Advanced Vehicle Testing Activity

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# Challenges and Experiences with Electric Propulsion Transit Buses in the United States

TECHNICAL REPORT

Leslie Eudy, National Renewable Energy Laboratory (NREL)
Matthew Gifford, Battelle

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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## Fleet Test & Evaluation Team

The Fleet Test & Evaluation (FT&E) Team at the National Renewable Energy Laboratory (NREL) was formed to accomplish the objectives of current and emerging programs at the U.S. Department of Energy (DOE). The team consists of personnel from NREL and Battelle and supports DOE's FreedomCAR and Vehicle Technologies (FCVT) and Hydrogen, Fuel Cells, and Infrastructure Technologies (HFC&IT) Programs.

FT&E projects at NREL include six to nine evaluation sites/fleets over the next four years; two or three fleets will be evaluated in parallel. The team will collect as much as 12 months of data from each site. Data collected from study and control vehicles (if available) include cost, operations, and performance. Final reports of the results are planned for publication. Alternative fuel vehicles (including compressed or liquefied natural gas) will be evaluated, as will hybrid electric and fuel cell vehicles.

The objective of DOE/NREL evaluation projects is to provide comprehensive, unbiased evaluations of currently available advanced technology and alternative fuel vehicles. This objective is customized for each evaluation site based on the vehicle technology development status and the site's expectations. Operators considering the use of these vehicles constitute the primary audience for this information.

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# Introduction

During the last decade, transit agencies have been under pressure to reduce overall fleet emissions. Although buses make up only 1% of the vehicles in the United States, they typically operate in the most populated areas where pollution is already a problem and exhaust smoke is easily noticed. Many agencies have switched to cleaner burning fuels, such as natural gas, but high capital costs for infrastructure have led some to look for other solutions. Powering buses with electric propulsion is one option.

The U.S. Department of Energy's (DOE) Advanced Vehicle Testing Activity (AVTA) supports the FreedomCAR and Vehicle Technologies Program's efforts to facilitate the transition of advanced technologies from research and development to the marketplace. The National Renewable Energy Laboratory (NREL), which manages AVTA's medium- and heavy-duty vehicle activities, provides potential buyers of advanced vehicles with the information they need to make informed decisions on purchasing and implementing vehicles into their fleets. These agencies need to be well informed about the vehicles' operational characteristics, costs, and performance. Understanding the implementation process of electric propulsion technology and lessons learned by early adopters is vital to fleet success.

# Document Objective

This document provides background for transit agencies and other fleets that are considering the use of electric propulsion technologies. It tells potential users what to expect and what to plan for when implementing vehicles with electric propulsion systems (such as dedicated electric vehicles, hybrids, and even fuel cells) into their fleets. This document also addresses the unique issues that electrical integration can pose for fleet personnel and points to the similarities between implementing electric propulsion and any other significant new technology.

Technical objectives include:

- Provide an accurate explanation of technical status of technology development
- Provide information on what transit agencies are doing
- Provide comments on lessons learned with current and future technologies
- Provide perspective for what a transit agency might expect during its implementation of electric propulsion technology

# Approach

This document was developed using the experiences of a focus group made up of professionals from transit agencies across the country that have experience working with electric propulsion vehicles. The following agencies participated in the focus group:

- New York City Transit (NYCT)
- Orange County Transportation Authority (OCTA)
- Santa Barbara Metropolitan Transit District (MTD)
- Santa Barbara Electric Transportation Institute
- SunLine Transit Agency
- Dallas Area Rapid Transit

Also involved in the focus group are the Federal Transit Administration and DOE.

As a part of the U.S. Department of Transportation, the Federal Transit Administration's (FTA) mission is to provide leadership, technical assistance, and financial resources for safe, technologically advanced public transportation, which enhances citizens' mobility and accessibility, improves America's communities and natural environment, and strengthens the national economy. FTA is currently developing a hydrogen and fuel cell bus initiative with a goal of accelerating the development of a zero-emission fuel-efficient bus. The strategic plan includes establishing partnerships with other government, industry, and environmental stakeholders to coordinate resources. The agency sees electric drive propulsion (including battery electric, hybrid electric, and fuel cell hybrid) as a path to reaching that goal.

Like FTA, DOE is interested in fuel-efficient transit bus technologies. For the last 12 years, DOE has been evaluating alternative fuel vehicles to determine the potential to reduce the use of foreign petroleum. DOE invests significant time and resources to develop batteries, motors, controllers, and other electric and hybrid vehicle system components that will improve efficiency and reliability, while lowering overall vehicle costs. As a part of these evaluations, understanding the implementation process and lessons learned has been a key step in providing a complete explanation of each site's experience with new propulsion and vehicle technologies.

The evaluation team developed a questionnaire for focus group members to solicit feedback on their experience and advice regarding the implementation of electric propulsion in transit service. The group's input has been compiled in this report. For profiles on participating transit agencies, see Appendix A. For questionnaire responses, see Appendix B.

**Questionnaire**

We asked the focus group to answer a series of questions to tap into their experiences with electric propulsion transit buses. Questions included:

- Description of the fleet, including electric propulsion buses
- Reasons for implementing advanced technology buses
- Overall impression of the specific technology used
- Problems encountered with the technology and resolutions to them
- Advice for other transit agencies investigating electric propulsion buses
- Top three things that need significant work and investment to commercialize the technology

Government participants were asked to provide their perspectives on the status of electric propulsion technology and the role of transit in developing this technology. They were also asked to offer advice to fleets considering these technologies.

# Steps to Success

According to transit agencies that participated in the focus group, research, planning, and teamwork are critical in the successful integration of electric propulsion technologies. Other steps to success include:

- **Building a Knowledge Base—**Understanding the technology is the first and most important step in developing an advanced technology vehicle program. In addition to gathering information from government and other organizations familiar with transit related technologies, an agency should also seek advice from other transit properties with appropriate experience.

- **Matching the Vehicle to the Application—**To ensure success, an agency must not only understand the different vehicle technologies but also have a firm grasp of their specific applications. What works well in one application might be a dismal failure in another. Don't forget that climate conditions could also present challenges for electric propulsion systems.

- **Organizing a Team—**Agencies with experience in electric propulsion vehicle technologies report excellent support from their development partners. Working closely with manufacturers, vehicle systems integrators, and funding partners will provide the best chance to make a project successful. Manufacturers should involve transit agencies early in the development process to ensure the bus will meet the fleet's needs and reduce excessive modifications during the break-in stage.

- **Expecting Higher Costs and Planning Accordingly—**Advanced technologies will require higher costs for purchase as well as for operations and maintenance. Plan ahead to meet these costs and involve upper management in the process. Look to outside organizations, such as federal, state, and local government partners, for potential funding sources.

- **Educating and Training Staff—**Understanding the new technologies will take time and effort on the part of the maintenance personnel and the fleet managers. It pays to invest in training to overcome this high learning curve. It may be necessary to assign several staff members to concentrate on the new vehicles and build an expertise in the technology. Expect some difficulties in obtaining manuals and replacement parts.

- **Determining Your Measure of Success—**Define the criteria you will use to determine the success of your project. Goals should be realistic and reasonable for the level of technology. Although it's difficult to quantify, don't underestimate the benefits of public relations. Publicizing the use of advanced technologies spurs public interest that can result in increased ridership.

## Why Are Transit Agencies Considering Electric Propulsion Technology?

Transit buses are ideal applications for alternative fuel or advanced technologies because they:

- Operate in congested areas where pollution is already a problem
- Are centrally located and fueled
- Are highly visible
- Are government subsidized
- Are professionally operated and maintained
- Operate on a fixed route and fixed schedule
- Have greater tolerance for added weight and volume requirements of advanced systems
- Have less rigorous start-up and pull-out requirements
- Offer greater public exposure to the positive benefits of advanced technologies which leads to a broader public knowledge and acceptance.

The American Public Transportation Association (APTA) estimates that 11.5% of the buses in the United States in 2002 were using an alternate power source (see reference 1). Although most of those buses use alternative fuels, recent trends show an increase in orders of buses using electric propulsion, particularly hybrids.

**Why are agencies choosing these newer technologies?** Air quality is a primary reason transit agencies are looking to advanced bus technologies. The focus group participants cited emission reductions as one reason they began using advanced propulsion technologies. Most of the agencies in the focus group are located in large cities where densely compacted businesses, traffic congestion, and often geography combine to cause problems with local air quality. Although SunLine Transit Agency operates in a less populated area, weather conditions often transfer smog from Los Angeles through the pass into the Coachella Valley near Palm Springs, California. This was cited as one reason SunLine chose to use clean bus technologies.

Electric propulsion vehicles use electricity generation and energy storage methods to increase the overall operational efficiencies, while reducing emissions. Emission improvements from battery electric or fuel cell vehicles range from moderate reductions to a full elimination of all hazardous onboard emissions. Emissions reductions from hybrid vehicles can vary with the efficiency of the hybrid system. In general, the cleanliness of electric propulsion vehicles varies with the technology used, but all electric propulsion technologies have the potential to reduce emissions.

However, the benefits of advanced technologies can expand beyond pollution reductions. Vehicle efficiency is another reason transit agencies are considering advanced technology buses. Both NYCT and OCTA cite the potential fuel efficiency gain as an important reason to consider electric propulsion. Many transit agencies acquire operating funds through local sales taxes. When the economy suffers, so do the agencies. A more efficient vehicle uses less fuel and may therefore reduce operating costs.

Electric propulsion vehicles present some unique advantages over other advanced technologies. Technology trends indicate that electric propulsion may become dominant in the future. Incorporating electric propulsion technologies today will prepare fleets for evolving technologies tomorrow. In addition, the public relations benefits prompt transit agencies to explore advanced propulsion technologies. Santa Barbara MTD wanted to increase ridership in its area. The goal was to provide quiet, emission-free transportation that would attract new customers. Ridership increased dramatically after the electric buses were placed into service.

# Electric Propulsion Technology Types

Electric propulsion technologies use electric power to drive a vehicle. These systems utilize components such as electric motors, electric energy storage devices, inverters, and electronic controllers. They differ significantly from conventional vehicle systems and require many specific considerations. The primary configurations for electric propulsion technologies are:

**Battery Electric**—Battery electric vehicles are powered solely by electric power and use an electric motor to drive the vehicle. All their energy is stored in batteries onboard the vehicle and the batteries must be recharged by an external source or swapped with freshly charged batteries when depleted. Battery electric vehicles can take advantage of “regenerative braking,” which recharges the batteries, to recapture some of the energy lost during braking. Results in Santa Barbara demonstrate that more than 30% of the traction energy can be recovered via regenerative braking.

**Hybrid Electric**—Hybrid electric vehicles typically combine an energy storage device, a power plant, and an electric propulsion system. Energy storage devices are most often batteries, but other possibilities include ultracapacitors and flywheels. Power plants can be internal combustion engines, diesel engines, gas turbines, or fuel cells. The efficiency of a hybrid system depends on a number of factors, such as the particular combination of subsystems, how the systems are integrated, and the control strategy employed. Like battery electric vehicles, hybrid vehicles can take advantage of regenerative braking. There are two basic strategies for hybrid propulsion:

- **Series Hybrid—**In a series configuration, the power plant provides electrical power to the motor, which drives the wheels. There is no mechanical connection between the power plant and the wheels. An advantage of this configuration is being able to set the power plant to operate at its maximum efficiency.

- **Parallel Hybrid**—This configuration has two power paths. It allows the wheels to be driven by the power plant, the electric motor, or both. A vehicle in this configuration has the advantage of higher power because the electric motor and power plant can provide power simultaneously.

**Fuel Cell**—Fuel cells, which have been used to generate power in space for decades, combine hydrogen and oxygen in an electro-chemical process to produce electrical power with water as the only byproduct. Many fuel cell vehicles are in a hybrid configuration, with the fuel cell as the primary power source. Fuel cells for vehicle applications are in their early stages of development, yet as a clean and efficient power source, they have great potential.


*The Orion VII hybrid (left) uses a series hybrid system. The Allison Electric Drives bus (right) uses a parallel hybrid system.*

These technologies all use electric power and drive systems for propulsion. Although conventional vehicles have long used electrical systems to power lights, air conditioning, and other accessory systems, using electricity as motive power to propel the vehicle provides challenges with which many vehicle maintenance personnel and fleet operators are not familiar.

Fleet managers and maintenance personnel will need to make significant adjustments to their operations to incorporate electric propulsion technologies. The adjustments will have the same types of impacts that implementing alternative fuel vehicles have had for transit agencies across the country. Adjustments to fueling practices, preventive maintenance inspections, incorporation of specialized equipment, scheduled regular maintenance, and training will be necessary to move forward with the advancements in vehicle technologies.

## Status of Electric Propulsion Transit Bus Implementation

*This battery electric bus, manufactured by Ebus, operates in New Haven Connecticut.*

**Battery Electrics—**The history of electric vehicles in public transit dates back to the turn of the 20th century with the first demonstrations of trolleybuses connected to overhead power lines in Massachusetts and Pennsylvania (see reference 2). Today, a few U.S. cities still operate trolleybuses, but most dedicated electric buses are battery powered. Battery electric buses are limited in size and application because of restricted range, although improved technologies are now being fielded. Batteries must be recharged (or replaced with recharged batteries) for extended operation. Most 22-foot battery electric buses in the United States are used in niche market applications.

*A diesel hybrid electric trolley bus by Trolley Enterprises.*

**Diesel Hybrids—**Although battery electric buses have been limited to smaller vehicles, hybrid propulsion systems are being developed in a wide range of vehicle sizes, including shuttle buses, 40-foot transit buses, 60-foot articulated buses, and over-the-road coaches. More than 30 organizations in the United States are currently demonstrating hybrid bus technologies. Early hybrid bus demonstration projects involved small numbers of vehicles, but interest has grown recently. The promising results from early projects have led several agencies to place large orders for hybrid buses. More than 600 hybrid buses could be placed into service around the country during the next few years.

*This turbine hybrid bus, operated in Coconut Creek, Florida, is fueled by propane.*

**Turbine Hybrids—**Another type of hybrid electric, turbine hybrids use a small turbine and generator set to produce electricity to power the bus. The turbine can operate on a variety of fuels, including natural gas, propane, biodiesel, and diesel. In a typical 30-kW configuration, the turbine supplies enough power to operate a small (commonly a 22-foot) bus in a hybrid application. The largest order to date for turbine hybrids is 20 buses, which are still in production (see reference 3). A larger, 60-kW turbine generator set is now commercially available for packaging in larger 40-foot hybrid bus applications.


*The prototype fuel cell hybrid bus from ISE Research uses a fuel cell by UTC.*

**Fuel Cell—**The newest technology being developed for bus propulsion uses fuel cells for power. Many of these vehicles have electric propulsion systems with a supplemental power and energy storage device, such as a battery. Although many fuel cell bus projects are being conducted throughout the world, these vehicles are still in the early prototype stage. In the United States and Canada, 14 fuel cell buses have been demonstrated in various cities; 11 more are expected to begin revenue service in 2004. However, much work must still be done to lower costs and improve reliability and durability enough to commercialize this technology.

## Development Path for Electric Propulsion Transit Buses

Developing new transit bus technologies can be very costly for vehicle manufacturers. Advanced propulsion technologies require significant investments simply to develop prototypes. Because of the limited market for buses, the transit industry cannot expect the same level of manufacturer-led product development as occurs in the consumer auto industry. According to APTA, the most buses built by a single original equipment manufacturer in 2001 were 1,548 (see reference 4). By comparison, General Motors produced more than 5.5 million light-duty vehicles in that same year, including more than 700,000 of the most popular vehicle model (see reference 5).

The difference in sales volumes limits bus manufacturers from allocating the level of resources that auto manufacturers allocate for research and development of these new technologies. As a result, new bus technologies are typically developed using venture capital, often by small niche companies. In addition, buses are often built to each agency's specification as opposed to building standard models that are available to all customers. These factors make extensive on-road testing unaffordable. Manufacturers must instead rely on transit fleets that are willing to operate vehicles as they progress from prototypes to full commercial models.

Order size also causes difficulties in the development process. Smaller orders give transit agencies a chance to work out the bugs in new technologies before they comprise a critical portion of their fleet. However, manufacturers are likely to have difficulty supporting small fleets when technical problems occur. Larger orders allow for lower capital costs but could be a problem for smaller agencies if a major issue arises in the fleet. The operator may not have enough spare buses to cover potential service interruptions. Smaller bus manufacturers can also be hard pressed to deliver a large order of new technology buses. Even one failing product could drive a small company out of business, and leave the transit agency with little or no support.

## Advanced Propulsion Bus Operating Experience

The experiences of our focus group are valuable resources for other agencies considering electric propulsion buses. Knowing the successes and challenges experienced by early adopters can help other organizations avoid potential pitfalls and help advance the technology to the next step. The group's advice is broken into four categories:

- Research New Technologies
- Plan for Higher Costs and Added Resources
- Apply a Teamwork Approach
- Train Maintenance and Other Staff

### *Research New Technologies*

Educating staff on the different technologies is one of the most important things a transit agency can do to ensure the success of an advanced propulsion technology bus program. This knowledge should be acquired before making a decision about which technology to use. There are a variety of new technologies being developed; a thorough understanding of the advantages and disadvantages of each is needed to make the best choice. An agency must also understand the specific application and the duty cycle on which the buses will operate. Matching the vehicle to the application is key to a successful implementation. For example, a battery electric bus has a limited range and must therefore be placed in appropriate duty cycles by the transit agencies.

Resources on electric propulsion vehicles can be found in a number of places. The Internet provides information on electric propulsion vehicles. DOE's Alternative Fuels Data Center (www.afdc.doe.gov) includes a wide variety of information on all types of alternative fuels and propulsion systems for light- and heavy-duty vehicle applications. The Transportation Research Board has published several reports on transit related issues, which can be ordered through the Web. Information is also available through organizations such as the Electric Drive Transportation Association (EDTA) and the APTA. These and other Web sites are convenient starting places for researching electric propulsion vehicles. (See References for Web site addresses.)

Seeking the experiences of other transit agencies is also a helpful way to prepare for a vehicle demonstration. Many agencies are eager to share their knowledge with the industry. There are several organizations that bring interested parties together to trade their experiences. APTA's Electric Bus Subcommittee meets twice yearly, typically in conjunction with events where transit professionals are already in attendance. The APTA Bus and Paratransit Conference held each year in early May is one of these events. The group includes members from transit agencies, bus manufacturers, fuel providers, and government agencies—all of which have interest in or experience with electric propulsion technologies. Another organization that brings transit professionals together to share information on advanced vehicles is the Electric Power Research Institute (EPRI). EPRI and EDTA have sponsored several electric bus workshops in the past few years where users and manufacturers where brought together to discuss available products as well as current issues with new technologies and the solutions to those problems.

## *Plan for Higher Costs and Added Resources*

Transit agencies that plan to implement electric propulsion technologies should expect to incur significantly higher costs until these technologies achieve commercial maturity. Not only will the vehicles and other equipment cost more to purchase but standard maintenance tasks will take longer while personnel become familiar with the new technology. Transit agencies should take the time to fully investigate the potential costs involved before making a commitment to operate advanced technology vehicles. Planning up front can reduce the potential of surprises during a demonstration.

Of course, the newer technologies are more expensive to purchase than conventional diesel buses. Table 1 shows the typical costs associated with various transit bus technologies. The relative price difference is indicative of the comparative commercial maturity of these technologies. For many cash-strapped agencies, these costs may be prohibitive. An agency needs to plan for these costs early in the project development phase. Demonstrations of advanced technologies are often heavily subsidized by government agencies such as the Federal Transit Administration, which provides 80% of the capital cost of advanced technology buses. Other grants may be available from DOE, the U.S. Department of Transportation, as well as government agencies at the state and local level. However, even with government aid, fleets can encounter difficulty funding the incremental cost of vehicles, upgrades, equipment, training, and other costs for advanced technology vehicle projects.

Transit agencies should also plan for potential added costs to upgrade maintenance facilities. For battery electric and hybrid buses, this could include lift equipment for trading out battery packs, battery charging/conditioning units, and safety equipment necessary for working with electric systems. Buses that operate on alternative fuels, such as compressed natural gas, will also require new fueling infrastructure to be added, as well as garage modifications to allow for safe maintenance practices.

**Table 1. Capital Costs For Transit Buses**

| Technology | Approximate Cost |
|---|---|
| Standard 40-foot Diesel Bus | $280-290K |
| CNG Bus (40-foot) | $300-320K |
| Hybrid Bus (40-foot) | $390-450K |
| Hybrid Shuttle Bus (22-foot) | $260-350K |
| Battery Electric Shuttle Bus (22-foot) | $180-230K |
| Fuel Cell Bus | $3 million |

In addition to the up-front costs of the buses, transit agencies must plan for additional resources to support the project. It is easy to underestimate the time required for project staff, from maintenance workers to project managers. Agencies can take several paths to meeting staffing resources. Some agencies treat the advanced technology no different from the conventional buses—training all maintenance workers to handle the vehicles. Other agencies find it helpful to assign specific staff to the new buses, developing several experts in the technology.


*The hybrid buses used on Denver's 16th Street Mall are fueled by CNG.*

### *Apply a Teamwork Approach*

Transit agencies considering electric propulsion buses should begin by building a team. While diesel bus technology is mature, electric propulsion buses are in an infancy stage. Organizations that have no significant experience with technologies other than diesel should be aware that there is often a gap between what they expect and the reality of the new technology bus. Forming a partnership between operator, manufacturer, and system integrator will help ensure success. Other potential team members include component suppliers, infrastructure developers (for vehicles operating on fuels other than diesel), and funding agencies. Experienced transit agencies suggest dealing with well-established organizations that will put up their own money to develop the product, are committed to commercializing the technology, and will support the product when problems arise. Transit agencies implementing electric propulsion vehicles should be wary of companies that are only interested in being paid for development work.

The transit agency should be involved/partnered in the design, development, and construction stages of the bus. Vehicles built from the ground up, as opposed to retrofitted vehicles, generally perform better. A custom designed vehicle is often more robust than a converted vehicle. An agency can achieve a better match between vehicle and application when they are involved in this process. This can have a significant impact on the number of road calls and vehicle downtime.

Once the first bus is delivered, the cooperation between bus manufacturer and transit agency becomes even more critical. Cooperation allows manufacturers to learn how their products need improvement and helps the fleet learn how the advanced systems work and how they affect operations. Transit agencies should understand that modifications might be necessary during the early stage of deployment. The operator's support to the manufacturer during this time is important to help push the development of the technology. In a sense, the transit agency becomes its own researcher to support the manufacturer and integrator of the technology. The most successful agencies assign a person or team to become experts in the selected technology. This team can dedicate their time to study the system and work through problems to keep the buses operating. Resolution of problem may not be obvious and could take significant effort to resolve. Having personnel dedicated to the project is a key to success.

### *Train Maintenance and Other Staff*

Because of the many issues and barriers associated with the transit bus development process, fleet managers should expect problems and setbacks when implementing new vehicle technologies. The first thing for fleet managers to understand when demonstrating new vehicle technologies is that their vehicles are not fully developed commercial products. Most electric propulsion vehicles that incorporate new technologies are in an early stage of development and are more likely to need greater attention from maintenance personnel than other vehicles. This is because electric propulsion systems incorporate new technologies that are unfamiliar to maintenance staff. Understand that there will be a longer "shakedown" period than with a conventional bus. It will take time for maintenance personnel to become familiar with troubleshooting and repairing new bus systems. However, the objective of this learning process is to help transit agencies to quickly reach the point where they can meet their maintenance needs without outside assistance.

For transit agencies that maintain vehicles in-house, training is extremely important for their maintenance personnel. The new systems will be very different from the typical diesel systems. It will take time and money to provide the training necessary to get the maintenance staff up to speed. Even after the training has been performed, troubleshooting advanced systems will be more difficult until personnel become more familiar with the systems through experience. Each vehicle may develop its own unique set of integration problems. There is potential for a long learning curve with new technologies, but proper training and planning can help a technology demonstration succeed.

Additional considerations should be made for transit agencies that have unionized maintenance depots. Depending on how the union is organized, there could be issues with maintaining systems that are not typical. For example, some maintenance shops have workers that specialize in specific systems, such as electrical or mechanical. An advanced technology bus has systems that may overlap specific job descriptions. Deciding who will maintain these systems could become an issue. Educating union representatives about the differences in the new technology buses could go a long way to avoid confusion when the first bus requires maintenance.

## Technical Challenges

When implementing any new vehicle technology, there are likely to be challenges and setbacks. The impact of these events can be minimized by developing a thorough understanding of the technologies being operated. Many components in electric propulsion vehicles may present new challenges to maintenance staff. A basic understanding of the most common difficulties associated with electric propulsion vehicles will help prepare transit agencies that intend to demonstrate these technologies.

Current electric propulsion systems typically lack the robustness that transit agencies expect from their vehicles. The components may be more sensitive to the environmental conditions of heavy vehicle operations, such as large swings in temperature and exposure to moisture. Some fleets have experienced intermittent electrical problems that can't be traced to a defect in the design or components.

Transit operators should not accept defective bus products. However, it is important to recognize that while the diesel-bus product is mature and well established, the electric-bus industry is still in its infancy.

The operator should proceed with an electric propulsion bus procurement only with the clear understanding that there may well be a longer shakedown period than experienced with diesel-bus orders. Despite such uncertainties, experience has demonstrated that the benefits that accrue with the successful acquisition and implementation of an electric-drive bus program far outweigh the potential disadvantages.

The following sections describe typical components in an electric propulsion system and some of the technical challenges the focus group encountered.

### *Energy Storage*

Batteries are the most common devices used for energy storage in advanced technology vehicles. The performance requirements needed for a battery depend on the specific application. The key performance variables for batteries are:

- **Specific Energy—**The ratio of energy output of a battery to its weight, expressed in watt hours per kilogram (Wh/kg).
- **Specific Power—**The ratio of power delivered by a battery to its weight, expressed in watts per kilogram (W/kg).
- **Cycle Life—**The number of cycles under specific conditions that a battery can experience before failure.

These factors indicate how long the battery can be expected to last and how much battery weight will be required to obtain a given amount of energy storage and power. These factors are important when selecting a battery for an advanced vehicle. For example, a battery electric vehicle needs high specific energy to provide sufficient vehicle range and high specific power for acceleration. In a hybrid electric configuration, the battery needs high specific power for acceleration and the capability to accept high power repetitive charges from regenerative braking.

The cycle life of a battery is affected by the way they are utilized in a particular configuration. Battery electric vehicles typically use batteries in a deep discharge mode, which means the vehicle is operated until the batteries are discharged to a certain level then fully recharged. Batteries in a hybrid system, however, are operated in shallow charge/discharge cycles. Batteries have been described as the "Achilles heel" for electric propulsion because few developers have yet produced a system that meets vehicle needs cost effectively. The most understood battery types tend to be heavy and don't have the cycle life of newer battery technologies. There are several types of batteries—all of which have implications for vehicle performance and reliability.

The energy storage system used for electric propulsion applications will have a significant impact on the vehicle's performance. Experienced transit agencies suggest considering the system's reliability, cost-effectiveness, and ability to maximize the energy recovered from regenerative braking when choosing an energy storage system. Another important factor to consider is the need for battery management, both thermally and electrically. A battery system can vary in temperature from module to module, which can cause an unbalance in the pack and reduce performance. Regulating temperature range and uniformity in the battery pack can affect the performance, charge acceptance (regenerative braking), and overall maintenance expenses (see reference 7). Current ambient temperature systems do not always include battery thermal management. Adding a management system could optimize performance, reduce maintenance costs, and increase the life of the battery pack, reducing the overall cost. Transit agencies looking into electric propulsion buses should investigate this option.

*Water cooled thermal management system on a battery electric bus.*

*A battery management system could help prevent failure of individual batteries in a pack.*

Energy storage options include (see reference 8):

**Valve-Regulated Lead Acid (VRLA)—**Unlike conventional batteries, VRLA batteries contain a limited amount of electrolyte that is either absorbed in a separator or in a gel. Lead acid batteries have been the most common rechargeable electrochemical storage system for longer than a century. This seems surprising because the amount of energy it can store is relatively modest because of the heavy weight of the reacting substances. Typical batteries have a specific energy of 35 Wh/kg, with a life of up to 800 cycles. While they are low in energy, VRLA batteries have a high specific power of around 200 W/kg. They are, however, adversely affected by lower temperatures. VRLA batteries have been used in vehicles since 1978 and are the most common technology used in vehicle applications. Commercial availability of these batteries makes them a lower cost option. They are low in range but high in power.

**Nickel-Metal-Hydride (NiMH)—**Utilizing the same technology pioneered in laptop computers and cellular phones during the past decade, NiMH batteries can be used effectively onboard electric propulsion vehicles. Although more costly than lead acid, NiMH batteries are used in most light-duty vehicle applications and are beginning to show up in heavy-duty hybrids. The specific energy of NiMH batteries varies depending on the application. For battery electric vehicles the specific energy ranges from 65 to 75 Wh/kg, while in a hybrid configuration it ranges from 45 to 60 Wh/kg.

**Nickel Cadmium (NiCd)—**The vented sintered-plate NiCd battery (sometimes called "flooded NiCd") is mechanically rugged and long-lived. It has excellent low-temperature characteristics and can be hermetically sealed. The initial cost is higher than lead-acid batteries, but the total life-cycle cost is somewhat lower. NiCd batteries are fast charging and have a long life span. NiCd batteries can suffer from a "memory effect" when exposed to charging followed by repetitive shallow discharge cycles. This effect, which causes a gradual decrease in power and capacity, is completely reversible by reconditioning the batteries. Disadvantages of this battery chemistry are the lower energy density and the presence of cadmium, which is a toxic substance. A NiCd battery system utilizing a liquid-cooling system is presently being used on a hybrid bus.

**Sodium Nickel Chloride (NaNiCl)—**This battery technology is reaching new levels of capacity, performance, safety, and cost-effectiveness. It has a high specific energy (around 115 Wh/kg) and a long cycle life (2,500 cycles). NaNiCl modules do not require topping-up, agitation, or direct battery cooling, reducing the need for costly ancillary equipment. It is a high temperature system, operating in the range of 250°C–350°C. Because the batteries operate under controlled temperatures in a sealed steel box, they are not affected by outside temperature. This battery has lately been the technology of choice in Europe for electric-drive buses.

**Lithium Ion (Li-ion) —**In these batteries, lithium ions are exchanged between the positive and negative materials during the battery cycle. The positive electrode is comprised of a metal oxide, typically lithium cobalt oxide or lithium manganese oxide. The market for Li-ion batteries has grown over the last decade, mainly in portable electronics applications. These batteries offer a high specific energy (more than 150 Wh/kg), high cycle life (more than 1,000 cycles), and operate in a wide temperature range. Because Li-ion batteries degrade when discharged below a certain level and lose capacity when overheated, they benefit from a management system to control temperature and charge level.

**Lithium-Metal Polymer—**These batteries have been in development for several years and are currently approaching a specific energy of 150 Wh/kg and a specific power of 1,200 W/kg. Current prototype lithium polymer batteries have a cycle life approaching 10 years, which meets the FreedomCAR 2008 life cycle goal for a dual-assist hybrid.

**Table 2. Comparisons of Battery Characteristics (See Reference 8)**

| Technology | Configuration | Specific Energy (Wh/kg) | Specific Power (W/kg) | Cycle Life |
|---|---|---|---|---|
| Lead Acid | Cell | 35 | 200 | 800 |
| Nickel Metal Hydride | Cell | 45-75 | 850 | 900 |
| Nickel Cadmium | Cell | 30 | 260 | 1,000 |
| Sodium Nickel Chloride | Cell<br>Battery | 115<br>95 | 260<br>170 | 2,500<br>1,000 |
| Lithium Ion | Battery | 100-158 | 700-1,300 | >1,000 |


*Lead acid battery pack in a hybrid bus.*

## Motors

Electric motors offer several advantages over engines for vehicle propulsion. Unlike engines, motors provide their highest torque at low speeds. This provides for exceptional acceleration from a stop and prevents the need to idle. Motors also offer the advantages of low noise and high efficiency. Motors generally require much less maintenance than engines. In addition, electric motors can facilitate regenerative braking by reversing field when the vehicle decelerates, thus becoming electricity generators that recharge battery packs.

**High Voltage and Current—**Electric propulsion systems involve electronic circuits that deliver relatively high voltages and currents. To prevent harmful or potentially fatal electric shock, maintenance personnel will need to be trained to safely work with electric propulsion systems. Special protective equipment (including diagnostic tools) is required to work with such systems. The vehicle developers must train maintenance personnel to safely maintain their vehicles and suggest appropriate equipment.

Electric propulsion vehicles require special wiring and harnesses capable of handling these high voltages and currents. Components should be designed for the vibration levels and environmental conditions associated with transit bus operations.

### *Hybrid-Specific Issues*

**Engine Issues—**Hybrid vehicles are unique because they involve a power generation system in addition to the electrical propulsion system. Diesel engines are often used in this application, although gas turbines and natural gas engines are also feasible alternatives. Current diesel engines and aftertreatment systems are not always sized well for hybrid applications. Improvements in efficiency and emissions could be achieved through diesel systems specifically designed for these applications.

**Certification of Hybrids—**There is an issue with the current certification process for hybrid buses. The certification process for heavy-duty vehicles requires the engine to be certified on an engine dynamometer—separate from the vehicle. This process doesn't take into account the emissions benefit of hybrid vehicles. Fleets want to get credit for the lower emissions to help meet regulations and justify the extra cost of hybrids. The FTA is leading a Working Group composed of industry, the U.S. Environmental Protection Agency, and the California Air Resources Board to find a way to credit fleets with lower emissions, while making sure the environmental benefits are realized throughout the life of the vehicle.

**Energy Storage Issues**—Although battery systems on current hybrid vehicles do not need to be recharged from the electricity grid, sometimes a conditioning of the battery packs is necessary to balance the modules and increase battery life. Equipment for this conditioning adds cost to the project and must be maintained. Transit agencies will also need to establish procedures for this conditioning and work them into their standard practices.

### *Other Considerations*

**Agency-Wide Support—**It is critical for advanced technology vehicles to be supported at all levels of an organization. Transit agencies should have the support of senior management, who should understand that new technology, in addition to incremental cost, brings a risk of experiencing difficulties or even failure. In addition, drivers and maintenance personnel should understand the reasons for the implementation and the role they must fill for it to be successful.

**Developing In-House Expertise—**Fleet operators could encounter complications because most electric propulsion vehicles cannot be considered fully commercial products. Agencies may not receive manuals for some of the newest technologies when the vehicles arrive. It is also likely that there will be limited parts availability for advanced technology components. Fleets may also have trouble obtaining the technical support they need as they implement advanced vehicles. To deal with these potential setbacks, agencies should draw on as many technical resources as possible and develop their own experts in the equipment they operate. Some transit agencies even suggested hiring an electrical engineer experienced with the implemented technology to work within the transit system. Transit agencies should also learn from outside resources, especially other transit agencies, before deciding to implement advanced technology vehicles and continue to learn and train after implementation.

**Warranty and Liability Issues—**Transit agencies should pay careful attention to warranty and liability issues and should clearly understand which components are covered under the vehicle warranty and how warranty service will be performed. Additionally, transit agencies could have trouble insuring advanced technology demonstration vehicles they don't own.

This was true for one of the fuel cell buses demonstrated at SunLine. Because SunLine didn't actually own the prototype bus, the insurance agency was hesitant to provide coverage. To reassure the insurance company, SunLine operated the prototype bus in simulated service, shadowing another bus on route for several weeks to create a record of safe and reliable operation. The demonstration bus passed the test and was put into service two weeks ahead of the insurance company's original schedule.

**Maintenance Challenges—**Fleets should also be aware of the significant operational impacts associated with maintaining advanced technology vehicles. Training will be necessary to prepare maintenance personnel to work with the advanced technologies. Additional maintenance equipment may also be needed to maintain the unique components onboard advanced technology vehicles. It may be difficult to identify failed components in an electric propulsion system, which hinders the troubleshooting process. It is important to train and prepare for maintenance difficulties, but transit agencies can still expect maintenance delays and challenges.

Certain maintenance practices can help transit agencies implement advanced technology vehicles more smoothly. Agencies will benefit from careful documentation of the maintenance issues they encounter. This documentation can be used to diagnose future problems and facilitate solutions. Keeping hard-to-procure parts on hand will minimize downtime should a failure occur. The most significant impacts on operation are likely to occur in the first few months of operation while staff becomes familiar with the vehicles and their components.

Transit agencies shouldn't jeopardize their ability to provide service if a vehicle breaks down. They should plan enough spare vehicles to avoid service interruptions during this development phase. After the first few months of operations, difficulties may still occur, but the staff will be better equipped to handle breakdowns quickly.

**Characterize the Benefits of Electric Propulsion Technology—**Assigning value to certain benefits of the technology can be very difficult. One benefit is emission reduction. Battery electric and hydrogen fuel cell buses emit zero tailpipe emissions, and tests of hybrid buses show major emission reductions compared to conventional diesel buses (see reference 15). This may be an easy selling point in crowded cities where pollution is a major concern, but how do you justify the benefit for rural areas? Recent studies investigated the health effects from diesel exhaust, which includes increased hospital admission rates for respiratory ailments such as asthma and bronchitis. Electric propulsion buses have the potential to reduce pollution by not only lowering tailpipe emissions, but by encouraging the use of public transportation. This, in turn, will reduce the total number of vehicles on the road.

Another benefit that is hard to characterize is increased public relations. Many transit agencies report increased ridership for clean technology buses. Publicizing the new technology and tracking increased use could help an agency justify the added capital cost.

## Conclusion

Early experiences indicate that electric propulsion technologies will provide low-emission transportation with high fuel economy. Yet these vehicles (for the most part) are not fully commercial products. Bus manufacturers rely on transit agencies to conduct on-road testing of new technologies. Agencies that participate in these early operations should work with their partners to further develop the technologies.

All the agencies in our focus group are excited about the potential for increased efficiency, high performance, and lower emissions that electric propulsion offers. They acknowledge that there is a high risk associated with being an early adopter of new technologies, but they are willing to invest the time and effort to help push the technologies to the next stage. Sharing their collective experiences will help other transit agencies plan for their own implementation of advanced technology buses.

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# Web Sites

**Focus Group Participants**

| | |
|---|---|
| New York City Transit | http://www.mta.nyc.ny.us/nyct/ |
| Orange County Transportation Authority | http://www.octa.net/ |
| Santa Barbara Metropolitan Transit District | http://sbmtd.gov/ |
| SunLine Transit Agency | http://www.sunline.org/ |
| Santa Barbara Electric Transportation Institute | http://www.sbeti.com/ |
| Dallas Area Rapid Transit | http://www.dart.org/ |
| Federal Transit Administration | http://www.fta.dot.gov/ |
| DOE's Advanced Vehicle Testing Activity | http://www.ott.doe.gov/otu/field_ops.html |

**Other Information Resources**

| | |
|---|---|
| Alternative Fuels Data Center | http://www.afdc.doe.gov/ |
| APTA Committees | http://www.apta.com/about/committees/index.cfm |
| Electric Drive Transportation Association | http://www.evaa.org/ |
| Georgetown University Fuel Cell Bus Program | http://fuelcellbus.georgetown.edu/ |
| Transportation Research Board | http://www.trb.org/ |

**Manufacturers or Systems Integrators of Electric Propulsion Technologies**

| | |
|---|---|
| Allison Electric Drives | http://www.allisontransmission.com/product/electricdrive/index.jsp |
| BAE Systems Controls | http://www.hybridrive.com/PowerSystems.htm |
| Ebus | http://www.ebus.com/ebus.htm |
| ISE Research | http://www.isecorp.com/ |
| Trolley Enterprises | http://www.trolleyenterprises.com/ |

# Appendix A: Focus Group Fleet Profiles

## *New York City Transit*

*An NYCT diesel hybrid electric bus in service.*

New York City Metropolitan Transportation Authority (MTA), which includes New York City Transit's (NYCT) Department of Buses, is the largest transportation system in the United States. Nearly 7.8 million passengers are transported daily by bus and rail. NYCT has 235 bus routes in the five boroughs, totaling 1,871 miles. Buses run up to 24 hours a day, seven days a week, and transport about 2.2 million people per day.

The MTA is committed to its Clean Fuel Bus program, which includes the purchase of compressed natural gas (CNG) and hybrid electric buses as well as use of ultra-low sulfur diesel fuel and catalyzed particulate filters on the diesel buses.

Table 1 outlines NYCT's bus fleet.

**Table 1. NYCT Bus Fleet**

| Type | Current Number |
|---|---|
| Diesel Buses (40-foot, articulated, and coach) | 4,227 |
| Diesel Hybrid Electric Buses | 10 |
| CNG Buses | 229 |
| **Total Bus Fleet** | **4,466** |

NYCT was invited to participate in this project because of its experience with hybrid buses, which began with the demonstration of a prototype bus in 1998. The success of the demonstration led to the purchase of 10 Orion VI buses with BAE SYSTEMS' HybriDrive™ propulsion system. Since delivery of the first buses in September 1998, NYCT's hybrids have operated in regular revenue service. NYCT's experiences with the Orion VI hybrids were detailed in a DOE/NREL evaluation project completed in July 2002 (see reference 8). Transit staff members have proactively pushed for technology development in the field of electric propulsion and demonstrated their commitment to hybrid technology by ordering 325 additional hybrid buses.

## *Orange County Transportation Authority*

Orange County Transportation Authority (OCTA) provides transportation programs and services for Orange County, California. Its urban bus fleet covers more than 500 square miles and serves around 2.8 million residents. OCTA's 569 buses travel on 76 local, rail connector, and express routes that carry more than 210,000 riders daily. Growing demand for service in the area led OCTA to plan a 75% service level increase by 2010. This must be accomplished using the cleanest technologies available. As a transit agency in the South Coast Air Quality Management District (SCAQMD), OCTA is subject to several rules and regulations governing bus emissions.

OCTA has demonstrated a strong commitment to advanced vehicle technology with its current fleet of 232 liquefied natural gas (LNG) buses. Table 2 summarizes OCTA's bus fleet. In late 2000, OCTA began testing its first full-sized hybrid electric bus. The two New Flyer buses received by the agency utilized the Allison Transmission series hybrid-electric drive system.

**Table 2. OCTA Bus Fleet**

| Type | Current Number |
|---|---|
| Diesel Buses (40-foot, articulated, and shuttle) | 335 |
| Diesel Hybrid Electric Buses | 2 |
| LNG Buses | 232 |
| **Total Bus Fleet** | **569** |

The buses were operated in service on various routes to determine their performance under different conditions. During the demonstration period, Allison Electric Drives decided to concentrate on its parallel hybrid technology. OCTA's two hybrids are currently being retrofitted with this parallel system and will be returned to OCTA to continue the demonstration. The agency is considering the addition of up to 10 hybrid electric buses to its fleet. Because of this experience with electric propulsion technology, OCTA was invited to participate in the focus group.


*OCTA's New Flyer-Allison Hybrid Bus*

### *Santa Barbara Metropolitan Transit District*

The Santa Barbara Metropolitan Transit District (MTD) covers approximately 52 square miles in southern Santa Barbara County, California. MTD's 96 buses provide service to about 7 million passengers per year on 30 transit routes. Like other California transit agencies, MTD is subject to state regulations governing vehicle emissions.

Although MTD is concerned about air quality, it was the desire to increase ridership and control traffic that led the organization to investigate battery electric technology in the early 1990s.

As a popular tourist destination, Santa Barbara needed a clean, quiet vehicle to transport passengers between the Downtown and the Waterfront districts. MTD's diverse electric fleet consists of 24 buses from various manufacturers and uses several battery technologies. Table 3 summarizes the MTD fleet.

*One of Santa Barbara MTD's newest electric buses.*

**Table 3. Santa Barbara MTD Bus Fleet**

| Type | Current Number |
|---|---|
| Diesel Buses (40-foot, and 30-foot) | 72 |
| Battery-Electric Buses | 24 |
| **Total Bus Fleet** | **96** |

Santa Barbara has been using dedicated electric bus technologies for more than 13 years and is committed to using electric propulsion to reduce emissions, while improving vehicle performance. During the early years of testing electric buses, MTD initiated the formation of the Santa Barbara Electric Transportation Institute (SBETI) to help the agency understand battery electric bus technology. The purpose of SBETI is to "facilitate the development and application of battery-electric vehicles". The organization works closely with MTD, researching battery chemistries and other components to help develop electric bus technology. Because of this extensive experience, the MTD was asked to participate in the focus group.

### *SunLine Transit Agency*

SunLine Transit Agency is a joint powers authority that provides public transit and community services to California's Coachella Valley. SunLine's fleet of buses operates on 13 fixed routes with 900 stops and serves the area's 320,000 permanent residents, as well as 4 million tourists.


*SunLine Transit Agency has demonstrated three fuel cell buses: Ballard's Zebus, ISE Research's ThunderPower bus, and Georgetown University's methanol fuel cell bus.*

Concern for air quality in the valley spurred SunLine to become the first public transit agency in the United States to switch to a fleet operated 100% by CNG buses. The SunLine fleet consists of 46 CNG and two Hythane® (a mixture of 20% hydrogen, 80% CNG) buses, three LNG powered "SuperBuses," and 25 CNG shuttle buses used for demand response service. Table 4 summarizes the fleet.

**Table 4. SunLine's Bus Fleet**

| Type | Current Number |
|---|---|
| CNG Buses (40-foot, 30-foot) | 46 |
| CNG Shuttle Buses | 25 |
| Hythane® Buses | 2 |
| LNG High Capacity Shuttles | 3 |
| **Total Bus Fleet** | **76** |

SunLine has shown continued commitment to advanced technologies and has positioned itself as a test bed for implementing advanced technology vehicles. The transit agency has taken a leading role in technology advancement by collaboration with multiple technology partners to work toward new developments. SunLine is further establishing itself as a pioneer in advanced technology by being one of the few transit agencies currently operating fuel cell transit buses. In addition to the 40-foot fuel cell bus developed by Ballard, SunLine has also helped test a 30-foot ThunderPower fuel cell bus developed by ISE Research using a fuel cell by UTC and is hosting a methanol fueled fuel cell bus developed by Georgetown University. All three of the fuel cell buses have electric propulsion systems powered by fuel cells. Because of this experience with electric drive technology, SunLine was asked to participate in the focus group.

### *Dallas Area Rapid Transit*

Dallas Area Rapid Transit (DART) operates more than 1,000 buses, railcars, and vans serve an area of approximately 700 square miles, including Dallas and 12 suburban cities. Its fleet of 877 buses covers 130 local and express routes in the area. DART has extensive experience integrating alternative fuel vehicles into its fleet. Table 5 summarizes the DART bus fleet. It has operated LNG buses since 1998 and has significant potential to expand its fleet to include advanced technology vehicles. NREL conducted an evaluation of DART's LNG bus experience, which was summarized in a report published in October 2000 (see reference 18).

**Table 5. DART Bus Fleet**

| Type | Current Number |
|---|---|
| Diesel Buses (40-foot, 30-foot) | 597 |
| LNG Buses (40-foot) | 184 |
| CNG Trolley Buses (30-foot) | 20 |
| **Total Bus Fleet** | **801** |

Although DART hasn't actually operated electric propulsion buses, it is currently researching the technologies for potential integration into the fleet. The knowledge gathered, along with the experience it has in implementing alternative fuel vehicles into its fleet, gives DART a unique perspective to this focus group. DART's report, *Technical Assessment of Advanced Transit Bus Propulsion Systems,* is posted on the AVTA Web site (see reference 22).

# Appendix B: Focus Group Responses to Questionnaires

## *New York City Transit*

**What are your reasons for implementing advanced technology buses?**
To reduce bus fleet exhaust emissions, improve fuel economy, improve customer satisfaction, and improve reliability.

**What problems did you encounter in integrating the technology?**
All major components of the hybrid buses have undergone redesign. Intermittent electrical problems (no defect found) are particularly difficult. Electrical harnesses need high-quality connections. Service manuals and training materials need to be developed. Logical and practical troubleshooting guides need to be developed and used. Service and parts manuals need to be accurate and useful. Parts need to be available.

**What advice would you give to other transit agencies that are thinking about implementing electric propulsion buses?**
Be prepared to spend time and money to support the development of a new technology. Get the support of senior management, which should understand that new technology, in addition to incremental cost, brings a risk of experiencing difficulties or even failure. Have a contingency plan if the technology doesn't work. Don't jeopardize your ability to provide service. Deal with well-established companies that will put up their own money to develop the product, are committed to commercializing the technology, and will support the product when things don't go well. Be wary of companies that are only interested in being paid for development work.

**What is your overall impression of the technology and your experience?**
NYCT is excited about hybrid-electric propulsion. We are certain that this technology represents a fundamental improvement in energy efficiency, offering improvements in emissions, fuel economy, and performance—all at the same time. However, we are very aware that the technology still needs to prove it can be reliable and cost-effective. We adopt an approach that tries to be objective and even scientific. We remain highly optimistic and, at the same time, purposefully skeptical in order to objectively test, evaluate, challenge, and ultimately improve the technology.

**What are the top three things that need significant work and investment in order for electric propulsion systems to become mainstream?**

1) Diesel engines and exhaust aftertreatment systems that are sized for hybrid buses and meet EPA urban bus certification standards need to be developed.
2) Energy storage systems that are reliable, cost-effective, and maximize the energy recovered from regenerative braking need to be developed.
3) Diagnostic and troubleshooting systems and tools need to be easier to use; positive identification of failed components needs to be more achievable.

**What went well that was a surprise?**
The initial acceleration and gradeability are exceptional. Hill holding is implemented in a unique and effective way.

**What one thing would you do differently in your project?**
I can't think of anything I would do differently.

## *Orange County Transportation Authority*

**What are your reasons for implementing advanced technology buses?**
Lower emissions, greater fuel efficiency, greater brake efficiency, quieter vehicles, and improved acceleration.

**What problems did you encounter in integrating the technology?**
Battery life; technology must be closely monitored.
As parts failed, they were upgraded in one bus and measured against the baseline bus.

**What advice would you give to other transit agencies that are thinking about implementing electric propulsion buses?**
Make sure you can afford to have the staff "baby" the new bus. You also need to have the maintenance staff and facilities to handle high voltage on the bus.

**What is your overall impression of the technology and your experience?**
High capital cost to achieve less-than-expected fuel efficiency gain.

**What are the top three things that need significant work and investment in order for electric propulsion systems to become mainstream?**

1) Batteries energy storage
2) Optimizing internal combustion engine and electric drive combination
3) Reduce weight

**What went well that was a surprise?**
The reliability in service reached 90% before buses were returned to install the parallel drive. Coach operators like accelerating from electric drive, especially when climbing hills. Fuel economy gains from diesel hybrid electric technology were less than expected.

**What one thing would you do differently in your project?**
More staff involved in learning about the technology.

## *Santa Barbara Metropolitan Transit District*

**What are your reasons for implementing advanced technology buses?**
The primary stimulus for the implementation of battery-electric bus service in Santa Barbara was a desire to increase ridership. When the project was originally conceived in 1989, it was believed that a creative "repackaging" of urban buses (generally viewed as a stagnant technology) might serve to increase interest in public transit and help overcome the psychological resistance that prevents many Americans from patronizing such services. Electric propulsion enabled quiet, exhaust-free, odorless operation, and proved to be an immediate success with riders.

**What problems did you encounter in integrating the technology?**
Metropolitan Transit District encountered numerous problems relating to both the novel propulsion system and conventional bus systems unrelated to propulsion. Foremost among the propulsion system problems was variable day-to-day driving range resulting from fluctuations in battery condition. A pragmatic and long-term commitment to making the technology work by the managers, operators, and maintainers of the buses overcame the problems that came up. This commitment was maintained by the enthusiastic reception the buses receive from the community.

**What advice would you give to other transit agencies that are thinking about implementing electric propulsion buses?**
It is critical that the operating agency have a thorough understanding of the benefits and limitations of electric buses prior to procurement and operation. This includes a strong familiarity with the maintenance requirements of the various battery options, and the influence that local climatic extremes will have on battery performance and longevity. It is essential that the application is thoroughly defined prior to selection and procurement of electric buses and that effective personnel training programs are implemented.

It has also been the Metropolitan Transit District's experience that simple systems are oftentimes more effective than sophisticated (complex) ones and that efforts to improve vehicle performance through the use of advanced technologies do not always yield the intended benefits.

It is also helpful to have an adequate spare-bus ratio in order to ensure uninterrupted service during periods when the "newness" of electric-bus technology manifests itself in problems with vehicle reliability. Such periods can be minimized by strictly following all practices recommended by manufacturers of the bus, battery, and ancillary components.

The longstanding Santa Barbara experience with electric buses has proven that the technology can be successfully deployed in carefully selected transit applications. The Metropolitan Transit District's success with, and commitment to, electric buses is probably best reflected by current plans to integrate an additional 40 electric buses into its public transit fleet.

**What is your overall impression of the technology and your experience?**
The technology has steadily improved over the last 12 years. Metropolitan Transit District has a successful battery-electric fleet, and we're proud of its accomplishments.

**What are the top three things that need significant work and investment in order for electric propulsion systems to become mainstream?**

1. Electric-propulsion systems on transit-quality buses from established bus makers would be number one on the list. Many electric buses were built by "boutique" builders, and their limited experience with the rigors of transit operations has been a serious shortcoming in electric buses.
2. Electric propulsion systems need to utilize battery technologies that are truly maintenance free. This does not simply mean that watering is not required; the battery must also not require load testing, cell replacements, inspection of intercell connections, or cleaning.
3. More of #1 and #2.

**What went well that was a surprise?**

Reception of electric buses by the community wasn't really a surprise, but the intensity of the community's support for the project surpassed expectations.

**What one thing would you do differently in your project?**

An intensive management and mitigation policy for technical risks should be part of any new technology project. Metropolitan Transit District has learned that the promises of new technology need to be demonstrated.

### *SunLine Transit Agency*

**What are your reasons for implementing advanced technology buses?**
Since 1992 our goals have been:

1) Air Quality: We see Los Angeles smog coming into the valley through the pass.
2) Overall Environment: Tourism and agriculture are the main industries in the area.
3) Health Effects

**What problems did you encounter in integrating the technology?**
With the CNG buses, there were early pressure relief device problems because of the immature technology. These problems were solved.

For the fuel cell bus demonstration there were no problems on SunLine's part. Maintenance was done by an original equipment manufacturer. We did have an issue with liability—if an agency participates in demo project and doesn't own the bus, insurance agencies have a problem covering the bus. This happened with the ThunderPower fuel cell bus demonstration. We had to have the fuel cell bus shadow another bus for three months before the insurance company would allow passengers to ride in revenue service. Another issue early on with fuel cell buses operating on hydrogen was codes and standards. SunLine raised this issue early on, and now there is much progress being made by both government and industry.

**What advice would you give to other transit agencies that are thinking about implementing electric propulsion buses?**
Before making a decision, learn all you can about the technology. Visit other transit agencies that have experience with the technology. There is a very high risk associated with being an early adopter of technology. It was difficult with CNG, it will be worse with fuel cell buses. Transit agencies will have an advantage if they have experience with CNG.

**What is your overall impression of the technology and your experience?**
Experience was great. Our concerns for the future are affordability, durability, and reliability.

**What are the top three things that need significant work and investment in order for electric propulsion systems to become mainstream?**

1) Reliability/Durability of the Fuel Cell
2) Cost
3) Infrastructure (for Hydrogen)

**What went well that was a surprise?**
With the ThunderPower bus, that it worked so well. We expected some difficulties, but they never happened.

**What one thing would you do differently in your project?**
Better planning for funds to cover project. It is easy to underestimate time, manpower, and other the needs it takes to run a project with advanced buses. It also took much more effort and time to maintain infrastructure.

## *Dallas Area Rapid Transit*

**What are your reasons for implementing advanced technology buses?**
Texas Clean Fleet program was fuel-based and was later revised to be an emissions-based program.

**What problems did you encounter in integrating the technology?**

- Multi-tank LNG systems did not fill, fuel economy was low, spark plug life was low, high fuel cost per mile, cylinder head valve and valve seat eroded (burn path)
- Oxygen sensors and calibration misfired
- Lack of tank information from supplier

**Based on your research, what advice would you give to other transit agencies that are thinking about implementing electric propulsion buses?**
Build your knowledge base on the technology and what's required for your specific service needs. Try not to introduce too many new technologies at once. There is a steep learning curve for maintenance staff with any new technology. You need to know what training is required to get workers up to the base level for the new technology. Plan for the transition by training staff about the new buses. This will be necessary for any large implementation of the technology.

**What is your overall impression of the technology based on what you've learned?**
We have determined fuel cell buses are not cost effective for DART at this stage, but we are very excited about hybrids. DART is investigating hybrid buses and plans to purchase a number of them by 2010.

**What are the top three things that need significant work and investment in order for electric propulsion systems to become mainstream?**
We would like to see reduction in capital cost of the buses, improvements to battery technology, and a demonstrated reliability of the buses in revenue service.

## *Federal Transit Administration (FTA)*

**What is FTA's perspective on the status of electric propulsion technology in transit?**
Hybrid propulsion systems for transit are in the early stage of commercial market introduction—a Generation I stage. Battery electric buses for certain niche applications are at the commercial stage. Transit agencies, however, need to look at the capabilities of battery buses and the needs of their specific application.

**What advice would you give to transit agencies looking at advanced technology buses?**
The key to success is to match the capabilities of the technology with the requirements of each agency's duty cycle. An agency must have a good understanding of what it takes to operate and maintain advanced technology buses. Also, the riding public has shown they like the new cleaner and quieter technologies. Although difficult, agencies should try to quantify the public relations benefit of using these technologies.

**What other activities does FTA have in the area of electric propulsion transit buses?**
The FTA is in the process of pulling together a comprehensive fuel cell bus program. The main goal is to achieve zero-emission, fuel-efficient buses. We see electric propulsion technology, including battery, hybrid, and fuel cell, as the path to this end. All work on electric drive systems help to push us closer to the goal. In the late 80s, FTA programs helped transit place natural gas vehicles into their fleets to help reduce pollution. That same kind of effort toward funding capital costs of electric propulsion vehicles would go a long way to pushing the technology to commercialization.

**What is the job/role that transit is playing in developing this technology?**
Transit has been at the forefront of advanced propulsion technology. Both FTA and transit agencies have critical roles to play in transition from R&D to commercialization. Transit systems also can help pave the way for light-duty applications. There are synergies for the work done in all transportation applications.

## *U.S. Department of Energy (DOE)*

**What is DOE's perspective on the status of electric propulsion technology in transit?**
DOE views transit applications as an ideal use for advanced electric and hybrid technologies. The size, performance requirements, and operational characteristics of transit buses allow for easier integration of electric and hybrid systems than in any other vehicle class. Although many issues are still being addressed, great advances have been realized recently and the remaining barriers are deemed far from insurmountable.

**What advice would you give to transit agencies looking at advanced technology buses?**
Transit agencies that are looking at advanced technology transit buses should collect information on all available technology options before locking in on a specific technology. Information sources include government programs, such as DOE's Advance Vehicle Technology Analysis and Evaluation Activities, transit and advanced vehicle associations, and transit agencies that have experience with advanced technology buses. Once this information has been obtained and reviewed, an educated decision on the appropriate technology for the agencies mission and vehicle requirements can be made.

**What other activities does DOE have in the area of electric propulsion transit buses?**
DOE is investing significant time and resources to develop batteries, motors, controllers, and other electric and hybrid vehicle system components that will improve efficiency and reliability while lowering overall vehicle costs. These technologies will be used in various models of advanced technology vehicles, ranging from passenger cars and light trucks to heavy-duty trucks and transit buses.

**What is the job/role that transit is playing in developing this technology?**
DOE is encouraged by the willingness of forward-thinking transit agencies to place advanced technology buses in revenue service and use their experiences to assist the manufacturers in improving and refining these technologies. This will ultimately allow advanced technology transit buses to reliably and cost-effectively serve in revenue service with other transit agencies across the country and thus help reduce the use of petroleum in the United States.

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This document provides background to transit agencies and other fleets who are considering the use of electric propulsion technologies in their fleet. It tells potential users what to expect and what to plan for when implementing vehicles with electric propulsion systems (such as dedicated electric vehicles, hybrids, and even fuel cells) into their fleets. This document also addresses the unique issues that electrical integration can pose for fleet personnel and points to the similarities between implementing electric propulsion and any other significant new technology into vehicle operations.

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