hybrid buses, use low-sulfur diesel fuel (less than 30 parts per million sulfur content).

THE PLAN to more aggressively convert NYC Transit's fleet to cleaner fuels accelerated in early 2000, when New York Governor George Pataki agreed to a capital spending plan for the 2000 to 2004 period. This plan provides funding for NYC Transit to

- Purchase additional CNG and hybrid buses.
- Use low-sulfur diesel fuel for the entire diesel fleet.
- Retrofit diesel buses with catalytic diesel particulate filters.
- Construct and renovate several depots and shops for the use of CNG buses.

THE NEW DIESEL HYBRID ELECTRIC BUSES are very different from any other buses in the fleet. The diesel engine is smaller and operates at a more constant speed, so it uses less fuel and produces a fraction of the emissions of a standard diesel engine while providing faster and smoother acceleration. The diesel engine uses low-sulfur fuel, and an electric motor drives the wheels.

THE PILOT FLEET OF 10 HYBRID ELECTRIC BUSES now operates from the Manhattanville Depot. Plans include splitting the 10 hybrid electric buses currently in the fleet and the 125 hybrid electric buses on order between two operating locations: Mother Clara Hale Depot and Queens Village Depot. Orion provides the chassis and assembles the buses. They are equipped with BAE SYSTEMS' HybriDrive™ propulsion system and engines manufactured by Detroit Diesel Corporation (for the pilot fleet) and Cummins Engine Company (for the 125 hybrid electric buses on order). NYC Transit chose the hybrid electric buses after a prototype project demonstrated that they have the potential to use less fuel and have lower toxic exhaust emissions.



The HybriDrive™ propulsion system works like this (see graphic*):

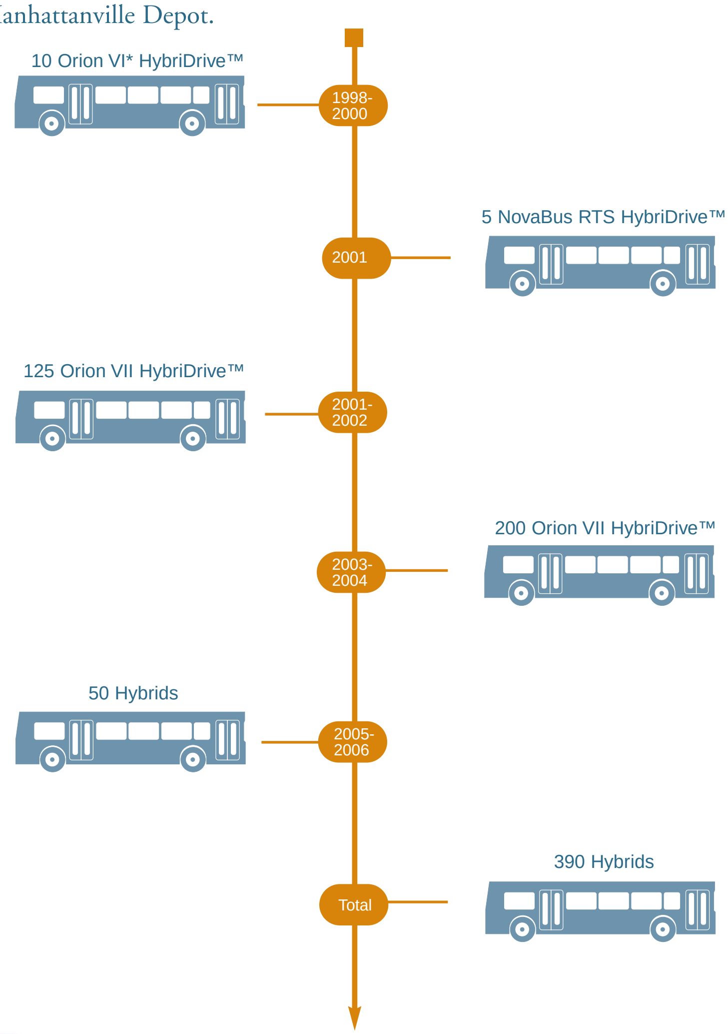
1. Batteries provide electricity to a traction motor through the propulsion control system.
2. The traction motor drives the wheels.
3. The diesel engine powers a generator that provides additional electricity through the propulsion control system to the traction motor and recharges the batteries. The range of the bus is limited by the amount of diesel fuel stored onboard, not by a need to recharge the batteries.
4. The propulsion control system manages the flow of electricity to make the bus move as the driver commands, and uses regenerative braking to slow the bus and simultaneously recharge the batteries. (Hybrid buses also have conventional brakes.)
5. It's an integrated system. During acceleration, energy flows from the generator and battery pack to the traction motor; during cruise mode, energy flows from the generator to recharge the batteries; and during braking, the traction motor acts as a generator, sending energy to the batteries for recharging.
6. The smaller diesel engine, operating at a more constant speed and with better overall fuel economy, can significantly reduce overall bus emissions.

**Bus/propulsion diagram courtesy of BAE SYSTEMS.*

The propulsion system may reduce maintenance needs in three ways. Hybrid buses are propelled by an electric motor, so there is no traditional transmission, only a gearbox. (A traditional transmission is a major maintenance item for most stop-and-go vehicles.) The regenerative braking system helps slow the vehicle, while producing additional electric power and reducing brake wear. The diesel engine operates at a more constant speed in revolutions per minute, which may reduce maintenance needs.

The pilot fleet of 10 diesel hybrid electric buses is currently participating in a year-long evaluation project being conducted by the U.S. Department of Energy's Office of Technology Utilization and Office of Heavy Vehicle Technologies. Information is being collected on fueling, maintenance, performance, and emissions of the diesel hybrid electric buses. The performance of the initial fleet of hybrid buses will be compared with results from seven NovaBUS conventional diesel-powered buses. Both fleets are based at the Manhattanville Depot.

Buses	**10 Orion VI**
- Model Year	1998, 1999
- Length/Width/Height	- 40 ft /102 in./125 in.
- GVWR/Curb Weight	- 41, 640/31, 840 lb
- Seats/Standees	- 31/32
- Service	- Manhattan
Engine	**DDC S 30 Diesel**
- Rating	- 230 bhp@2300 rpm
	- 605 ft-lb@1500 rpm
- Calibration	- MY 2000
Diesel Fuel Storage	**100 gallons**
Hybrid Propulsion	**BAE SYSTEMS HybriDrive™ Series**
- Traction Generator	- 170 kW@2000 rpm
- Traction Motor	- 187 kW 346 Vrms@500 Hz
- Traction Batteries	Sealed lead acid 2 Roof mounted battery tubs 23 (12V) batteries in each tub 580V Total
- Regenerative Braking	Yes
Emissions Equipment	NETT Technologies catalyzed particulate filters



*Fleet being evaluated by DOE/NREL

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Web Sites
NYCT: www.mta.nyc.ny.us/nyct • BAE SYSTEMS: www.hybridrive.com • DOE/FOP: www.ott.doe.gov/otu/field_ops

Appendix C

Advanced Technology Vehicles in Service:
Tempe Transportation Division LNG Turbine Hybrid Electric Buses

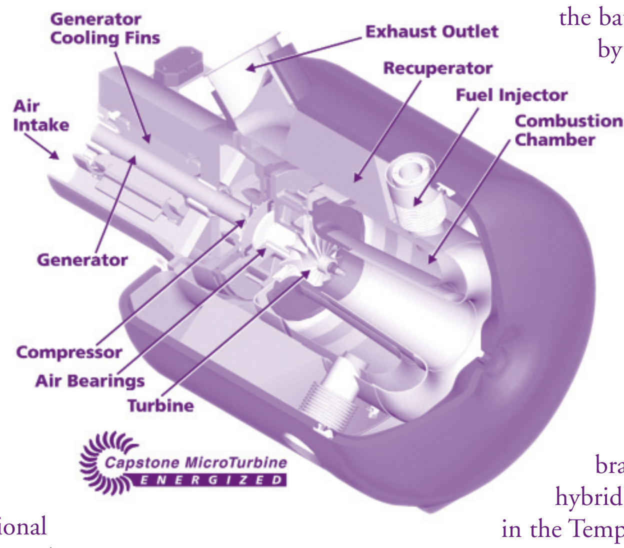
LNG Turbine Hybrid Electric Buses

TEMPE, ARIZ.'S TRANSPORTATION PLANNING AND TRANSIT DIVISION, also known as Tempe in Motion (TIM), purchased the first fleet of buses in the world that uses a new engine system fueled by electricity and liquefied natural gas (LNG). The Transportation Planning and Transit Division is responsible for long-range planning and the implementation of alternative transportation modes. The new LNG turbine hybrid electric buses are quieter and produce oxides of nitrogen at a level 70% cleaner than the U.S. Environmental Protection Agency's year 2004 requirements.

THE NEW TURBINE HYBRID ELECTRIC BUSES are part of Tempe's Free Local Area Shuttle (FLASH) service, which is funded by the city and the Federal Transit Administration, and connects neighborhoods with major destinations in Tempe (i.e., Arizona State University and downtown Tempe neighborhoods). The neighborhood shuttle operates 13 hours a day and runs every 15 minutes, seven days a week.

Tempe's FLASH service also connects with the Valley Metro, which is the regional fixed route bus service. Fixed route buses serve the Phoenix metropolitan area and will eventually connect to the new light rail system. The Valley Metro service area covers 183 square miles and carries about 31 million riders annually. In Tempe, more than 4.5 million riders used the fixed route bus system in calendar year 2000, including FLASH routes. Tempe's FLASH buses are operated and maintained under contract with ATC-Tempe.

ADVANCED VEHICLE SYSTEMS (AVS), INC., of Chattanooga, Tenn., manufactures the hybrid electric buses (AVS-22), which have advanced sealed-gel, lead-acid batteries and an on-board battery charging system. These buses are 22 feet long, 102 inches wide, and have a kneeling position of approximately 11 inches above ground. The buses have 22 passenger seats, one wheelchair position, and aisle room for 12 standing passengers. The AVS hybrid electric buses in Tempe are equipped with a Direct Drive Propulsion System developed by AVS. The hybrid system is monitored and controlled by the Battery Control Unit (BCU), manufactured by PEI Electronics, Inc., of Huntsville, Ala. The BCU controls the thermal management systems and power demand for the Capstone MicroTurbine™ to regulate battery environment, equalization, and state of charge (SOC). Thermal management is provided through insulated battery boxes and forced-air cooling systems for the batteries and electric control systems, which were designed for providing optimum performance.



A MICROTURBINE manufactured by Capstone Turbine Corp. of Chatsworth, Calif., recharges the batteries. The microturbine is fueled by LNG and produces electricity to charge the batteries via an integral generator (see diagram). This system has just one moving part and uses no lubricants, no coolants, and has no gearbox. This design is compact, lightweight, and requires minimal maintenance. The propulsion system incorporates regenerative braking to slow the vehicle while producing additional power and reducing brake wear. The range of the AVS hybrid electric buses is 250 to 300 miles in the Tempe service environment.

At the end of each operating day, the hybrid buses are fueled and washed. The microturbine is left on until the batteries are at 80% SOC. The buses are then plugged into the electrical grid system to equalize the batteries for extended battery life and to bring the batteries to 100% SOC for the next operating day.

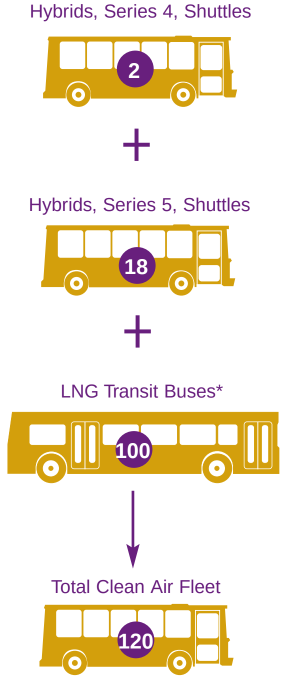
As of December 2001, the City of Tempe had two AVS Series 4 and one AVS Series 5 hybrid electric buses in its fleet. AVS will deliver the remaining 17 Series 5 hybrid buses to Tempe between December 2001 and April 2002, bringing the fleet's total number of hybrid buses to 20. Tempe opted for the Series 5 for most of its order (18 of 20 buses) because a more robust (heavier-duty) front axle and braking system will better meet its requirements of operation. The new LNG turbine hybrid electric buses will share the fueling station with Tempe's clean burning fleet, which consists of 100 LNG buses.

The fleet of hybrid electric buses will participate in an evaluation project conducted by the U.S. Department of Energy's (DOE) Field Operations Program. Information will be collected on operation, maintenance, performance, and emissions to provide comprehensive, unbiased evaluations of currently available advanced technology. NREL's Fleet Test and Evaluation Team supports the Field Operations Program in evaluating fleets of alternative fuel trucks and buses, including New York City's hybrid electric transit buses. For more information, visit www.ott.doe.gov/otu/field_ops.

Buses	AVS-22 Series 5
Model Years	2001, 2002
Length/Width/Height	22 ft /102 in./107 in.
GVWR/Curb Weight	27,000/19,050 lbs.
Seats/Standees	22/12
Service	Tempe, Ariz.
Turbine-Generator	**Capstone Model 330 MicroTurbine™, Natural Gas**
Rating	30 kW, 250V-700V DC
LNG Fuel Storage	71 gallons
Hybrid Propulsion	**AVS Direct Drive Propulsion System**
Traction Motor	2-AC55 Solectria wheel mounted
Traction Batteries	2 tubs, 24 cells each, sealed gel lead acid
Regenerative Braking	Yes
Emissions Results *	**Natural Gas, No Catalyst**
NO_x	0.26 g/bhp-hr
HC	0.42 g/bhp-hr
CO	0.41 g/bhp-hr
PM	0.004 g/bhp-hr

* Actual emissions results certified by the California Air Resources Board.

Tempe's Clean Air Fleet



* As of the end of 2001


PIX 10900

Tempe FLASH bus


PIX 10832

LNG fueling station


PIX 10830

ATC-Tempe facility

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Web Sites
Tempe Transportation Planning and Transit Division: www.tempe.gov/tim • Advanced Vehicle Systems, Inc.: www.avsbus.com • DOE/FOP: www.ott.doe.gov/otu/field_ops
Capstone Turbine: www.microturbine.com/hev

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