

ADVANCED TRANSIT VEHICLE CONSORTIUM

Los Angeles County Metropolitan Transportation Authority
One Santa Fe Ave., MS 63-4-1,
Los Angeles, CA 90012

JUNE 2, 2015

TO: ATVC BOARD OF DIRECTORS
FROM: RICHARD HUNT, PRESIDENT
SUBJECT: TECHNOLOGY UPDATES

RECOMMENDATION:

Receive and File the attached ATVC reports on Metro's Composite Bus Program, and on testing a BYD All Electric Articulated bus on Metro's Orange Line.

BACKGROUND

At the December 4, 2014 Board Meeting, ATVC Director Fasana requested that ATVC staff report back on advanced technology projects, and Metro's Composite Bus program in particular.

Attached to this is a report from ATVC's technical consultant on Metro's Composite Bus programs.

Also attached is ATVC staff's report on testing conducted with BYD's All-electric articulated bus that was demonstrated on the Metro Orange Line in December 2014.



Richard Hunt
President, Advanced Transit Vehicle Consortium

Copies: ATVC Board Members and Alternates
Phillip A. Washington, Metro CEO
Stephanie Wiggins, Metro Deputy CEO (Interim)
Robert A. Holland, Metro COO (Interim)

BYD All-Electric Articulated Bus Demonstration

In-Service Testing on Los Angeles Metro Orange Line

December 15-19, 2014



EXECUTIVE SUMMARY

The following report summarizes operating statistics, observations and findings during a test of BYD's 60' articulated bus that was demonstrated on Metro's Orange Line during the week of December 15-19, 2014.

Overall the performance of the bus and its electric battery storage and propulsion systems was impressive and showed that this bus could be suitable for limited operation as outlined in this report. Overall, the bus was positively received by operators, maintenance personnel and passengers. Vehicle performance was very good, particularly in areas of acceleration and top speed; the bus also provided a smooth, very quiet ride.

During the week of testing, there were only two reported mechanical issues, and neither was related to the batteries or propulsion system.

The limited operating range of this bus configuration would not allow for this bus to be used as a direct substitute for CNG articulated buses currently operating on the Orange Line. There may be future options to augment the operating range of this bus by utilizing mid-day re-charging at the division, and/or with periodic en-route "Opportunity Charging."

BACKGROUND

The BYD Articulated Battery Electric Bus is among the first prototypes bus of this size worldwide. The bus is powered by BYD iron-phosphate batteries, and is designed to travel 170 miles on 90% charge. The bus has 520 kilowatt hours of battery storage and is designed to carry 100 or more passengers. This is a new articulated bus design for BYD; they have delivered one other similar battery electric bus to a South American customer for testing there.

The testing methodology was to put the BYD articulated bus into limited revenue service on Orange Line, and increasing the operating mileage each day. The first day the bus ran two round trips morning run of 68 miles. The next day the bus ran three round trips afternoon run of 104 miles. By the end of the week, staff had worked the bus up to running both a morning and afternoon runs, 170 miles in total, with a 2:15 hour charge between each run.

The Orange Line was opened in October 2005 and its initial run was from North Hollywood Station to Warner Center; a run of approximately 15 miles. In June 2012, Metro added 4-mile segment to Chatsworth Station along Canoga Avenue and constructed a bridge over the railroad tracks to get into the turnaround loop at the Chatsworth terminal. The typical route during the day involves alternating terminals so that one run will start at North Hollywood and end at Warner Center and the next trip from North Hollywood will go to Chatsworth Station. The Chatsworth to Warner segment of the line (about 6.5 miles) is run by standard coaches during peak periods to provide a direct connection between the regional rail system and Warner Center. Speeds are scheduled at approximately 21 mph on average although the top speed on the line, depending on the section is 45 mph. There are 13 stations on the branch from Warner Center to North Hollywood and 5 stations on the branch to Chatsworth for a total of 18 stations. Deadhead distances are approximately 3-4 miles to start buses at Warner Center. Otherwise, a special roadway entrance from the division to the Orange Line at Prairie Avenue was constructed so that Orange Line coaches would have direct access to the line. Distance from the division to Chatsworth is approximately 1.5 miles via the bus way.

During these test runs, the operator was able to maintain Orange Line operating speed in service, while fully loaded, both on the Orange Line ROW and at the layover zones. The bus carried similar heavy passenger loads as the current CNG buses operating on the Orange Line, estimated at up to 90 passengers at peak loads.

The bus has quick and smooth acceleration from 0 to 45 mph on the Orange Line regardless of the passenger load. Except for the afternoon run on Thursday December 18, the bus ran all scheduled service without any reported issues.

The bus did leave the division late on Thursday December 18th due to a minor front door interlock repair (not related to electric propulsion system). After this issue was repaired by BYD, the operator then used the freeway from Warner Center Station to Hollywood Station to make up some time. Freeway traffic allowed the operator to attain only 59 mph, but the bus appeared to have power to go faster. Weight distribution on all three axles made it comfortable for the operator to maneuver the bus in freeway traffic and at higher speeds. The following table shows the battery state of charge and the mileage travelled during each run:

Date	Scheduled Service	Operator	% SOC Used	In Service Miles	Projected Range (Based on 100% to 10% SOC)
12/15/14	Morning	Mandeep Sagoo	52%	68	127.5
	Afternoon	Efrain Gomez	Not in service*	Not in service	Not in service
12/16/14	Morning	Mandeep Sagoo	Not in service**	Not in service	Not in service
	Afternoon	Efrain Gomez	54%	104.7	174.5
12/17/14	Morning	Mandeep Sagoo	43%	71	149
	Afternoon	Efrain Gomez	54%	104.1	173.5
12/18/14	Morning	Mandeep Sagoo	41%	67	147
	Afternoon	Efrain Gomez	53%	104	176.6
12/19/14	Morning	Mandeep Sagoo	Not in service***	Not in service	Not in service
	Afternoon	Efrain Gomez	53%	104.5	177.5

* Minor oil leak at rear axle. Bus held from afternoon service for BYD review.

** Bus held from service to install triple bike rack.

*** Division scheduling conflict (not mechanical or bus related)

The same two drivers operated the bus, one in the morning run and the other in the afternoon run, to limit variation in the driving. Based on the data provided in the table above, the afternoon driver consistently achieved average energy use of approximately 2.7 kWh/mi., while the morning driver achieved average energy use of approximately 3.2 kWh/mi. The afternoon driver, therefore, achieved approximately 17% greater range (miles) than the morning driver on a single charge of battery pack.

The bus averaged 50% SOC for 89 miles in service and the projected range (based on 90% SOC depletion of the battery pack from 100% to 10% SOC) is 160.2 miles.

PASSENGER FEEDBACK

Overall passenger feedback was very positive. BYD articulated bus color and design were unique and the vehicle received many positive comments from Metro passengers. The exterior noise level of BYD articulated bus is so low that some inattentive passengers were surprised by the bus's approach. In a few cases, some passengers stepped-off CNG articulated buses in order to ride the BYD articulated bus. Some passengers were disappointed to learn that this was only a limited test; other passengers wanted to know how many electric buses Metro intended to buy and when would they be available in service. During testing BYD's articulated bus ran with passenger loads typical for Orange Line service, estimated at up to 90 passengers during most runs (this bus did not have a passenger counter).

OPERATOR FEEDBACK

Operators' comments:

- Speed – Good take off, can go up to 50mph when needed; limited speed on freeway—maximum is 59mph.
- Braking – very smooth with no problems
- Air conditioning – works well
- Doors – No. 3 door (rear door) cannot be seen by operator from the front of the bus. Need to be able to see people going in and out. Would like a system that adds a camera view on the exterior and elimination or reduction of one of the interior battery towers so that the doors can be seen by mirrors.
- Sun visor is too small for the front. Doesn't cover enough area, although this may interfere with placement of Smart Drive
- Rear step – Steps to go to rear of bus has extra high risers and may make it difficult for passengers. Some passageways through the coach may be too narrow.
- Windshield – good view
- Left outside mirror – just the right height
- Bus height – rear part of the bus is lower than the CNG buses we operate.
- Wheelchair ramp is too slow to deploy. There is a 5 second delay and the emergency lights did not flash when the wheelchair is being deployed.
- Kneeling feature was inoperative during testing.

- Lock – the bus needs an external lock so that the bus can be locked from the outside.
- Bus was responsive in all-weather condition – rain, fog, or sunlight
- The bus overall is a great bus; the BYD representatives indicated that all of the items mentioned above are fixable.

Transportation Manager's comments:

- Bus needs rollback protection
- Additional illumination facing forward
- A camera that views the operator
- Increase passenger door width to promote faster boarding and alighting

Data collected during the test period provides valuable information for Metro and BYD. BYD will use the data to optimize the second prototype bus scheduled for Altoona testing in 2015. Metro can use the data to update current 60-ft. articulated battery electric bus specifications for potential use in future vehicle procurements.

OPPORTUNITY CHARGING

While not part of this demonstration, several firms are working to develop “opportunity charging” systems that might allow for extended range and full day operation. There are several firms working on this technology, and BYD does have operating experience working with WAVE out of Salt Lake City. Other companies that are developing similar opportunity charging systems include Eaton, Bombarier and Wampler.

According to BYD, the en-route or on-route charging for a BYD 60' articulated bus is going to cost approximately \$300,000.00 for a 200kw charger (inductive unit, no overhead wires or exposed cables. The entire unit is mounted underground), and about \$50,000.00 per bus for the secondary pad (the part of the charger that is onboard the bus). This would charge at the same rate as the BYD overnight charger but does not include the bringing in of power to the location where the in-ground unit is located. This unit will be deployed within 18 months.

Right now BYD is also testing a 50kW system for AVTA, and WAVE is demonstrating another 50kW inductive charge system in Utah as well.

CONCLUSIONS

During service, the overall operational performance of the BYD articulated bus was excellent. This bus was significantly quieter than standard CNG 40-ft. buses, and is even quieter than BYD's 40' battery electric buses. It has very smooth acceleration, deceleration and a responsive regenerative braking system. Operators were impressed with the performance and maneuverability of this bus on the Orange Line and in freeway traffic. Electric bus energy consumption rates did appear to vary significantly depending on how aggressively the bus was driven.

Metro's operating experience shows that introduction of this bus into the Orange Line operating system would require significant changes to operator training. Based on the data obtained during the test, changes to operator training for operators of electric buses would be highly beneficial. It could significantly reduce average energy use and extend effective vehicle range. Metro should consider changes in driver assignment (i.e. dedicating drivers to electric buses only rather than allowing drivers to drive electric buses one day and CNG buses the next day) and an on-going monitoring of driver average energy use combined with a recognition/incentive program for achieving low energy use. Based on the test result, there is a high probability that Metro will, one-day soon, introduce electric buses on a large scale to the Orange Line, therefore, Metro should begin planning operational changes required to optimize their use, in addition to threshold technical requirements based on current operational practice.

The bus performance was similar (maybe better) than standard CNG articulated buses, and it would not require significant changes to the traffic signal priority system, the top operating speed or the schedule time on the Orange Line. The only maintenance required to this bus involved checking door systems and axles, both standard bus repair items that are similar to equipment currently in use at Metro. The battery and propulsion system required no maintenance during the test.

Even with the extensive battery storage system on this bus, the range of this bus was inadequate and would be unsuitable as a direct replacement of existing Orange Line CNG buses. Running additional 60' electric articulated buses is not likely practical until these buses can provide at least 250+ miles operating range. Even with mid-day charging, this testing showed that the BYD 60' all electric design was able to deliver about 150 miles each day, about half of what Metro currently schedules for CNG buses on this line. While battery charge level measurements are not very precise, and battery vehicles should never be run down to a zero charge state, staff did extrapolate that this bus could have an in-service operating range of approximately 150-190 miles.

While not tested this week, there may be technical approaches available using in-route “Opportunity Charging” to increase vehicle range, similar to systems used by Foothill Transit’s Proterra buses. There are several new opportunity charging systems being introduced into the transit marketplace that could potentially extend the operating range for an electric bus. Integrating opportunity charging into Orange Line operations would have both capital and operating budget implications.

Finally, assuming there continue to be improvements in battery technologies, particularly in terms of energy storage density and battery costs, it is feasible that an all-electric articulated bus could become a more viable option for use on Metro’s Orange Line and other services in the future.

- January 15, 2015

Prepared by: John Drayton, Director of Vehicle Technology
 Kwesi Annan, Project Engineer

Intended for
Advanced Transit Vehicle Consortium
900 Lyon Street
Los Angeles, CA 90012

Document type
Report #01

Date
May, 2015

**New Transit Vehicle Technologies and Advanced
Technology Implementation (OP33203093)**

COMPOSITE STRUCTURE BUSES:

Current Experience & Recommendations For Future Bus Purchases



**COMPOSITE STRUCTURE BUSES:
CURRENT EXPERIENCE & RECOMMENDATIONS FOR
FUTURE BUS PURCHASES**

Date **May 05, 2015**

Authors **Dana Lowell and David Seamonds, M.J. Bradley & Associates**

Approved by **David Park and Garrison Turner, Ramboll Environ
Lit Chan, Ramboll Environ**

Acknowledgements: This report was developed with significant assistance from staff of the Los Angeles County Metropolitan Transportation Authority, without whose help it could not have been completed. The authors would like to acknowledge and thank John Drayton, Kwesi Annan, Amy Romero, Maria Reynolds, Dan Quigg, Gloria Derado, Lillian Ford, Rob Bauer, Sam Gold, Dac Bang, Chris Haile, Albert Ramirez, Nolan Robertson, and Paul Rankin for their help and insights.

The authors would also like to acknowledge and thank Bill Coryell of NABI Bus and Michael Hennessey, Gordon Dollar, and Brian Robinson of Proterra for their insights on manufacturing issues associated with composite bus structures.

CONTENTS

EXECUTIVE SUMMARY	1
1. PURPOSE	1
2. CURRENT COMPOSITE BUS FLEET	1
2.1 Composite Bus Description	1
2.2 Composite Bus Location and Usage	4
2.3 Operating Experience	4
2.3.1 Fuel Usage	4
2.3.2 Accident Rates	5
2.3.3 Mean Distance between In-service Failures	5
2.3.4 Bus Out-of-Service Time	5
2.3.5 Bus Operator Perspective	6
2.4 Maintenance Experience	7
2.4.1 Division Running Repairs	7
2.4.2 Mid-Life Overhauls	9
2.4.3 Major Accident Repairs	10
3. MANUFACTURER PERSPECTIVE	12
4. LIFE CYCLE COST ANALYSIS	13
5. RECOMMENDATIONS	15
5.1 Future Bus Purchases	15
5.2 Current CompoBuses	16

TABLES

Table 1	Comparative metrics for 45-ft composite buses and 40-ft steel buses.	1
Table 2	Average maintenance costs for 45-ft CompoBuses and 40-ft steel buses.	8
Table 3	Average mid-life overhaul cost.....	9
Table 4	Major assumptions for life cycle cost analysis.....	14
Table 5	Results of life cycle cost analysis.	15

FIGURES

Figure 1	Steel structure bus without body panels.....	2
Figure 2	Laying up bottom section of CompoBus structural tub in the mold.	2
Figure 3	Top and bottom section of CompoBus structural tub being joined.	3

EXECUTIVE SUMMARY

This report summarizes an analysis of the Los Angeles County Metropolitan Transportation Authority's (LACMTA) experience with operating 45-foot composite structure buses over the last ten years. Based on this experience the authors developed a life-cycle cost analysis to compare the total ownership cost of these buses to traditional 40-foot steel structure buses, as well as to hypothetical 40-foot composite structure buses.

See table 1 for a summary of comparative operating and cost metrics for LACMTA's existing 45-ft composite structure buses compared to their 40-ft steel structure buses over the last two years. Also included in Table 1 are projected total average life cycle costs for each bus type, based on the life cycle cost analysis.

As shown, compared to 40-ft steel buses LACMTA's 45-ft CompoBuses have higher mean distance between failure and lower per-mile maintenance costs, but they have significantly higher accident rates. Despite higher accident rates the average per-mile cost of major accident repairs is only slightly higher for CompoBuses than for steel buses because the average repair cost per accident is lower.

Projected average life-time total costs (\$/mile) are approximately 9% lower for CompoBuses than for steel buses despite higher purchase and overhaul costs. This is due both to lower annual maintenance costs and longer bus life (18 years rather than 14). Given their higher capacity (44 seats compared to 36) the cost advantage of 45-ft CompoBuses is even greater on a seat-mile basis; projected life-time average costs per seat mile are almost 26% lower for 45-ft CompoBuses than for 40-ft steel buses.

Table 1 Comparative metrics for 45-ft composite buses and 40-ft steel buses.

METRIC	UNIT	45-ft	
		Composite Bus	40-ft Steel Bus
Mean Distance Between Failure	mi	4,182	2,701
Maintenance Work Orders	#/100,000 mi	384	420
Total Accidents	#/100,000 mi	4.0	3.1
Major Accidents	#/10 million mi	2.9	1.1
Major Accident Average Repair Time	Days	59	123
Fuel Cost	\$/mi	\$0.37	\$0.37
Maintenance Cost	\$/mi	\$0.78	\$1.04
Major Accident Average Repair Cost	\$/accident	\$25,032	\$61,192
	\$/mile	\$0.0072	\$0.0066
Average Mid-life Overhaul Cost	\$	\$42,531	\$34,242
Projected Total Life Cycle Cost	\$/mi	\$5.40	\$5.95
	\$/seat-mi	\$0.123	\$0.165