Advanced Energy
909 Capability Drive, Suite 2100
Raleigh, NC 27606-3870
919 857-9000 | www.AdvancedEnergy.org

Hybrid Electric School Buses: The Road to Reduced Fuel Consumption, Healthier Children and Cleaner Air

Final Report

July, 2009

This document was prepared by Advanced Energy.

Primary Authors
Jeff Barghout
Diane Cutler
Josh Lawrence
Ewan Pritchard
Robert Underhill
Ken Dulaney

Table of Contents

Background

In June 2006, Advanced Energy was awarded a grant under the State Technology Advancement Collaborative (STAC) program administered by the National Association of State Energy Officials (NASEO) with the objective of promoting the market adoption of an efficient, sustainable, near-term advanced vehicle technology through direct market intervention. The award amount totaled $840,000 and was passed through to school districts that purchased plug-in hybrid electric school buses from International Corporation (IC). This project was a resounding success and resulted in the first commercially available plug-in hybrid vehicles in the United States. Project results and other information can be found at www.hybridschoolbus.org. This document is the final technical report required as part of the STAC award. This report contains no patentable, classified or proprietary information.

Introduction

School buses are an integral part of the U.S. transportation sector. There are more than 440,000 school buses in the United States that transport over 24 million children on approximately 10 billion student trips each year. Nationwide, school buses consume an estimated 1.1 billion gallons of diesel fuel every year, and produce thousands of tons of air pollutants.

Like the rest of the transportation sector, school bus fleets are facing the same challenges of increasing fuel costs and more stringent emission limits. They also face the challenge of adverse health due to the impact poor air quality has on this nation's children. There are several ways to address these challenges, including more efficient engines and use of non-petroleum based fuels. A solution promoted in the passenger car and transit bus markets is hybrid technology.

The Hybrid Electric School Bus (HESB) Program was initiated in 2002 when Advanced Energy formed an advisory group to lay the groundwork for the development and deployment of plug-in hybrid school buses. With funding from several key sponsors, Advanced Energy completed technical and economic feasibility studies that demonstrated plug-in school buses would prove to have valuable socio-economic benefits over conventional buses. Overall, plug-in technology was determined to be a good fit for school buses because their typical transportation style consisting of slower speeds with frequent stops and starts. This, combined with a daily cycle of less than 100 miles per day lends itself to the benefits of plug-in technology. Another important factor was the benefit of reduced diesel emissions that directly affect the young children who ride school buses daily.

Advanced Energy formed a consortium representing bulk purchasing power and awarded a 20 bus order to International Truck and Engine Corporation in 2006. The first generation of buses included:

- 6.0 L, 210 hp diesel engine
- Enova Systems hybrid system with:
    - Plug-in capability
    - Post-transmission parallel drive
    - 80 kW Hyundai electric motor
    - 35 kWh Li-ion phosphate battery pack

International manufactured and delivered a total of 15 buses in 2007 and 2008. Five of the 20 buses were not manufactured or delivered due to funding shortfalls. Table 1 below lists the HESB Program distribution.

Table 1: HESB Program School Bus Distribution

Date Delivered	No. of buses	District	State
March, 2007	2	Florida Department of Transportation (Manatee County)	FL
April, 2007	1	Jennings Transportation (Nazareth, PA)	PA
May, 2007	2	North Carolina Dept. of Transportation (Wake County, Mecklenburg County)	NC
June, 2007	1	Little Rock School District	AR
June, 2007	1	Lake Chelan School District	WA
August, 2007	1	Napa Unified School District	CA
October, 2007	2	South Carolina Dept. of Education (Rock Hill, Columbia)	SC
November, 2007	1	Austin Independent School District	TX
December, 2007	1	Sigourney Community School District	IA
December, 2007	1	Nevada Community Schools	IA
August, 2008	2	New York State Energy Research and Development Authority (NYSERDA)	NY
Not purchased	1	Durham School Services (Everett)	WA
Not purchased	1	City of Seattle	WA
Not purchased	1	Killeen Independent School District	TX
Not purchased	1	Fairfax County	VA
Not purchased	1	DC City Schools (Washington, DC)	DC

Upon delivery of their buses, each district hosted a press event to announce their purchase and educate the media and local community on the benefits of plug-in hybrid technology. All of the press events were well received and helped to create a platform for continued media coverage nationwide. Since August, 2007, Advanced Energy's tracking service has documented nearly 400 media hits regarding the Hybrid Electric School Bus Program.

In March of 2008, International started manufacturing plug-in school buses for the open market at a $100,000 premium. As a result of the Hybrid Electric School Bus program, school buses are the first commercially available plug-in vehicle in the nation. Since that time over 20 other hybrid school buses have been delivered by International outside of our program.

District Participation

Each district in the program plays a unique and valuable role through their continued participation. District representatives champion the cause in many ways. They collect and report data, provide their buses to be used for educational and outreach activities, avail themselves to the media to help educate the community on the merits of the technology, and promote the purchase of plug-in hybrid buses. For example, Napa Unified School District learned that Vice-President Gore would be in town and made arrangements to have their bus available for Mr. Gore to see.

Fuel economy and maintenance data is collected by each district and reported to Advanced Energy where it is tracked to evaluate overall performance and trends. Every plug-in hybrid is paired with a diesel-engine control bus of similar make and model to help in evaluating fuel economy improvements over conventional buses. Data collected from both the control bus and plug-in hybrid are input to an on-line database by district personnel. Advanced Energy uses this information in evaluating the data.

Problems and Issues

As to be expected with any prototype, the plug-in buses have had a few problems since their deployment. All of the problems to date have either been corrected or are in the process of being corrected. The list below provides a summary.

- Battery Pack Modification – IC designed the initial hybrid buses with a single battery pack located behind the driver. This detrimentally impacted the balance and handling of the buses more than expected. To correct this design flaw, IC installed 1,400 pounds of steel ballast on the opposite side. This additional weight noticeably decreased fuel economy. Later model year buses were designed with a split battery pack that evenly distributed the weight. Earlier models were retrofit with split packs at no cost to the districts.
- Plug Cords – Six of the buses reported burned receptacles on the plug face of the charging cord where it connected to the bus. IC and Enova determined that this problem was caused by an electrical short in the plug due to insufficient or absent tinning of the plug wires. Enova fixed the problem by installing new plugs for all the affected buses and issued a service bulletin to eliminate the problem from happening on new buses.
- Bus Programming – Data from the Nazareth, PA bus consistently showed the control bus had better fuel economy than the plug-in hybrid bus. When the plug-in hybrid bus was serviced, the maintenance provider discovered that the hybrid system control program had somehow been reset or deleted causing the bus to

operate without any hybrid system benefits. The programming was reinstalled and now the plug-in bus is out-performing the conventional diesel bus.

- Hybrid System Control – Initial models used a simple control algorithm for the hybrid system that did not properly integrate with the diesel engine controls. Later models used a more complex algorithm that now accounts for engine operations and other feedback mechanisms. Most of the earlier models have been retrofit with the corrected control programming and have increased fuel economy.
- Remote Monitoring – Both plug-in and control buses were initially equipped with a remote monitoring system from IC called AWARE. It used the existing cell phone network to transmit real-time location and performance data to a secure website for viewing by fleet managers. Advanced Energy anticipated that this system would provide data that would help to improve fleet performance. However, the system proved to be unreliable and relatively difficult to administer. Another option was provided by Enova Systems but this system also proved to have issues that limited its usefulness for our program.
- Data Collection – Data collection has proven to be one of the most difficult issues for this program. As mentioned above, remote monitoring has had limited success despite attempts with two different systems. There are data entry errors and missed entries when we rely on district personnel. We've also attempted on-board data logging that records performance information to a removable memory card. However, this requires intervention by the operators or district personnel to switch memory cards and send the data for analysis. Advanced Energy continues to try new ways to collect information on the performance of the buses.

This combined list seems daunting but is not unusual for new technologies just entering the marketplace. Most of the fleet-wide performance issues have been resolved and we are now dealing with bus-specific issues. However, this requires detailed data in order to diagnose issues.

Monitoring

Online Database

Advanced Energy has created an online database used to gather and analyze the fuel consumption data of each hybrid school bus. Throughout the monitoring period, fuel and electric consumption, mileage, fuel cost and maintenance records are being collected on both groups of buses for each school district by the drivers or district owners. All data is posted on a website created and managed by Advanced Energy. This data allows us to properly establish vehicle performance for each district and find out where our efforts need to be focused in order to optimize this technology. The initial problems with this method of data gathering are a potential for human error and a varied level of district participation. Because data is manually recorded, input to a website, and then extracted for analysis, there is a possibility to be receiving invalid data. Through our other methods of performance analysis we are creating a way to verify all data gathered through the online database. The districts are playing an integral role in our performance analysis; however, we are running into participation issues. Gaps in recorded data make performance analysis less accurate and keep us from establishing correct vehicle performance for each district. New data gathering methods are being explored.

Dynamometer Testing

A portion of the STAC funds supported a chassis dynamometer test of a 2006 model hybrid bus using three standard drive cycles: Torrance City, New York Bus, and West Virginia University Suburban (WVUSub). Results from these tests have show upwards of an 85% improvement in fuel economy when compared to a conventional diesel bus. WVUSub was selected as the preferred drive cycle for detailed analysis because it was developed after extensive testing and research by West Virginia University. The other drive cycles were created using less rigorous methods The conditions represented in the WVUSub cycle are also most representative of typical school bus driving conditions for the majority of school districts.

During dynamometer testing, data was collected primarily from the Panther System, a unit designed by Enova Systems to log data broadcast on the bus' Controller Area Network (CAN). Many parameters are logged, including information about the engine, transmission, vehicle dynamics, electric motor, and hybrid system batteries. Fuel usage was measured in several different ways, but this study only uses the Panther fuel data, as it is the most suitable and accurate for second-by-second analysis. Tailpipe emissions were also logged for both the hybrid and conventional school bus.

Table 2: Dynamometer Test Results

	MPG	THC	CO	NOx	CO2	PM	NO	NMHC	NO2
Diesel	7.1	0.479	2.773	6.043	1435.1	0.158	5.64	0.479	0.404
Hybrid	12.9	0.624	2.401	3.64	793.8	0.105	3.08	0.624	0.564
Change	82.3%	30.4%	-13.4%	-39.8%	-44.7%	-33.5%	-45.5%	30.4%	39.8%

As indicated in Table 2, there is a noticeable decrease in emissions as well as a substantial increase in fuel economy. These results compare very favorably with modeled results predicted when Advanced Energy staff simulated the performance of a plug-in hybrid school bus using industry standard software. Based upon this close agreement, we anticipated similar performance at the fleet level. This has not proven to be universally true. Some hybrid buses are performing very well and achieving nearly 80% increases in fuel economy compared to the control bus running the same route. Other hybrid buses are not seeing significant improvements and are actually achieving nearly identical fuel economy to the control buses. Advanced Energy is currently evaluating all the factors that impact the performance of each bus.

Panther Wireless Module

Several of the hybrid buses are equipped with a Panther Wireless Module (PWM) developed by Enova Systems. This system records hybrid system parameters as well as general engine operating parameters by monitoring the Controller Area Network (CAN). The CAN is the modern standard for in-vehicle communications systems. The PWM then transmits recorded data over the wireless cellular network to a server monitored by Enova. Figure 1 shows the PWM.

Figure 1: Panther Wireless Module

One of advantage of the PWM over other CAN loggers is the ability to transmit data wirelessly. This eliminates manual retrieval of data from the logger, saving both time and money. The wireless feature also allows data to be viewed in real-time, which can aid in diagnostics.

Enova System's PWM records dozens of parameters about the vehicle's engine, transmission, electric motor, batteries, and more. At the current stage of the hybrid-electric school bus project, these modules are useful in tuning the hybrid drive system to maximize its benefits. The PWM data also provides quantitative evidence of the advantages of the hybrid-electric drive over a traditional diesel bus with respect to fuel economy, power, and drivability.

The PWM allows the fuel economy of both hybrid-electric and traditional diesel buses to be analyzed for real world driving conditions. This has a distinct advantage over dynamometer testing because actual bus routes are used instead of standard drive cycles. However, the PWM can still be used for dynamometer testing because of its ease of use.

Next Steps

To date, the primary efforts were focused on building the base users group and insuring that the buses worked properly. Dynamometer testing showed the HESB performance potential; however, real world results varied significantly. Based on the data and input from the districts, continuous, incremental improvements have been made by the buses.

2009 began a new phase in the HESB program with an increased focus on individual bus performance. A major goal over the next year will be to quantify how the buses perform in varying real-world conditions/applications. Advanced Energy understands the future success of electric, plug-in and hybrid technologies is dependent on a logical deployment - matching need with capability. Poorly matched technologies to applications typically result in diminished use and acceptance. It is in everyone's best interest to deploy HESBs where they will perform well and make a positive impact. Quantifying how and where plug-ins, hybrids and conventional buses make the most sense will enable individual districts to understand and justify the best deployment strategies and thereby improve acceptance.

In order to better quantify bus performance, electronic data acquisition systems will be used - increasing the fidelity of the data collected, while reducing the data collecting burden on participants. This should result in a better understanding of how each bus is performing under varying real-world conditions and enable Advanced Energy to troubleshoot issues and make recommendations to districts. In other words, does the bus work for a particular district's application? If it does, what can be done to make it work better? If not, what is needed to make it work with specific routes and conditions?

In addition to the technical aspects of the program, Advanced Energy will expand the outreach initiative. There will be increased interaction with districts to better understand their individual needs and to troubleshoot issues in a more timely manner. Additionally, there will be a renewed effort to build regional "HESB Communities" consisting of interested parties such as industry, local electric vehicle groups, universities and high schools. These HESB Communities will help build the needed support to expand the program and promote the advancement of the HESB's capabilities. The larger the grass-roots support, the better the business case is to continue to evolve the plug-in hybrid bus – which in turn means a more capable, lower cost bus for the districts.

Conclusions

The HESB program has been a tremendous success. It resulted in the development and sale of the first commercially available plug-in hybrid vehicle in the US. Additionally, the program increased the acceptance and dissemination of advanced transportation technologies that use less fuel, save money, and are gentler on the environment. The contributions made by each of the districts have been critical to the success of the program. Over the coming year, increased emphasis will be placed on individual bus analysis and outreach initiatives. Quantifying HESB capabilities and increasing community involvement in the program should have tangible benefits to the participating districts.

Advanced Energy would like to thank all of the participants for their continued dedication and support. If there are any questions, please contact Jeff Barghout at Advanced Energy, JBarghout@AdvancedEnergy.org or 919-857-9000.