July 24, 2020

To: Executive Board

Subject: **Cost Comparison and Fuel Technology Direction – Battery Electric Bus vs. Fuel Cell Bus**

Recommendation

Provide direction regarding the fuel technology to be used in Foothill Transit's next order of 20 buses.

Analysis

As a result of operating BEBs for the last ten years we've learned that BEBs present several challenges including, range limitations, long charging times, high electricity rates, complicated utility rate structures, and higher capital costs. To minimize or alleviate these challenges, FCEBs appear to be an alternative zero-emissions technology solution. FCEBs, however, have some challenges as well, with higher bus price and fuel cost.

As the market for zero-emissions buses matures, some of the challenges faced today can be minimized or mitigated with economies of scale and technological improvements.

Foothill Transit has an existing Transit and Intercity Rail Capital Program (TIRCP) grant to deploy 20 zero-emissions buses on Foothill Transit's Line 486, a 42-mile roundtrip route from the Pomona Transit Center to El Monte Station.

To understand the cost difference of operating a BEB versus a FCEB on Line 486, specifically, we need to consider the following elements:

- Block miles - The miles driven by a particular bus on a specific line
- Bus quantity - The required number of buses to operate on a line
- Fueling infrastructure cost
- Cost of fuel
- Scheduled maintenance cost
- Mid-life replacement cost

These cost elements are further described below.

Based on our experience of operating a 440 kWh BEB, we can confidently attain at most 150 miles of range on a single charge. So, under BEB on the chart below, any block beyond 134.88 miles will require two buses to complete that block. On the other hand, FCEB have a range of 320 miles, similar to CNG buses, and can complete any block on Line 486. As you can

see in the chart below the operation of Line 486 will require 34 BEBs versus 23 FCEBs or a 1.5 to 1 ratio of buses between the two technologies.

Line 486	El Monte Station to Pomona Transit Center					
					Bus Quantity	
Block	Start	End	Distance (Miles)	Duration	BEB	Fuel Cell
23	16:26	20:10	47.89	3h44	1	1
15	6:26	9:58	47.89	3h32	1	1
7	5:00	10:44	88.02	5h44	1	1
11	5:50	11:42	88.86	5h52	1	1
6	4:50	11:44	91.39	6h54	1	1
21	13:33	23:29	131.71	9h56	1	1
19	12:33	22:30	131.71	9h57	1	1
22	13:50	23:27	132.35	9h37	1	1
20	13:02	23:59	134.88	10h57	1	1
18	8:02	19:04	134.88	11h02	1	1
17	7:26	18:13	134.88	10h47	1	1
14	6:14	17:12	134.88	10h58	1	1
16	6:27	19:57	175.20	13h30	2	1
9	5:20	18:11	175.84	12h51	2	1
10	5:35	18:59	175.84	13h24	2	1
8	5:05	19:30	178.37	14h25	2	1
1	4:15	19:38	216.17	15h23	2	1
3	4:30	20:07	216.17	15h37	2	1
5	4:45	21:32	218.70	16h47	2	1
12	5:51	23:00	218.70	17h09	2	1
13	6:02	22:59	219.34	16h57	2	1
2	4:20	20:36	219.34	16h16	2	1
4	4:35	23:54	262.63	19h19	2	1
Fleet Requirement					34	23
Ratio					1.5	1

The number of buses needed for operations using BEB versus FCEB determines the capital cost for bus purchases under each approach. As shown below, a fleet of BEBs will cost $30.2 million while FCEBS will cost $25.3 million - a difference of $4.9 million.

Line 486	El Monte Station to Pomona Transit Center			
			Bus Cost	
	Fleet Requirement		$890,000	$1,100,000
Block	BEB	Fuel Cell	BEB	Fuel Cell
23	1	1	$890,000	$1,100,000
15	1	1	$890,000	$1,100,000
7	1	1	$890,000	$1,100,000
11	1	1	$890,000	$1,100,000
6	1	1	$890,000	$1,100,000
21	1	1	$890,000	$1,100,000
19	1	1	$890,000	$1,100,000
22	1	1	$890,000	$1,100,000
20	1	1	$890,000	$1,100,000
18	1	1	$890,000	$1,100,000
17	1	1	$890,000	$1,100,000
14	1	1	$890,000	$1,100,000
16	2	1	$1,780,000	$1,100,000
9	2	1	$1,780,000	$1,100,000
10	2	1	$1,780,000	$1,100,000
8	2	1	$1,780,000	$1,100,000
1	2	1	$1,780,000	$1,100,000
3	2	1	$1,780,000	$1,100,000
5	2	1	$1,780,000	$1,100,000
12	2	1	$1,780,000	$1,100,000
13	2	1	$1,780,000	$1,100,000
2	2	1	$1,780,000	$1,100,000
4	2	1	$1,780,000	$1,100,000
	34	**23**	**$30,260,000**	**$25,300,000**
Bus Ratio	**1.5**		**Cost Variance**	**$4,960,000**

Fueling or charging infrastructure is needed to power the buses. It will cost approximately $4 million to construct a hydrogen fueling station for delivered hydrogen. While only 20 FCEBs are needed for the project under consideration, the hydrogen fueling infrastructure will accommodate up to 30 buses. For BEBs, it will require $10.95 million for infrastructure and charger systems based on the Burns and McDonnell report.

Fueling Infrastructure		Cost/bus
Fuel Cell – Up to 30 buses	$4,000,000	$133,333
BEB - Chargers for 34 buses	$10,948,000	$322,000

FCEB fuel cost is approximately $7 per kilogram of hydrogen per recent quotes from a hydrogen supplier. Since 1 kilogram of hydrogen provides seven miles of range, the cost of fuel is $1 per mile. The BEB cost per mile is based on Southern California Edison bills for the in-route charging station at Pomona Transit Center. The average cost is $0.35 per kW and the bus efficiency is 2.16 kW per mile or $0.76 per mile. A total of 3,576 daily miles are driven on Line 486, or 1,305,112 miles annually.

Fuel Cost/Mile/Bus		Annual
Fuel Cell	$1.00	$1,305,111.63
BEB/kW	$0.76	$986,664.39

Cost for preventive maintenance or scheduled maintenance for FCEBs has declined over the last few years. Orange County Transit Authority (OCTA) in Southern California is currently demonstrating 10 fuel cell buses. According to Leslie Eudy of the National Renewable Energy Laboratory (NREL), OCTA's maintenance cost per mile at $0.12 is slightly inflated because the agency is spending extra time on maintenance as part of their FCEB demonstration project. Decline in maintenance cost of FCEBs is foreseeable in the near future.

Scheduled Maintenance per Mile		Annual Cost
Fuel Cell	$0.12	$156,613.40
BEB	$0.04	$52,204.47

Another consideration for this cost comparison is the cost for mid-life replacement. Mid-life replacement involves replacing major components that have worn out, or are no longer operable after mid-life defined as 300,000 miles of operation or six years of use. On internal combustion engine powered buses, this involves replacing the engine and rebuilding the transmission. For BEBs, the battery packs are replaced while on FCEBs the fuel cell stacks are replaced.

Mid-life Replacement Cost/Bus	
Fuel Cell	$30,000
BEB	$200,000

The chart below shows the comparative costs between BEBs and FCEBs over 12 years of life.

The chart demonstrates that the cost of operating BEBs on Line 486 is higher than FCEBs over a 12-year period by $12.9 million. The cost differential stems from the higher capital cost of BEB buses due to having to operate more buses to accommodate its limited range capacity. The costs of fueling infrastructure for FCEBs and mid-life maintenance are also lower compared to BEBs.

12-Year Lifecycle Cost Comparison		
	34 BEBs	**20 FCEBs**
Capital Cost – Buses	$30,260,000	$25,300,000
Capital Cost - Fueling Infrastructure	$10,948,000	$4,000,000
12 Year Fuel Cost	$11,839,973	$15,661,340
12 Year PMI Cost	$626,453.58	$1,879,361
Mid-life Maintenance Cost	$6,800,000	$690,000
	$60,474,426	$47,530,700
Cost Savings with FCEB	$12,943,726	

Line 486 is operated by Keolis from Foothill Transit's Pomona Operations and Maintenance facility, and they operate 16 of Foothill Transit's fleet of Proterra battery electric buses. Keolis has experience operating fuel cell buses in France and The Netherlands for the last two years. On December 17, 2019, Keolis began operating eight 60-foot articulated fuel cell buses on a Bus Rapid Transit (BRT) platform in the city of Pau, located in southwestern France. This international fuel-cell experience by our contractor will be extremely valuable should the decision be made by the Board to pursue a hydrogen fuel-cell program at Foothill Transit.

Please note that the costs identified above are our best estimates based on information that is currently available. We fully expect that our actual results will vary as we gain more experience with either of these technologies. As has always been the case with our entire zero emission bus program, we will be at the forefront of advancing this technology.

There are still many decisions that will be needed to deploy an additional 20 zero emission buses, including award of contracts for procurement of transit coaches and fueling infrastructure. Each of these items will be brought to the Executive Board for action. It will be valuable to have the Executive Board's general direction regarding fuel technology for this next group of buses. The options available to you include:

- Implementing a 20-bus fuel cell powered fleet
- Implementing a 20-bus grid powered electric bus fleet
- Returning the grant funding and delaying the deployment of any additional zero emission buses at this time.

We look forward to receiving your direction on how to proceed.

Sincerely,

Roland M. Cordero
Director of Maintenance
and Vehicle Technology

Doran J. Barnes
Executive Director