TRANSIT TRAINING

FLORIDA DEPARTMENT OF TRANSPORTATION AND THE CENTER FOR URBAN TRANSPORTATION RESEARCH

FLORIDA MAINTENANCE TRAINING PROGRAM

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SPECIAL EDITION

Hydrogen and Hybrid Electric Transit Technologies

In support of the "Assessment and Evaluation of Alternative Fuel Options for Florida's Mass Transit Systems Study," the FDOT Office of Public Transportation asked CUTR to conduct a follow-up program to the March 2005 Fuel Options for Florida Transit Forum. The program would be a conduit for providing up-to-date information about biodiesel, hybrid electric, hydrogen, and ultra low sulfur diesel transit technologies. The Fuel Options for Florida's Mass Transit Summit was held in April 2006. Facilitated by Stephen Reich, Director of the Transportation Program Evaluation and Economic Analysis (TPEEA) Program at CUTR and Principal Investigator for the study, the Summit was successful in addressing technology concerns and bringing current industry information to the audience.

Two special edition newsletters will provide summaries of Summit presentations. In this issue, summaries of the presentations on hydrogen and hybrid electric transit technologies are included.

Hydrogen Transit Technology Part I: Myth or Emerging Reality?

User's Perspective

Doug Byrne, Project Manager
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The Fuel Cell Program

The Fuel Cell Program (FC Program) operates three zero emission buses and two fueling stations and will ultimately test up to nine light duty vehicles. Additionally, the FC Program provides on-site production of hydrogen and on-site fleet management. Independent, objective evaluation by the National Renewable Energy Laboratory and the University of California-Davis is an integral part of the Program.

Fuel Cells

Fuel cells are electro-chemical devices that convert hydrogen and oxygen into electricity; what comes out of the tailpipe is basically water vapor and heat but no emissions. There is no need to re-charge a fuel cell; as long as it is supplied by hydrogen and water, it will produce electricity.

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Transit—A Good Choice for Technology Development

Transit settings are excellent for testing fuel cell technology. As a transit agency with a very diverse service sector—steep hill runs, flat trunk lines, high speed cruising on trans-bay routes, and stop and go theater routes—AC Transit can push the limits of the technology by providing all of the necessary environmental components for hydrogen bus demonstration, except for conditions of extreme heat.

Transit also provides the advantages of centralized fueling and maintenance; the size of the bus provides excellent public exposure for awareness about new technologies.

AC Transit initially tested an ISC prototype bus that had 8,000 revenue miles and was at the end of its useful life expectancy. In was placed in service in areas for which it was not designed and performed very well, achieving a gasoline equivalent of 7.5 mpg. Though the availability was not what AC Transit wanted, the acceptance by the public was extraordinary.

AC Transit Fuel Cell Program Buses

The current buses are based from a standard diesel 40' A330 Van Hool. They look much like standard transit vehicles except for cowling at the top where equipment is located. The buses are equipped with a Van Hool chassis, a UTC 120K fuel cell power plant, and hybrid integration by ISC. The buses were designed and successfully tested for 18% sustained grades with seated load; expectations of miles per hour were exceeded when the buses demonstrated ability to reach 65mph (not a routine speed).

The bus includes, at the very front on the roof, an electronic cooling system for drive motors and inverters and eight SCI Type 3 hydrogen storage tanks (carbon filter wrapped aluminum) that can hold up to 50kg of total fuel storage providing for a range of 250-300 miles. Through regenerative braking, additional power is created for acceleration and climbing deep grades.

The air conditioning unit is a C-track all-electric drive unit with all compressors and floor motors contained within the unit. An extraordinarily large radiator system is necessary for the hydrogen fuel cell power plant, not because it produces high grade heat, but because it produces a lot of low grade heat that needs to be dissipated. At the rear of the bus is the fuel cell power plant, at the side are the inverters, and below are the 2, 85K drive motors and the gear box. The three Zebra battery packs are located behind the front wheels. The bus is a full low-floor model with platforms in the back for seating that are reached by stepping-up.

The performance, power and speed are consistent with what would be expected from diesel; the ride quality is probably better, and the virtually noiseless environment is a feature diesel does not provide. The first thing passengers comment on is the quiet atmosphere. ACT has received complaints from the public that the buses sneak up on them; normal squeaks and rattles muffled by engine noise on conventional diesel buses are readily noticed on these quiet buses.

AC Transit believes that the reliability and durability of hydrogen fuel cell buses will be at acceptable or better levels. The buses have been in revenue service for about four months and have done very well.

Fuel economy is excellent, reaching 7-7.5 equivalent mpg and, under controlled conditions, 10 mpg (1 kilogram of hydrogen roughly equals 1 gallon of gasoline).

The technology is set up as "plug and play"; components such as the battery pack and fuel cell can be changed out and, as technology improves, upgrades can be plugged in—the buses were designed with advancements in technology and ease of upgrading in mind.

ACT is exploring the potential of using the buses as emergency power sources; the 120K power plants and the mobility of buses make an excellent combination for rolling energy sources fueling hospitals, police stations, etc.

The cost is somewhat staggering at $3.1 billion, but much of the current cost covers the initial and ongoing research and development. ACT is currently working on the development of a new fuel cell bus for another transit agency; the projected cost of this bus is significantly less at $2.2 million, so the cost is already starting to decrease.

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Hydrogen Transit Technology Part II: Myth or Emerging Reality?

Manufacturer's Perspective

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Beginnings of a New Era: Hydrogen Infrastructure

Looking to the future, Chevron has been involved in the development of hydrogen as a potential source for meeting the growing energy demand through environmentally friendly, zero impact fuels. Hydrogen can be produced in many ways and from many sources such as crude oil, coal, solar, hydro, wave, geothermal and biomass. Vehicle fleets/centralized fuel supply, high quality distributed power, and defense and specialty infrastructures are seen as early stage market opportunities and early adopters of hydrogen technologies.

Chevron is involved in several hydrogen fueling demonstration projects in California, Florida and Michigan. These projects are designed for fuel cell vehicles and stationary power applications. Primary objectives of the projects are to explore safe and practical hydrogen technologies in real-world settings and to identify technical challenges and subsequently, find solutions.

Demonstration Projects: California

Chevron's first hydrogen energy station opened in February 2005 in Chino, California. The Chino project is a small-scale project limited to a fleet of six vehicles powered by hydrogen fuel cells, hydrogen is produced on site. This Chevron-lead effort is part of a five-year USDOE program and is a collaborative effort with Hyundai Motor Company and UTS Fuel Cells.

California is also home to another Chevron hydrogen demonstration collaborative: the Oakland Hydrogen Energy Station. Chevron and AC Transit have designed and implemented a state-of-the-art fueling station that provides hydrogen for three fuel cell buses and ten light-duty vehicles. This project was formally dedicated in March 2006 and is discussed more fully in the newsletter's AC Transit article.

Infrastructure Development: Florida's Role

Closer to home, Chevron has joined Progress Energy, Ford Motor Company and the Florida Department of Environmental Protection to develop a small-scale hydrogen energy station in Orlando. The station will serve up to eight Ford V-10 (Model E450) Shuttles Buses with Hydrogen Internal Combustion Engines and will produce hydrogen on-site utilizing natural gas reformer technology.

Natural Gas to Hydrogen: Reformation Process

Hydrogen that is produced by reformation of natural gas works this way: natural gas is introduced into a hydrogen generation unit where it is reformed into hydrogen-rich reformate and travels as such to a compressor. From the compressor, the reformate is sent to a purification unit, then to a storage compressor where it is turned into high-pressure hydrogen and sent to hydrogen storage; from storage, the hydrogen is dispensed to pump.

The Future & Challenges Faced

Chevron has learning goals over the next five years. By 2010, Chevron and its demonstration project partners plan to know which hydrogen technology performs the best, is the most economically viable, and deserves further funding and development.

All of this experience and knowledge is necessary to learn how to overcome some of the challenges associated with transition to a hydrogen fuel economy. Not only is hydrogen expensive to produce—there are also limitations on station storage capacity as well as on-board storage capacity. Fueling stations are not fully tested, learning curves are steep, costs are high, and hydrogen-related experience is limited. Fuel cells are expensive and need improvement in reliability, durability and performance. There is a need for substantial public education especially in the area of hydrogen safety.

Hybrid Electric Part I: Gap Filler or Long Term Technology?

User's Perspective

Ed Bart, General Manager, Vehicle & Facilities Maintenance
HART (Hillsborough Area Regional Transit)

HART ventured into the world of hybrid electric bus technology in the 2004, when the agency implemented three Gillig buses with Allison parallel drive train technology.

The significant capital investment in the buses prompted HART to look closely at cost justifications as data on fuel economy, maintenance costs for parts and labor, and emissions from the last 18 months were collected and reviewed. Clean air is a clear benefit of hybrid technology. Although it can be measured and quantified, clean air cannot be converted to actual dollar benefits. However, at 4.6 mpg and a goal of reaching 5 mpg, the hybrids are achieving fuel economy; at 60,000 average miles of service, the maintenance and labor costs are minimal.

The price of hybrid technology is coming down. Today, the cost of each vehicle would be approximately $50,000 less than what HART paid. HART's data suggest that, with 30 hybrid buses, $232,440 in fuel savings alone could be realized; however, more data and time are needed to fully evaluate costs versus benefits.

Smooth Ride, Great Graphics

Feedback from drivers and patrons is positive. Passengers love the bright graphics and smooth, quiet ride. Drivers love they way the buses operate and the smoothness of ride, which could be attributed to weight distribution—the location of the batteries on top might be a big factor.

Clean Air

As HART was searching for ways to further justify acquisition costs, Cummins approached the agency with a request to test current emissions on the old system in preparation for the 2007 EPA guidelines. HART agreed to the testing with the stipulation that the hybrids also would be tested.

Routes 1 and 32 were selected as the test routes to compare and contrast the two technologies. Two 40' Gillig buses and two 40' hybrid electric buses were used. The Cummins data indicated that significant emission reductions were achieved with the hybrid electric technology. Total hydrocarbons were significantly reduced; reductions in CO, CO_2 and NOX also were realized.

Fuel Economy/Accelerator Torque

When the hybrids were first placed into service, the drivers immediately realized the buses were too quick from the curb. Program changes in accelerated torque were needed. The original settings were at the maximum torque output of 0.18; adjusted settings were 0.12 (parameter can go as low as 0.8). The results were safer acceleration and better fuel economy. The torque acceleration might be changed again as HART continues to explore ways to achieve its goal of 5 mpg while maintaining acceptable accelerator torque.

Maintenance Economy

The hybrids are basically a 40' Gillig bus with a hump where the batteries are located; the AC is on top and drive train is a blended torque parallel system.

Some maintenance issues were encountered: lift pump failures were resolved by switching the 24-volt supply originally installed with a 12-volt supply. In addition, there was an EGR failure in one unit, and voltage regulator failures in two units.

At 60,000 miles of service, the brakes are barely worn. There have been no issues with the batteries. Replacement cost for a battery pack ranges from $25,000-$40,000, with a realistic projection of $30,000-$35,000. Actual battery life and whether batteries will last the advertised life of 5 years is a potential issue.

Conclusions

So far, HART's overall experience has been good. The biggest benefit is clean air. As HART collects more data and becomes more experienced with the technology, the agency will share the findings, including data related to battery life, brake life and the efficiencies/economies of fuel and maintenance.

Hybrid Electric Part II: Gap Filler or Long Term Technology?

Manufacturer's Perspective

Gary Willms, Vice President, Business Development
ISE Corporation
www.isecorp.com

Since the company's conception in the mid 1990's, ISE has been primarily dedicated to the development of hybrid-electric drive systems for heavy-duty vehicles and to the development of vehicle prototypes. Company founders sought to combine the combustion engine (as the primary power source) with an electric motor power storage system that would function as the secondary power source.

The primary bus applications offered by ISE are gasoline, diesel, hydrogen-hybrid and hydrogen fuel cell with long-term developmental projects for a 40' total battery electric that would run on lithium ion batteries. This battery-powered bus would initially be heavy in weight and cost but it is projected that with time this technology could be a viable option, given battery technology continues to make the same progress as it has been making in the past few years.

With an eye to the future, ISE is currently working with San Diego Transit and other transit agencies on the development of a compressed natural gas (CNG) hybrid. Though seen as more costly largely due to the complexity of technology, projections are for a 30-50% fuel savings over conventional CNG vehicles. Traditionally CNG vehicles have less torque at the start but with hybrid systems there is immediate torque helping with the acceleration phase.

Technology inclusive, ISE is also working on grants that would help fund research and development of projects to explore and build hybrid drive systems that could utilize any type of fuel—ethanol, propane, diesel, gasoline, etc. The Ford V-10 engine (the same engine used for the ISE hydrogen fuel cell buses) will be the one used in these developmental efforts.

Gasoline Hybrid System

Billed as cost-effective and good for large buses with combined inner city and highway service, ISE delivered New Flyer 40' transit buses with Ford V10 engines to Long Beach Transit in March 2005. It is estimated that this technology will significantly reduce exhaust emissions, require less fuel and maintenance and, thus, reduce the cost of ownership for the transit agencies who acquire this type of transit technology.

The ISE website states the following about gasoline hybrid technology: "Despite the lower energy content of gasoline compared to diesel fuel and the less efficient spark ignition compared to diesel ignition, the ISE hybrid technology maintains fuel consumption on a par with conventional diesel buses being replaced."

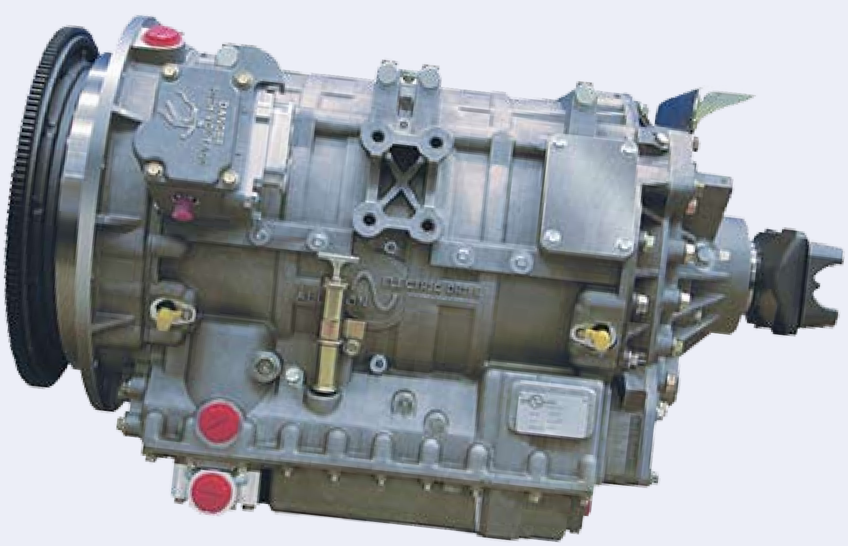
It is important to remember that though fuel efficiency is very good with gasoline hybrids, one needs to be careful with what you compare gasoline to as fuel; engine efficiencies are only about 20% less in gasoline products when compared to diesel fuel. CNG is more of an equivalent to gasoline hybrid technology. Gasoline hybrids demonstrate between a 30%-40% improvement in these efficiencies over CNG.

Looking for a financial incentive to invest in gasoline hybrid? Ford Power Products offers a maintenance savings with their V10 engines. The initial cost of the engine is approximately $6,000; at the end of the 6 year engine cycle Ford will take the engine back in trade and provide a replacement engine for about $2,500.

Diesel Hybrid Drive Systems

ISE, Allison and BAE diesel hybrid systems compare favorably. The system used by ISE consists of:

- Cummins ISB02 5.9 liter engine
- Electrically driven power steering, braking and air conditioning accessories (components allow the engine to stop without loss of accessory functionality)
- Advanced control system including features that shut off the engine when vehicle stops helping to increase fuel economy and decrease emissions



Hydrogen Transit Technology Part I—cont'd. from p.2

As part of the Fuel Cell Program, ACT is collaborating with Chevron and Hyundai-Kia on a DOE light-duty vehicle demonstration project. Up to nine fuel cell vehicles will be made available for use by ACT's road supervisors; ACT will be testing the trucks until about 2009.

The primary hydrogen fueling station is located in Oakland and provides on-site natural gas reformation; excess hydrogen will be used for the stationary fuel cell that will supply power to the facility. This station opened in November 2005 and incorporates a divider wall to seal off the hydrogen; fire and gas protection systems warm of leaks, if an alarm sounds ventilation is upped to six changes an hour.

In 2007, ACT will implement a new infrastructure facility that will produce hydrogen through a solar-powered, pressurized electrolyze process. This totally renewable fuel process will bypass the compressor system, a big step in technology development.

Training, Education & Outreach: Keys for Success

ACT has remote data collection capability; performance information, vehicle location, fuel levels can all be accessed from any location, making this a valuable tool for program management and maintenance. The remote data collection tool will be used a part of the outreach efforts and incorporated into a learning center ACT is developing adjacent to the Oakland fueling station. The Center will provide the general public with the opportunity to learn about hydrogen and fuel cell technology, see working fuel cells, and learn from other education and awareness exhibits.

The maintenance staff receives comprehensive training; as the program expands all aspects of hydrogen fuel cell technology and vehicle components will be incorporated into the training. Safety and storage issues will be important parts of the training design. AC Transit Board Members, employees, and first responders (police, fire and rescue) have received training about hydrogen and hydrogen safety as part of community outreach and awareness efforts.

Hybrid Electric Part II—cont'd. from p.5

- Choice between ultracapacitors and advanced nickel sodium chloride Zebra batteries.

New Jersey Transit (NJT) has been tracking their experiences with diesel hybrid technology. Since mid 2004, NJT Diesel hybrid buses have accumulated more than 50,000 miles of vehicle testing and operation with 40,000 miles of revenue service. Diesel hybrids are the only transit buses in the U.S. that have approached or exceeded 6 mpg —an average of 25% fuel economy over must fuel-efficient buses in the NJT fleet. NJT also found the reliability of the technology comparable or better than conventional transit technology.

Hydrogen Hybrid ICE Drive System (HHICE)

HHICE buses are a lower cost alternative to fuel cell buses. In 2003, ISE and Ford Power Products began the development of a prototype hybrid using a Ford hydrogen-burning engine and a cradle assembly similar to the ISE production gasoline hybrid systems. Currently, ISE has the first commercially-viable near-zero emission drive system for 40' plus transit buses. The HHICE bus was introduced in December 2004 and has logged approximately 15,000 miles of revenue service.

The HHICE bus has been used in an extreme cold weather demonstration project in Winnipeg during the coldest winter month where it achieved designated benchmarks of success. The bus was then placed in a tour of the Northeast United States returning to the owner of the bus, Sunline Transit for incorporation into their Palm Desert Fleet.

Fuel Cell Hybrids

The current ISE drive system offers high power and efficiency while eliminating harmful emissions. The 30' bus has achieved over 9.5 mpeg while the 40' logged over 7 Miles per equivalent gallon (mpeg). The development of the latest generation of 40' fuel cell buses was through a collaboration of ISE, UTC and Van Hool. AC Transit received 3 of these buses; see the summary of Douglas Byrne, AC Transit in this edition for more information on the AC Transit demonstration project and these fuel cell hybrids.