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Foothill Transit Ecoliner Electric Bus Program

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Abstract

Electric-powered transit buses are ideal applications to address climate change and diminishing oil supplies because they potentially offer an environmentally friendly and economically feasible option for transit agencies to consider in their move to clean modes of transport. As part of Foothill Transit's organizational commitment to innovation and environmental stewardship, we committed $6.5 million American Recovery and Reinvestment Act (ARRA) dollars to deploy three initial Ecoliner electric buses into revenue service in September 2010. The Foothill Transit Ecoliner can operate on its route 24 hours a day, seven days a week on its route, outfitted with a fast charge station. The key to this project is the utilization of the fast-charge battery which can be quick-charged from a 10 percent to a 95 percent charge in ten minutes or fewer while the bus is at a layover. Foothill Transit is the first public transit agency in the world to deploy this technology into heavy-duty transit operations. This paper addresses the Foothill Transit Ecoliner Electric Bus Program's scope, implementation, and initial challenges including utility-imposed demand charges.

Keywords: BEV, BMS, electric vehicle, EV, public transport

1 Introduction

As part of Foothill Transit's organizational commitment to innovation and environmental stewardship, the agency committed $6.5 million American Recovery and Reinvestment Act (ARRA) dollars to launch the Foothill Transit Ecoliner Electric Bus Project (herein after referred to as the "Ecoliner.") Foothill Transit deployed three initial Ecoliners into revenue service in September 2010 and is the first agency in the world to deploy this technology into heavy-duty transit operations.

The Ecoliner is a 35' composite body electric transit bus that reduces greenhouse gas (GHG) emissions from the transportation sector by leveraging advanced lithium-ion battery quick-charge technology.

The Ecoliner bus offers: zero emissions, the potential for 90% reduction in fuel costs, lower maintenance costs, a quiet drive system, and up to 90 percent regenerative braking recapture

The Ecoliner is different than most battery drive vehicles where range is dictated by the number of batteries. The Ecoliner can operate on its route 24 hours a day, seven days a week on routes outfitted with fast-charge stations. The key to the Ecoliner project is the utilization of the fast-charge battery; it will retain its energy reserve and charging profile from 8,000 to 25,000 charge-discharge cycles and can be quick-charged from a 10 percent to a 95 percent charge in ten minutes or less while the bus is at a layover. The Ecoliner battery utilizes Nanosafe lithium titanate technology, which has been laboratory tested at four to 10 times the usable charge-discharge cycles over conventional batteries and has a shelf life of up to 25 years.

Foothill Transit utilizes a fast-charge system operating directly from the grid. Mid-route, the Ecoliner pulls into the fast-charge station at the Pomona Transit Center (PTC), and docks wirelessly. The Pomona Transit Center is located in the middle of the Ecoliner's approximately 17 mile route. When the parking brake is applied by the operator, an overhead charging arm lowers down, clamps on to the bus bar located on top of the Ecoliner, and current begins to flow into the bus bar.

The Ecoliner buses are used for revenue service on Line 291, an existing "loop" spanning from the City of La Verne to the City of Pomona. The Ecoliner operates identically to existing compressed natural gas (CNG) coaches on the line, with the exception of its need to fast-charge at the PTC. With funding from the Department of Transportation's (DOT's) Transit Investments in Greenhouse Gas and Energy Reductions (TIGGER II) grant, Foothill Transit will purchase an additional 9 Ecoliners for deployment in 2013. With a total of 12 electric buses, Line 291 will be fully electrified. Foothill Transit received the largest grant in the nation under this funding program.

2 Agency Snapshot

Foothill Transit, a joint powers authority of 22 member cities in the San Gabriel and Pomona Valleys, was created in 1988 after the former Southern California Rapid Transit District (RTD) announced service cuts and fare increases that would negatively impact the San Gabriel Valley. In an effort to provide better public transportation options for the community while reducing costs and improving local control, the Los Angeles County Transportation Commission (LACTC) approved Foothill Transit's application to assume operation of 14 lines which were operated by the RTD.

Foothill Transit now operates 33 fixed-route local and express lines, covers 327 square miles, and serves 14 million customers each year.

In 2002, Foothill Transit entered a cleaner new era by beginning its conversion to a compressed natural gas (CNG) fleet. Since then, Foothill Transit has put into service 291 CNG buses and is planning to retire the last vehicles in its diesel fleet by 2013.

In 2007, Foothill Transit launched the region's first cross-valley, high occupancy bus service – the Silver Streak. Covering approximately 40 miles – from Montclair to Grand and Olympic in downtown Los Angeles – the Silver Streak route spends about five percent of its total trip time on surface streets, utilizing freeways and HOV lanes for quick commuting between designated station stops.

Electric Bus Program Background

In February 2009, Foothill Transit did not hesitate to take advantage of President Obama's economic recovery program. Foothill Transit anticipated that legislation, designed to restore a crumbling U.S. economy through the creation and preservation of jobs, was on its way. With lofty goals in mind, Foothill Transit knew that an electric bus project, deploying zero emissions buses in regular revenue service, would put the organization at the forefront of transit agencies with respect to sustainable operations. This venture would also provide prime

avenues to stimulate the transit market during grim economic times.

3.1 ARRA Funding

On February 17, 2009 President Obama signed the American Reinvestment and Recovery Act (ARRA). This comprehensive economic stimulus legislation provided $789 billion dollars in spending and tax relief to help kick start the nation's economy. The recovery package included $8.4 billion dollars for new capital investment in public transportation. Of this total, $6.9 billion was made available for capital projects eligible for funding under the existing transit formula programs. In mid-February 2009 the Foothill Transit Executive Board authorized the Executive Director to issue a notice requesting indications of interest from bus manufacturers relative to their capabilities to produce a composite body electric bus. Proterra Inc was the only entity that responded which could offer a bus and the wayside fast charging equipment that fully meets the Foothill Transit requirements. Foothill Transit was particularly interested in securing a full-system for this project as opposed to separately purchasing the components of the system.

3.2 Prototype Born

In April 2009 Foothill Transit team members took the response from Proterra Inc to the Foothill Transit Executive Board and on that date, transportation history was made. Team members explained to the Executive Board that the project not only had the potential to reduce Foothill Transit's vehicle emissions, but would also have a relatively low operating cost.

The Foothill Transit Executive Board approved a $5.8 million contract with Proterra Inc for Foothill Transit's groundbreaking electric bus project. The entire Foothill Transit Executive Board seconded the motion in unison, a first in Foothill Transit's history.

4 Bus Innovation

This is the only transit technology to offer the combination of zero emissions at the tailpipe, a significantly reduced carbon footprint on a "well to wheel" basis, and the potential for elimination of fossil fuels as an energy source, compared to conventional diesel technology.

The Ecoliner's composite body is lightweight which results in significant energy savings and its nonconductive qualities make it the safest structure for an electric drive bus. The composite structure not only protects passengers, but it absorbs energy which lowers maintenance costs in the case of an accident. The energy-absorbing feature reduces exterior body damage, making minor damages negligible, comparatively. The Ecoliner seats as many or more passengers (35-40) while maintaining the DOT 20,000 lbs per axle weight limit as compared most 40' buses due to its purpose built design using a small engine compartment. This shorter length has been engineered to reduce weight and make the vehicle more maneuverable and lighter in neighborhood environments.

5 Safety

The Ecoliner is designed with industry leading safety features allowing for the safest transport of public passengers in a quiet efficient manner, including:

- Crash and electrical resistant composite structure
- Widest temperature range and impact resistant energy storage (battery)
- Interior and exterior local and remote camera monitoring/recording system
- Redundant electrical and mechanical systems
- Limited hydraulic and fuel lines which reduces fire hazards
- Forward motion front door places passengers into driver's field of vision when exiting and crossing the bus
- Low center of gravity with independent front suspension for best in class handling
- Built in automatic fire sensing/suppression system
- Class leading all-wheel braking system with 200 brake horsepower (BHP) instant regenerative braking
- Anti-Lock Braking and Traction Control system

The composite structure contains the following benefits over a conventional steel body:

- Improved safety with crash-resistant composite structure
- Di-electric body material eliminated potential for high voltage ground transmission to the vehicle structure
- Less costly to maintain than conventional metal bodies; no corrosion
- 40%+ longer life
- 20-40% weight reduction

6 Noise Reduction

The zero emissions bus technology realized through the implementation of the Foothill Transit Ecoliner results in a measurable improvement of air quality and thus the livability of communities in the South Coast Air Basin. In addition to short- and long-term economic benefits, the Ecoliner program produces several intangible paybacks in terms of the community's standard of living. Clean and quiet, with a modern, attractive appearance, the Ecoliner is welcome in the communities it serves.

The Ecoliner employs the following proven advanced components to minimize noise progression both interior and exterior to the vehicle:

No engine required for normal operation

- Only noise is drive train and electric accessories such as air conditioning, power steering and air compressor
- Air conditioning is roof mounted with variable speed fans directed vertically to minimize street noise

All electric accessories

- Power steering, air compressor, air conditioning, and cooling systems are all driven with variable speed all electric drives to allow for controlled output of all such systems to minimize noise while maximizing performance and efficiency

Suspended cradle mounting structure

- Composite unibody cushion mountings to the propulsion drive system minimizes noise transmission from rotating components to body
- The vibration physics of the composite body also act to further reduce any noise

Component Layout

- By designing a vehicle around the hybrid components, the Ecoliner is able to locate specific components in opportune places not typical to a conventional low floor bus model.
- Long absent rear window returns to the transit bus
- The electronics radiator is front roof mounted allowing for ram air cooling, reducing fan noise
- The hydraulic pump is located at the steering box thus minimizing hydraulic piping, reducing noise and hydraulic system failures

GPS-based controls

- Vehicle can monitor location through on-board global positioning system (GPS) hardware
- Can create geo-fenced locations/ portions of routes where certain higher noise equipment (such as roof mounted cooling systems) can be controlled to operate at a lower maximum speed such as a hospital zone

7 Fuel Economy

The Ecoliner has demonstrated unrivaled fuel economy and life-cycle costing as calculated by recent testing. With a 30-mile range of the bus on battery power alone, fuel economy testing was conducted for the bus on simulated central business district, arterial, and commuter courses. The results were (diesel equivalent) of 21.35 mpg, 17.55 mpg, and 29.23 mpg, respectively. Considering that a conventional 40' diesel bus averages 3.8 mpg and current hybrid electric buses average 4.8 mpg, these findings indicate that the Ecoliner results in a minimum of 400 percent increase in fuel economy.

8 Energy Storage System Battery Technology

The Ecoliner is configured with a 74 kWh TerraVolt^{TM} energy storage system. The system

includes eight battery packs, each of which houses eight, 1.1 kW-hr battery modules. The TerraVolt™ system is comprised of four parallel strings each containing two packs and sixteen battery modules for a total of 368 volts per string. Each of the parallel strings is independently fused and has a contactor that is controlled by the vehicle master control system. The modules include 10 serially connected 23.0 volt, 50 Amp-hr nano Lithium-Titanate cells.

The safety control system has multiple levels. Each of the 480 cells in the battery system is independently monitored by the (BMS) Battery Management System to ensure that every cell is operating within the specified voltage range. Additionally, each module has three separate temperature sensors to immediately detect any variance. The modules are constructed using high dielectric, high thermally conductive materials to ensure that the entire battery system maintains the proper temperature while maintaining electrical isolation. The battery packs are constructed using a high temperature stainless steel enclosure and are watertight to Ingress Protection (IP) 65 rating, meaning they are protected against the ingress of dust and low pressure water jets.

The Ecoliner utilizes six battery packs and conduit layout. In addition to the battery pack's steel enclosure, each battery compartment is coated with a high temperature thermal spray coating to insulate for roadway heat and/or other environmental conditions.

Because the Lithium-Titanate battery chemistry can accept a rapid charge, complete system charging can be accomplished in less than 10 minutes. Charging of a less than fully depleted pack can be accomplished in approximately five minutes.

Battery temperature management is achieved through predictive pre-cooling methods using an active and passive rooftop mounted fully integrated all electric water-glycol based cooling system.

9 Altairnano Technology

Using a unique manufacturing process, Altairnano creates nanoparticles of titanium dioxide and other ceramic oxide materials and compounds. This flexible, patented process establishes precise control over the nanomaterial properties, including surface area, morphology, particle size and purity. The result is high-quality components including their novel nano-structured Lithium-Titanate anode material. Altairnano is developing technology that operates in the high power region previously not served by other technologies shown in the diagram above.

The principal advancement that Altairnano has made is in the optimization of nano-structured Lithium-Titanate Spinal Oxide (LTO) electrode materials that replace the graphite electrode materials found in negative electrodes of current Lithium-Ion batteries. So far these have been combined with positive electrodes from common Lithium-Ion batteries.

An electrode made with nanomaterials does not react with the electrolytes used in most Lithium-Ion systems. No reaction means that no Solid Electrolyte Interphase (SEI) barrier is formed around the electrode, making it easier for Lithium Ions to reach the surface of the electrode. And, with a nano-structured component, there's more surface area available to the ions—up to 100 times more surface area than with conventional, graphite electrodes.

The nanomaterials facilitate access to the active sites required for battery operation. What's more, the small size of the materials dramatically reduces the distance from the surface to the sites—all of which helps accelerate recharging and discharging.

10 Charger Infrastructure

One advantage to the duty cycle of a fleet vehicle is the nature of the vehicle to return at a fixed time to a predetermined location or 'layover' for operator breaks and to re-align the schedule with the fixed route time points. These layovers are often 10 to 15 minutes long and present an opportunity for the Ecoliner to recharge.

The charge system's hardware and software allows for rapid charge of the energy storage from 10

percent to 95 percent in 10 minutes or fewer. While such power transfer normally might require a substantial grid connection to feed the rapid charge rate, this unique architecture allows for lower cost and lower impact grid connections while maintaining high charge rates.

The Ecoliner buses are used for revenue service on Line 291, an existing Foothill Transit route spanning from the City of La Verne to the City of Pomona. The northbound bus travels 8.4 miles to the end of the route while the southbound bus travels 8.7 miles. The roundtrip is 17.1 miles. This line was specifically chosen for commercialization of the technology because of its roundtrip mileage, minimal deadhead from the Pomona Operations and Maintenance Facility, and its ridership demographic. Coaches on Line 291 transport five percent of Foothill Transit's total ridership annually, or 750,000 people.

After meeting with City officials in Pomona, the Foothill Transit team identified the PTC as the best location for the in-route charging station. The PTC is at the mid-point of the route, where most passengers on the northbound and southbound lines will disembark to connect to other Foothill Transit lines or Omnitrans lines. Since the bus has a capacity to travel approximately 30 miles per full battery charge, charging at PTC is the ideal operational location for installation of the charging equipment. The charging station features one central enclosure that feeds two charging arms. This design simultaneously charges two buses and utilizes existing bus bays. The PTC offers both a convenient location for the charger and the opportunity for community and programmatic development.

To assure total zero emissions, Green E certified renewable energy certifications (RECs) were purchased through broker "3Degrees," an organization specializing in hydroelectric, solar, tidal, or wind electricity generation support. With a true 'zero emissions' goal in mind, securing renewable sources of energy to offset the charge of the bus batteries is a critical component of the ground-breaking example the Ecoliner will set for the transit world.

11 Sustainability CARB Support

The Foothill Transit Ecoliner fully complements state and federal efforts to achieve ambient air quality standards as funds dedicated to this project fully support GHG reductions in the South Coast Air Basin. This project provides a vital link in helping California reach its environmental goals outlined in Assembly Bill (AB) 118, AB 32, and subsequently in Senate Bill (SB) 375. In testing, the Ecoliner bus' performance significantly exceeded the FTA goal to quadruple fuel efficiency of 40' transit buses to greater than 12 miles per diesel equivalent gallon by 2030.[1]

The CARB has already demonstrated its full support of the Foothill Transit Ecoliner and noted specifically that this project was not undertaken in response to mandatory regulation. In a letter from Tom Cackette, Chief Deputy Executive Officer of CARB, CARB concluded that:

> *"The demonstration of this technology will result in the reduction (as compared to diesel buses) of .47 tons of criteria pollutants and 77.73 tons of climate change emissions, per bus placed each year…ARB believes these emission reductions will benefit California's air quality, and help to meet California's long term clean air goals. This bus would meet the requirements of the ZEBus regulation; though CARB understands that the regulation is not the driver of this project…CARB is very interested in this project and is willing to provide support in any way possible."*

To scale back GHG levels to those of 1990, clean transit is key. As noted by the Regional Targets Advisory Committee (RTAC) in its final recommendation to CARB, transit will have to expand its services substantially over the next decade to meet these goals and to accommodate increased service demands as a result of population growth. Funding to projects like The Foothill Transit Ecoliner enables the viability of long-term policies, consistent with AB 32. Specifically, it sparks a cycle of comprehensive planning, clean

[1] Kulyk, Walter; *Presentation at EDTA Conference and Exposition,* December 2008.

fuel propulsion technologies, and green job growth.

12 Electric Drive Strategic Plan

The Foothill Transit Ecoliner and associated infrastructure provides a vital link in helping the FTA achieve the 20-year vision outlined in the *Electric Drive Strategic Plan* (EDSP). Developed in FY 2008, the EDSP not only communicates the long-range vision for transit electric drive research, it also provides the short-term research priorities necessary to ensure success.[2] By 2030, FTA expects commercial availability of zero/near-zero-emission, efficient, and affordable transit vehicles from domestic suppliers.[3] The bus outlined in this proposal meets or exceeds the proposed FTA 2030 Electric drive performance criteria today. It is estimated that the life cycle cost of the Ecoliner will be comparable to that of a CNG bus. The Ecoliner buses operate on a current Foothill Transit route under varying conditions, providing significant real-world application data, including documentation of energy savings and GHG reductions. As a result, this project provides replicable examples that can then be transferred to transit agencies across the nation.

The project complies with the SCAQMD regional regulations as well as the CARB ZEB purchase rule set to be implemented in 2012.

13 In-Service Deployment

The Ecoliner electric buses were launched into revenue service on September 7, 2011 and have successfully transported thousands of customers more than 25,000 miles.

Due to a series of scheduled upgrades at the Proterra manufacturing facility in Greenville, SC, the Ecoliners initially operated unscheduled "shadow service" on Line 291. The upgrades have been performed one bus at a time, and the third and final upgraded bus is scheduled to return to Foothill Transit in March 2012.

In September of 2011 the first regularly scheduled Ecoliner run commenced, during the upgrades. The Ecoliner is one of the first buses out on Line 291 in the morning and one of the last buses in at night. The buses operate over 16 hours per day, seven days a week, and accumulate about 160 miles each day. At this service rate this bus will accumulate about 48,000 miles per year and, as previously mentioned, is a direct replacement for CNG buses currently operated on Line 291.

In March 2012, when all of the scheduled upgrades are complete, the second regularly scheduled Ecoliner run on Line 291 will begin.

14.1 First Year Analysis

The shakedown of the buses has gone well. Coach operators and customers like the bus, technical problems (such as transmission failure) were foreseeable, and resolutions appear effective. Electric bus program marketing, vehicle introduction, and the initial operating experience have met expectations.

The cutting edge technology this project promised has met expectations. As of time this paper is written, Proterra is the first and only US manufacturer to complete Altoona testing of a heavy duty electric transit bus.

14.2 Electric Rates

As Foothill Transit becomes more deeply entrenched in this cutting edge program, challenges, some unforeseen, have arisen. First, while electricity in and of itself is relatively inexpensive, the utility-imposed midday demand charges raise the base cost of energy to charge the bus. In late 2011, Southern California Edison (SCE) migrated the Foothill Transit rate structure to one which will moderately lower peak demand charges to a more acceptable level. When the fleet expands to the planned 12 buses, this cost will lower even further. The SCE rate adjustment will put fuel costs on par with that of CNG.

At the request of Foothill Transit, in early 2012 SCE filed an advice letter with the California Public Utilities Commission (PUC) requesting that electric bus rates be covered by the "cold ironing"

[2] Federal Transit Administration; *FTA Multi-Year Research Program Plan (FY 2009 – FY 2013),* October 2008, p. 5-16.
[3] Kulyk, Walter; *Presentation at EDTA Conference and Exposition,* December 2008.

rate. PUC leadership has previously indicated they are supportive of this request as they encourage the deployment of EV buses and recognize the effects of the current rate schedules, namely demand charges, have on battery technology projects. As such, the PUC is expected to approve this request. This is clearly a step in the right direction for the future of this and other fast-charge EV projects.

14 Authors

Lauren Festner
As the Sustainability Manager Lauren leads Foothill Transit's sustainability program to assure that the agency's commitment to sustainability is made operational by developing and implementing goals, policies, projects, and partnerships that focus on promoting sustainable transit. Lauren has a Masters of Public Administration from the University of Southern California (USC) Sol Price School of Public Policy and a BA in Political Science from the University of Texas at San Antonio.

George Karbowski
George has more than 43 years of heavy-duty truck and bus fleet experience as a journeyman mechanic, supervisor, and Director of Fleet Operations and Maintenance at both LA Metro and Foothill Transit. George is a recognized expert on the use of alternative fuels in heavy-duty transit buses and was the past Project Manager of MTA's Methanol and Ethanol fleets (both the largest in the country) and MTA's first fuel cell bus project. George is the current project manager for the Ecoliner electric bus. George has been involved in the regulatory side of heavy-duty engine emissions including the writing of AB2766 and Carl Moyer grant proposals.