Pilot Green Transport Fund

Final Report On
Trial of Electrical Shuttle Buses on Campus (CUHK)

(7 July 2017)

PREPARED BY:

Dr. C.S. Cheung
Dr. W.T. Hung
Dr. D.W. Yuen

List of Monitoring and Evaluation Team Members

Dr. C.S. Cheung (Team Leader)
Professor
Department of Mechanical Engineering
The Hong Kong Polytechnic University

Dr. W.T. Hung (Deputy Team Leader)
Associate Professor
Department of Civil and Environmental Engineering
The Hong Kong Polytechnic University

Dr. D.W. Yuen (Project Administrator)
Teaching Fellow
Department of Mechanical Engineering
The Hong Kong Polytechnic University

Pilot Green Transport Fund
Trial of Electrical Shuttle Buses on Campus (CUHK)

Final Report
(Trial Period: 1 March 2014 – 29 February 2016)

Executive Summary

1. Introduction

1.1 The Pilot Green Transport Fund (the Fund) is set up to encourage transport operators to try out green and innovative transport technologies, contributing to better air quality and public health for Hong Kong. The Chinese University of Hong Kong (CUHK) was approved under the Fund for trial of two electric buses with associated charging facilities for shuttle service to staff and students within its campus. Through the tendering procedures stipulated in the Subsidy Agreement, CUHK entered into with the Government, CUHK procured two Wuzhoulong electric buses (EV-1 and EV-2) for trial.

1.2 PolyU Technology and Consultancy Company Limited (PolyU) has been engaged by the Environmental Protection Department as an independent third party assessor to monitor the trial and evaluate the performance of the trial vehicles. CUHK assigned two diesel buses (DV-1 and DV-2) that provided similar services as the conventional vehicles for comparing with the two EVs.

1.3 This report summarizes the performance of the EVs in the 24-month trial as compared with their conventional diesel counterpart.

2. Trial Vehicles

2.1 Key features of the EVs and the DVs are shown in Appendix 1 and photos of the vehicles are shown in Appendix 2. These vehicles were used for providing shuttle service to staff and students within its campus. Day-to-day travel for providing such service was generally less than 100 km for each EV. Each EV is designed to carry one driver with 60 passengers, including 40 standees. According to its manufacturer, the EV has a designed travel range of about 280 km per charge on flat road, fully laden and with air-conditioning.

2.2 CUHK has set up inside the campus two 125 kW charging stations to charge the batteries of the EVs as well as to record their electricity consumption. During the trial period, the EVs were only charged at these stations. It took 5 hours to fully charge the batteries of each EV. Photos of the charging facilities are in Appendix 2.

2.3 The EVs started providing routine shuttle service on 5 March 2014 but they soon encountered intermittent temporary suspension/reduction of power due to overheating of the motor during heavy load operations, when travelling up the road with high gradient, the bus operated normally afterward while the motor was cooled down. In order to prevent reoccurrence of similar situation on a hilly campus, EV-1 and EV-2 were handed back to the supplier in March 2014 for replacing with a more suitable motor and its associated system and re-obtained type approval. They were returned to CUHK and resumed normal service in early September 2014.

3. Trial Information

3.1 The trial started in March 2014 and lasted for 24 months. CUHK was required to collect and provide trial information including the EV mileage reading before charging, amount of electricity consumed and time used in each charging, operation downtime due to charging, and cost and downtime associated with scheduled and unscheduled maintenance of the EVs and the charging facilities. Similar data from the DVs were also recorded. In addition to the cost information, reports on maintenance work, operational difficulties, opinions of the drivers and recipient (CUHK) were collected to reflect any problems of the EVs.

4. Findings of Trial

4.1 Operating Costs

4.1.1 The average fuel economy and cost statistics of the EVs and the DVs are summarized in Table 1. The fuel costs comparisons are as follows: EV-1 $4.06/km (71%) lower than DV-1; EV-2 $3.73/km (69%) lower than DV-2.

Table 1: Key operation statistics of each vehicle

		Electric buses		**Diesel buses[1]**	
		EV-1	**EV-2**	**DV-1**	**DV-2**
Total distance travelled/km		19,779	20,618	48,432	52,189
Average fuel economy/	(km/kWh)	0.609	0.583		
	(km/litre)			1.95	2.04
	(km/MJ)	0.169	0.162	0.054[2]	0.056[2]
Average fuel cost ($/km)		1.62	1.69	5.68	5.42

[1] Since the EVs mainly started providing service from September 2014, the DV data collection was also started in the same month.

[2] Assuming lower heating value of 36.13 MJ/litre for diesel fuel

4.1.2 Table 2 summarizes the operating cost data of each vehicle. The total operating cost is $1.62/km for EV-1 and $1.69/km for EV-2. As compared with their DV counterparts, the total operating cost was lower by 75% for EV-1 and 70% for EV-2.

Table 2: Summary of all the costs and downtime

		EV-1	**EV-2**	**DV-1**	**DV-2**
Fuel cost/$		32,116	34,910	275,292	282,929
Maintenance cost/$[2] [3]		0	0	34,084	14,799
Other cost/$		0	0	0	0
Total operating cost/$		32,116	34,910	309,376	297,728
Average total operating cost/ ($/km)		1.62	1.69	6.39	5.70
Downtime/day[1]		323	318	0	0
By Vehicle type	Average total operating cost/ ($/km)	1.66		6.05	
	Average downtime/ day	321		0	

[1] Downtime refers to the period the vehicle is not in operation, which was counted from the first day it stopped operation till the day it returned to operation.
[2] No maintenance cost was incurred for the EVs throughout the trial period as it is under warranty.
[3] Maintenance not related to the performance of the vehicle was not included for comparison of the performance of the vehicles.

4.1.3 Apart from the fuel costs, the table also shows the average total operating costs which included maintenance costs and other indirect costs such as towing fee and vehicle replacement fee. The EVs incurred only fuel cost while the DVs incurred only fuel and maintenance costs in this trial. The average total operating cost of the two EVs was $1.66/km. Compared with the DVs, the average total operating cost of the EVs was lower by 73%, given that CUHK did not pay for the repair cost of the EVs which were still covered by warranty.

4.1.4 During the trial period, each EV had three (3) scheduled maintenances while EV-1 had ten (10) and EV-2 had twelve (12) unscheduled maintenances. Each DV had two (2) scheduled maintenances while DV-1 had seventeen (17) and DV-2 had eleven (11) unscheduled maintenances. The downtime was 323 days for EV-1 and 318 days for EV-2. Both DVs did not have reported downtime as the maintenance works were conducted in-house during non-operational hours by CUHK. The downtime of EVs were mainly incurred in the early stage of the trial (March – September 2014) when the EVs were first operated under hilly terrain and frequent start-stop conditions in the shuttle service in CUHK campus. The supplier reported that both incidents were probably due to the triggering of safety mechanism which temporarily reduced/suspended the power supply from motor operation as a result of overheating of the motor during heavy load operations when travelling up the road with high gradient. The EV was able to operate normally afterward while the motor was cooled down. The solution mainly involved replacement of the original motor from 100kW to 170kW and improving the cooling system for each EV so as to increase its power to

cope with the problems aroused. Prolong downtime was recorded during this replacement and re-acquiring of type approval period.

4.1.5 Scheduled maintenance of EVs was simpler than the DVs since the latter required replacement of filters, engine oil and passing the smoke test.

4.2 Performance and Reliability

4.2.1 The drivers of the two EVs had no problem in operating the EVs but reflected that the EVs lack of power on uphill operation and the performance of the EVs affected their normal operation. The passengers' feedback were in general positive, despite some passengers have reservation in the uphill power of the EVs and on replacing all existing conventional vehicles with electric vehicles.

4.2.2 Overall, CUHK agreed that using electric vehicle is good because it can provide a greener and quiet environment as well as its much lower fuel cost. However, CUHK would not replace all its existing conventional vehicles with the green vehicles because (a) high capital cost; (b) cost and time delay on repair and maintenance of EVs are higher compared with DVs because DVs were maintained or repaired in-house while EVs were maintained or repaired by vehicle supplier; and (c) frequent malfunction of the EVs and the charging stations.

4.2.3 To remove the effect of seasonal fluctuations, 12-month moving averages were used to evaluate the trend of the vehicles' fuel economy. For the EVs, the 12-month moving averages for EV-1 and EV-2 dropped by 8% and 5% respectively over the trial period.

4.2.4 During the trial period, there were frequent problems with the battery management system and the charging stations such that there were problems in charging the battery packs of the EVs properly. Thus, it is difficult to assess if there was any deterioration in the battery packs.

4.2.5 The equivalent CO_2 emissions from the EVs and the DVs are 38,343 kg and 56,140 kg, respectively. Result indicated a reduction of 17,797 kg (32%) CO_2 emission throughout the trial period.

5. Summary

5.1 The trial showed that the EVs had lower fuel cost as compared with their conventional diesel counterparts, with an average saving of $3.89/km or 70%. The total operating cost for the EVs was 73% lower than the DVs, given that CUHK did not pay for the repair of the EVs which were still covered by warranty.

5.2 The EV drivers found no problem in operating the EVs but the operation of the EVs was not smooth. Utilization rates were 56% for the EVs and 100% for the DVs.

5.3 There is indication that the fuel economy has deteriorated in the trial period but deterioration in the charging capacity of the battery could not be judged due to frequent breakdown of the charging system.

5.4 The trial showed that under CUHK's operating conditions where there is hilly terrain, the Wuzhoulong electric buses could not meet the user's daily mileage requirements. The frequent breakdown and excessive downtime were also conspicuous. Suggest the vehicle manufacturer should provide better technical support to the trial EVs.

Appendix 1: Key Features of Vehicles Involved in the Trials

1. Trial EV

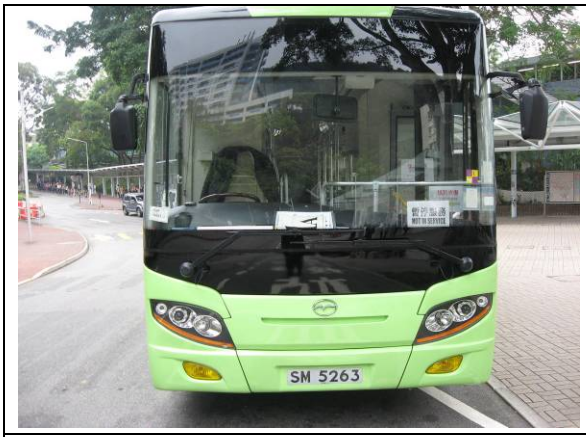
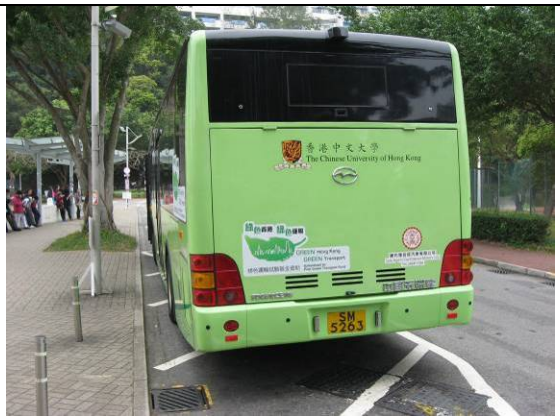
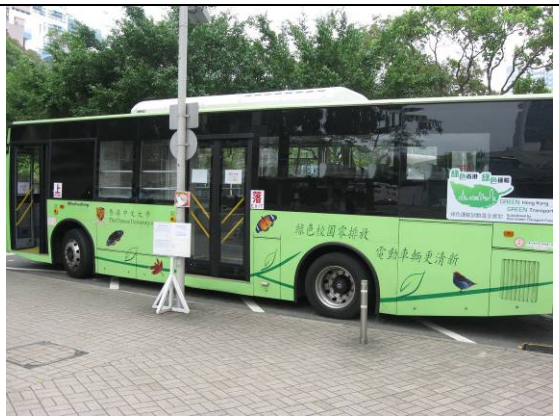
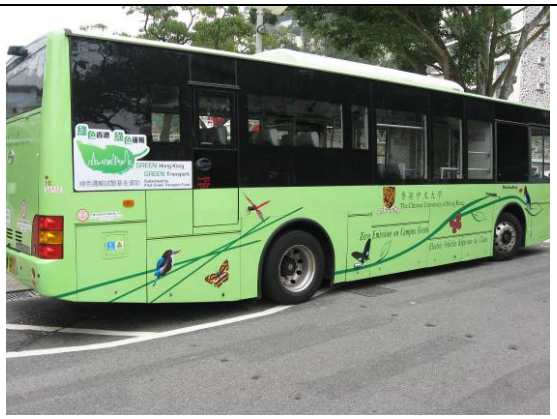
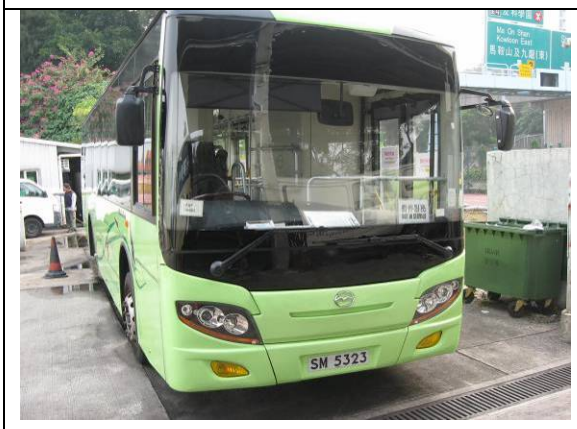
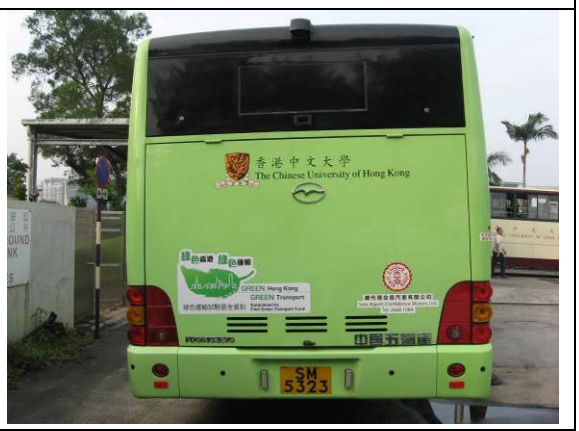
Registration Mark	**SM5263, SM5323**
Make:	Wuzhoulong
Model:	FDG6102EVG
Class:	Public bus
Gross vehicle weight:	18 tonnes
Capacity:	driver + 60 passengers (including 40 standees)
Rated power:	170 kW (upgraded from 100 kW after early breakdown)
Travel range:	~ 280 km (air-conditioning on, flat road, fully laden)
Maximum speed:	over 70 km/h
Battery material:	Lithium iron phosphate battery
Batteries capacity:	324 kWh
Charging time:	~ 4-5 hours [125 kW]
Year of Manufacture:	2013

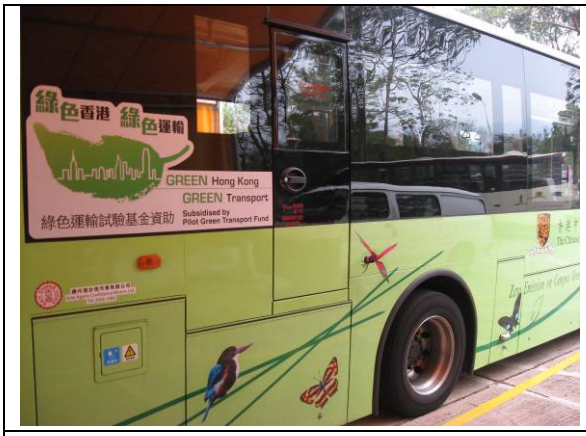
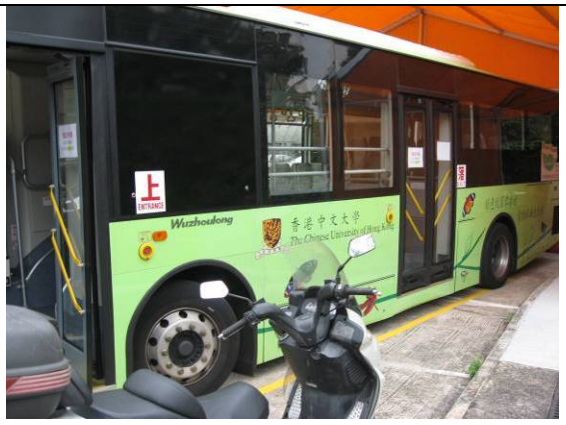
2. DV used for comparison

Registration Mark	**LN2016**	**RA5606**
Make:	Isuzu	Isuzu
Model:	LT134LR	LT134L-6S-V
Class:	Public Bus	Public Bus
Gross vehicle weight:	14.5 tonnes	14.5 tonnes
Seating capacity:	driver + 68 passengers (including 22 standees)	driver + 62 passengers (including 22 standees)
Cylinder Capacity:	7790 c.c.	7790 c.c.
Year of manufacture:	2004	2010

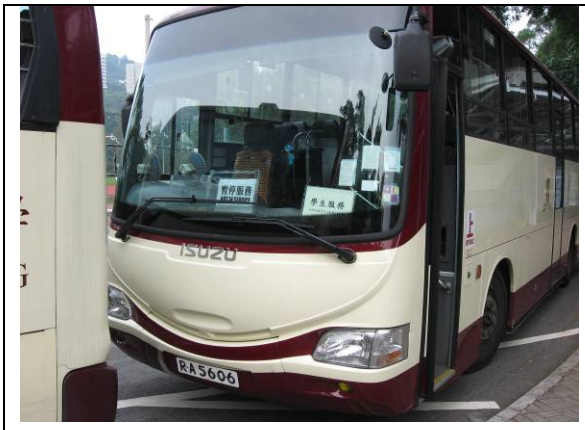
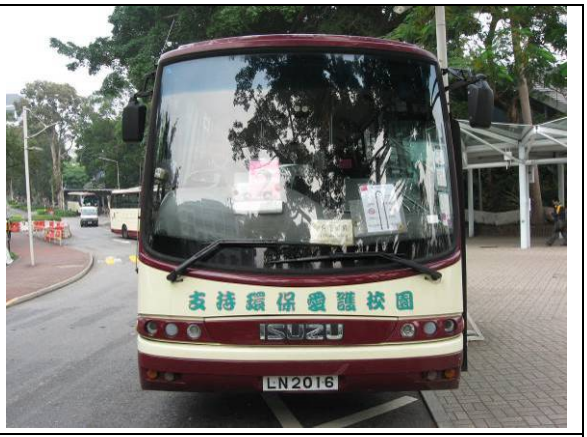
Appendix 2: Photos of Vehicles and Charging Facilities

1. Trial EVs and Charging Facilities

<table>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>EV-1 front view</td><td>EV-1 end view</td></tr>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>EV-1 side view 1</td><td>EV-1 side view 2</td></tr>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>EV-2 front view</td><td>EV-2 end view</td></tr>
</table>

	
EV-2 side view 1	EV-2 side view 2
	
Charging station with charging cable – external view	Charging station – internal view
	
Electric bus with charging cable connected	

2. DVs for comparison

	
DV-1 front view	DV-2 front view