Wednesday, August 4, 2010

A Green Yellow Bus Arrives

by Leo Wiegman and Jim Arwood

On Earth Day 2010, a dedicated group of 8- and 9-year-old students at South Shore Public Charter School in Norwell, Massachusetts, learned they had been chosen America's Greenest School, beating out 550 other schools. The children erupted in a happy frenzy. Their entry, a mock-newscast and tour of the school's numerous green initiatives, landed them first prize in a contest with over a million ballots cast for the top 10 projects.

When the award was announced in her classroom, "I actually heard the cheers from all around the school," said teacher Sarah Roberts. The school will receive a hybrid bus from the contest sponsor, IC Bus, as well as a $20,000 green audit to improve the school building, $3,000 in scholarships and a concert by the contest's official band, The Maine.

IC Bus will deliver one of its new plug-in hybrid electric school buses, valued at $200,000. The new bus uses an induction electric motor, lithium ion batteries and power-management software to improve fuel economy by up to 65% and reduce greenhouse gases by up than a third.

Ewan Pritchard poses on one of Wade County's hybrid school buses. Photo by Roger Winstead, North Carolina State University

"The plug-in hybrid kind of gives you all the benefits of the electric vehicle as well as the reliability of both systems added on to one another," says Ewan Pritchard, program manager of the Advanced Transportation Energy Center (ATEC) at North Carolina State University and a consultant for the nonprofit research group Advanced Energy, where in 2002 he launched a program looking into the potential of the plug-in hybrid electric school bus. "What we have here is not only the first plug-in hybrid electric school bus in the world. We have the first commercially available plug-in hybrid in the world."

School buses transport some 26 million school children each school day in the United States. The vast majority run on diesel fuel, annually using more than 300 gallons of diesel per child passenger. The emission of particulate pollutants from diesel engines has long been a known source of poor air quality. Exposure is particularly dangerous for children because they breathe in 50% more air per body weight than do adults. Along with many states, the U.S. Environmental Protection Agency (EPA) has long investigated how to reduce children's exposure to diesel fumes during trips and from bus idling.

Since 2006, federal law has required all diesel-powered vehicles to run on low-sulfur diesel fuel, which has helped reduce the emission impact of diesel engines. All the same, the EPA lists 40 individual chemical compounds in diesel exhaust as toxic air contaminants that cause cancer. Cleaner alternatives such as propane and natural gas are available but have been slow to catch on.

In 2001, the Coalition for Clean Air and the Natural Resources Defense Council released some startling research. Based on careful monitoring of school bus fleets in California, researchers concluded that a child riding inside of a diesel school bus may be exposed to as much as four times the level of toxic diesel exhaust as someone riding in a car ahead of it. Around the same time, Advanced Energy's Pritchard began to investigate the feasibility of bringing plug-in hybrid technology to the school bus market.

Pritchard had examined the possibilities of the plug-in hybrid school bus in his master's thesis at nearby North Carolina State University, where he's currently pursuing his doctorate. He found that plug-in hybrids could save school districts money and cut emissions. Pritchard estimated that such buses could achieve a 95% increase in fuel economy by drawing power from the battery pack for the first 45 miles of a trip, with a 40% improvement the rest of the way. School buses travel an average of 50 to 150 miles per day.

Conventional hybrids charge their batteries through regenerative braking while driving, whereas plug-in hybrids also recharge by plugging into the electric power grid while stationary. The internal combustion engine and electric engine in plug-in hybrids are separate but parallel systems. Plug-in hybrids typically have more battery capacity and a different control strategy than standard hybrid vehicles, as well as a method for plugging into a charging station or outlet.

Advanced Energy chose to pursue plug-in hybrid technology with rechargeable batteries over conventional charge-sustaining hybrid systems. They did so because plug-ins had the potential to reduce harmful tailpipe emissions more substantially than conventional hybrids could. With plug-in technology, the capability could exist to drive the bus solely on the rechargeable batteries while near schools or other locations where children would be nearby. In short, for school buses, reducing harmful diesel fumes remains even more important than raising fuel economy.

"Plug-in hybrid technology offers the benefits of potentially reducing harmful emissions, diesel fuel consumption and the maintenance costs of buses," says Ken Dulaney, director of the industrial and commercial solutions division at Advanced Energy.

"We have 35 kilowatt-hours' worth of lithium-ion batteries," says Pritchard about the resulting buses. "We can fill them from the electric port on the side of the bus. For the first 44 miles of its daily trip [the bus is] predominantly pulling electricity from that battery pack and adding it to the drive shaft [in order] to reduce the fuel consumption."

The Hybrid Electric School Bus (HESB) project also evaluated the buses' technical and economic feasibility. They produced a basic design for the buses and examined the economics of the buses from a school district's perspective. Advanced Energy then formed a buyers' consortium to guide the manufacture of the buses, identify funding for the buses and serve as the initial purchasers of the first generation of the hybrid buses. The consortium included school districts in 12 states who agreed to rigorous performance monitoring on the buses.

Among other findings, their technical feasibility study revealed two key gaps. Bus manufacturers needed a reliable, powerful hybrid drive system that could integrate the combustion and electric engine power for heavy vehicles such as school buses. Electric drive system manufacturers needed an adequately funded pilot group of heavy-duty vehicles for which to develop the new inverter innovations to commercial scale for deployment.

Moreover, a big economic hurdle remained: startup funding and knowledge transfer sufficient to help this program cross the valley of death between initial technology development and successful market deployment. The project's original manager, Ward Lenz, describes it as "a chicken-and-egg situation" that required bringing potential manufacturers and purchasers together for a technological step forward that would be expensive at the outset.

By mid-2005, Advanced Energy's HESB team had amassed sufficient technical and economic information to submit a cost-sharing application to the State Technology Advancement Collaborative (STAC), a pilot program to spark energy-related innovation by leveraging expertise and funding across state lines. STAC was funded by the U.S. Department of Energy and administered by the National Association of State Energy Officials (NASEO) and Association of State Energy Research and Technology Transfer Institutions (ASERTTI) between 2002 and 2007.

"The STAC funding was critical to enabling the project. The initial costs of the plug-in hybrid buses were very high, and these funds helped offset those costs," says Staci Haggis, a project manager at Advanced Energy.

STAC agreed to fund $840,000 of the $1.89 million price tag on the delivery of up to 20 hybrid school buses. The project's participants would contribute the remaining $1.05 million in cost-sharing and in-kind services.

As a result, Advanced Energy and the buyer's consortium developed detailed specifications for the new buses and then put out a call for RFPs from several bus manufacturers. They chose IC Bus, a well-established bus manufacturer, which partnered with Enova Systems for the hybrid drive system.
"We've been doing this for almost 20 years," says James Baladamenti, Enova's global marketing director. "Our system

will integrate into a broad range of chassis platforms, and we have the expertise to integrate the drive systems with the other vehicle functions, such as ABS brakes, air conditioning, heating and power steering."

Of the three hybrid drive technologies that Enova has developed, the post-transmission hybrid drive system promised the most benefits for use with the IC Bus chassis platforms. In this drive system, the electric motor and combustion engine work in tandem, assisting each other to drive the wheels during acceleration. When the driver brakes, the electric motor recharges the batteries. Another benefit of this drive system is that it could be easily integrated into a production line or as a retrofit onto an existing diesel engine bus.

The requirements specified by the buyers' consortium included performance standards, battery-depleting ranges and the life cycle cost of the bus. In 2007, IC Bus and Enova delivered the first plug-in hybrid electric school buses. As of mid-2010, Advanced Energy is monitoring 15 hybrid buses located throughout the country, with several others deployed independently beyond the scope of the program.

"STAC did have a long-lasting impact. When the STAC funding came through, that boost enabled the project to happen," says Haggis. "If we had not had STAC funding, it is fair to say that we would not have plug-in hybrid school buses on the road today."

What has Advanced Energy and the buyers' consortium learned from the testing and monitoring program? Real-world data on performance suggests that fuel economy can be increased substantially by replacing conventional diesel with a plug-in hybrid bus. When operating in charge-depleting mode during neighborhood driving characterized by many stops and starts, somewhat hilly terrain and slow speeds, the hybrids' median fuel economy was approximately 75% higher than the median control bus fuel economy. The savings on intra-city or highway routes were lower—47% and 2%, respectively.

The monitoring program did not take direct measures of tailpipe emissions. The estimated benefits of plug-in hybrid bus specifications point to a potential reduction of particulate matter by as much as 90% and a 60% reduction in NOx (oxides of nitrogen) emissions.

"It's is not just the hybrid technology that you have to adjust to optimize bus performance. All the other parts of the bus transport system—from the bus driver to the route planner to the mechanic—can have a major influence on fuel economy and emission reduction," notes Dulaney.

Four important observations emerged about the plug-in hybrid electric school buses.

Three address the human components of the system. First, route selection is critical to performance. Plug-in hybrids perform best on routes that have low average speeds and many starts and stops.

Driving style can affect fuel economy achievements. The highest efficiency derives from nonaggressive driving techniques, accurate and timely data collection and maximizing midday recharging time for the battery set.

Maintenance personnel must be trained to troubleshoot and repair basic hybrid system issues. If maintenance staff are not trained on subsystems specific to plug-ins, the hybrid vehicles may suffer excessive downtime for even relatively minor technical issues.

Availability of charging infrastructure may help to improve fuel economy savings. Installing multiple charging locations would allow batteries to recharged midday. The fewer miles a bus travels solely to reach a power plug, the higher the fuel savings.

The estimated benefits of operating a plug-in hybrid bus include a greatly reduced annual fuel cost. If a school district's electricity rates are $.10/kWh, and a plug-in hybrid bus achieves 1.25 miles per kWh while operating on battery and 7.4 miles per gallon while on diesel, the plug-in's electricity cost is the equivalent of $.60 per gallon. That is a huge savings compared to diesel prices of $2.80 per gallon.

These developments open new customization options for school districts beyond reducing tailpipe particulate emission and fuel consumption. In early 2010, IC Bus delivered a CE Series plug-in hybrid bus to Irvington High School in Fremont, California, that had been customized with a smaller wheel base and special-needs lift in order to make the bus accessible to wheelchair-bound students. The goal was to reduce the cost of transporting special-needs students.

According to David Hillman, director of marketing for IC Bus, "The last few rows of seats are removable, making room for up to four wheelchairs. This enables students to go with their classmates on field trips, rather than being transported in a parent's car or another van."

Data being gathered by North Carolina State University from the plug-in hybrid bus in nearby Wake County and hybrid buses in other districts will be used to make future improvements. Going forward, Advanced Energy will focus on the development of second generation bus technology that includes a full 'engine off' drive capacity. This would allow a bus to operate solely on batteries as it approaches a line of waiting school children, emitting no exhaust while the children are boarding or disembarking.

"This is just the beginning of plug-in hybrid school buses," says Ewan Pritchard. "We're helping drive the momentum forward and helping the manufacturers understand what they need to know to get the vehicle to be even better."

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