International Scientific Journal
Environmental Science
http://environment.scientific-journal.com

The importance of new technologies in sustainable public transportation: a review for potential application of hybrid vehicle use in Turkey and a cost-benefit analysis

S. Erbas[1], H. Handan Demir[2], U. Alyuz[3], G.Demir[3]*

[1] Istanbul Metropolitan Municipality, Department of Rail System

[2] Bahcesehir University, Vocational School, Department of Business Administration

[3] Bahcesehir University, Environmental Engineering Department

Istanbul, Turkey

Presenting author e-mail: hacerhandan.demir@bahcesehir.edu.tr

Abstract— International studies on effects of climate change put concrete limits to reduce greenhouse gas emission. Significant fuel consumption and air emissions are common in cities where traffic jams exist. According to National Emission Inventory Report of Turkey, road transportation contributed nearly 10% of CO_2 equivalent emissions. The purpose of this study is to examine existing systems and to compare operating and capital costs of these systems with hybrid systems by making a cost-benefit analysis for the buses of urban public transportation. Diesel hybrid, diesel and CNG vehicles were compared in terms of life-cycle costs.

Buses as means of public transportation could considerably reduce the problems caused by traffic in the urban areas through the usage of innovative techniques and technologies of vehicle propulsion systems. Fuel costs comprise significant portion of transit budgets. Hybrid buses offer an attractive option and have the potential to reduce operating costs for agencies significantly. The hybrid technology that combines both electrical and mechanical propulsion systems has moved the technologies from demonstration stage to implementation stage. This paper reviews the advantages and disadvantages of hybrid bus operation in Turkey. It reviews worldwide practices for types of hybrids, their performance, and cost of operation, and the situations if those vehicles are adapted to Turkey.

Diesel vehicles have slightly higher life-cycle cost in comparison with diesel hybrid vehicles. Also diesel hybrid vehicles have 30% better fuel economy than diesel vehicles. CNG vehicles have the lowest life-cycle cost because fuel cost in the CNG vehicles is less than almost half of the diesel fuel cost. Initial purchase cost of vehicles is higher and there is almost no significant difference between CNG vehicles and diesel vehicles. This research showed that CNG vehicles are more economical than diesel and diesel hybrid vehicles in terms of life cycle cost and technology but they depend on diminishing fuel sources exported from abroad. Moreover, hybrid vehicles are gaining importance and their number is increasing because of their positive effect on fuel economy, air emissions and reducing our dependence on petroleum. These possibilities make hybrid vehicles better than conventional ones. In addition, better fuel economy and less usage of fuels bring more economical solution for transportation industry. The optimization of hybrid vehicles based on the vehicles road, the knowledge of the average of speed, places and stop sequence on the road should be taken into consideration to maximize yield of hybrid cars.

Keywords— Alternative Bus Technology; Hybrid and Fuel Cell Buses; Cost-Benefit Analysis

I. Introduction

Air pollution, dependence on oil, and greenhouse gas emissions are inherent in internal-combustion-engine vehicles. Fuel cell vehicles have been proposed as a potential solution to the automobiles that use internal-combustion-engine technology [1–2]. The environmental concerns and limited reserves of fossil fuels have increased the interest for alternative propulsive systems of vehicles. Buses as means of public transportation could reduce considerably the problems caused by the traffic in the urban areas through the usage of innovative techniques and technologies of vehicle propulsion systems [3]. Fuel costs comprise significant portion of transit agency budgets. Therefore hybrid buses offer an attractive option and have the potential to reduce operating costs for agencies significantly. Hybrid technology has been available in the transit market recently [4]. By 2009, there are more than 1,200 hybrid buses in North America in more than 40 transit agencies (Transport Canada 2011). The transit agency in New York had approximately 1,000 hybrid vehicles by 2009 (Maynard 2009). Information about the costs and benefits of hybrid technology attributed to use of hybrid transit buses are found in the literature [4]. The researchers reported that air emissions are lower then conventional bus [5] and fuel economy for the hybrid bus was 54 percent higher than the two regular diesel buses [6, 12]. Clark et al. (1987) [7]

evaluated six transit buses with traditional diesel engines, two powered by spark-ignited compressed natural gas (CNG), and one hybrid transit bus in Mexico City using a mobile heavy-duty emissions testing lab. Buses were tested over a driving cycle representative of Mexico City transit bus operation, which was developed using global positioning system (GPS) data from in-use transit buses. Depending on how fuel economy was evaluated, the hybrid bus ranked fourth and first in fuel economy.

Depending on the degree of electrification of propulsion system, three key electric drive technologies for the electric vehicles are: hybrid electric, battery electric and fuel cell electric technologies. A hybrid electric technology uses both an electric motor (EM) and an internal combustion engine (ICE) to propel the vehicle. Vehicles equipped with this technology are called Hybrid Electrics Vehicles (HEVs). Special case of hybrid electric technology is plug-in hybrid electric (PHE) technology. It has a battery that can be charged off board by plugging into the grid and which enables it to travel certain kilometers solely on electricity. Vehicles equipped with this technology are called Plug-in Hybrid Electrics Vehicles (PHEVs). Battery electric technology uses a relatively large on-board battery to propel the vehicle. Battery provides energy for propulsion through an electric traction motor(s) as well as power for all vehicle accessory systems. Some electric vehicles (EVs) can use to drive auxiliary devices like an on board generator, which makes them have characteristics of hybrid solutions. Vehicles equipped with this technology are called Battery Electrics Vehicles (BEVs). Fuel cells are energy conversion devices that are set to replace combustion engines and compliment batteries in a number of applications. They convert the chemical energy contained in fuels, into electrical energy. During the process, heat and water are generated as by-products. Fuel cells continue to generate electricity for as long as a fuel is supplied, similar to traditional engines. Unlike engines, where fuels are burnt to convert chemical energy into kinetic energy, fuel cells convert fuels directly into electricity via an electrochemical process that does not require combustion. Vehicles equipped with this technology are called Fuel Cell Electrics Vehicles (FCEVs). Electric drive technologies reduce energy consumption, for example regenerative braking. That allows the electric motor to re-capture the energy released during braking. This improves energy efficiency and reduces wear on the brakes [3].

Hybrid electric drive configurations consist of a fuel-burning prime power source – generally an ICE – coupled with an electrochemical or electrostatic energy storage device. These two power sources work to provide energy for propulsion through an electric traction drive system. Power for all vehicle accessory systems can be provided electrically or mechanically from the ICE or combinations of both. There are currently many different hybrid-electric system designs utilizing ICE, alternative fuels engines, gas turbines or fuel cells in conjunction with batteries [3]. These design options are grouped in three categories: series, parallel and series-parallel configurations. A series hybrid-electric drive system consists of an engine directly connected to an electric generator (or alternator). In a parallel hybrid-electric drive system, both of the power sources (engine and electric motor) are coupled mechanically to the vehicle's wheels. In a parallel hybrid-electric drive system, both of the power sources (engine and electric motor) are coupled mechanically to the vehicle's wheels. Furthermore In fuel cell drive system fuel cell is providing the electric energy needed to run of vehicles. There are two types of fuel cell drive configuration: fuel cell drive without energy storage device (non-hybrid fuel cell vehicles) and fuel cell drive with energy storage device (hybrid fuel cell vehicles). Fuel cell hybrids operate much like other hybrid electric vehicles but with fuel cells producing electricity that charges the batteries, and a motor that converts electricity from the batteries into mechanical energy that drives the wheels

There are some major advantages of electric drive technologies but there are also some disadvantages. Hybrid vehicles have lower fuelling cost and reduced fuel consumption. Therefore it is a valuable vehicle for Turkey which has expensive oil costs. However it has high initial cost and after purchasing combining two power trains is complex and components are not available in the local market and not easily accessible in international market. Additionally it has low tailpipe emissions thanks to lower fuel consumption [12]. Battery electric vehicles use cleaner energy than hybrid vehicles and battery charging period is overnight. It has lower fuel and operational costs. However battery technology is still to be improved and there is a need for recharging infrastructure. Fuel cell bus has high initial cost and it has no dependence on petroleum and has zero tailpipe emissions. It has high energy efficiency than the hybrid cell vehicle. However, hydrogen generation and onboard storage and availability and affordability of hydrogen refueling are the disadvantages for this type of buses in Turkey.

The hybrid technology that combines both electrical and mechanical propulsion systems has moved from the demonstration stage to the implementation stage. This paper reviews types of hybrids and its advantages and disadvantages for Turkey by making a cost analysis in comparison with diesel and CNG bus.

II. Materials and Methods

In this study, a numerical approach was followed in order to estimate costs. Required data was gathered from producers, municipality and fuel sellers. Finally a comparative review was prepared for three public transportation vehicle types.

Only technology-dependent factors relevant to bus propulsion were considered; driver and management cost were excluded. Bus price, equipment and infrastructure cost (to support novel technology), fuel cost, propulsion-related systems maintenance, facility maintenance were considered. Little information was found on brake life extension for hybrid

technology, but it was determined to be a relatively small cost factor [9]. Buses were assumed to be operated at an average speed of 20 km/h, to travel for 60000 km per year, and to seat 40 passengers for the purposes of calculation as performed in the previous studied [9, 10]. A bus 12-year life cycle cost (LCC) analysis for a fleet size of 100 buses was performed based on information available in the literature, manufacturers' specifications, and fuel economy data gathered. Followings are all data used for calculations of fuel consumption costs: the lifespan of each bus was considered to be 12 (T = 12) years. A fleet of 100 CNG, diesel and hybrid buses was used for calculations. The value of dimension for all buses were 12 m in length. All buses were assumed to travel 60.000 km per year. An assumed value for a conventional diesel bus fuel consumption was 48.7 liters per 100 km and a standard hybrid diesel bus fuel consumption was 32.8 liters per 100 km. According to this, it was found that a diesel hybrid-electric bus provided 33% fuel saving compared to conventional diesel bus. An assumed value for a CNG bus fuel consumption was 32 m^3 per 100 km. An assumed value for a 1 liter diesel fuel price (FP) was 4 TL/L. 1 m^3 CNG purchase cost was considered the half price of diesel pump purchase cost and an assumed value for this was 2.05 TL/L. Based on the given data, the total fuel consumption of each bus technologies were calculated using formulations below. In this study methodologies of the studies in the literature were considered [11,13, 14]

Annual fuel consumption of a bus:

$$FC\left(\frac{lt}{year}\right) = X\left(\frac{km}{year}\right) \times FC\left(\frac{lt}{100\ km}\right) \quad (1)$$

Annual fuel consumption cost of a bus:

$$FCC\left(\frac{₺}{year}\right) = FC\left(\frac{lt}{year}\right) \times FP\left(\frac{₺}{lt}\right) \quad (2)$$

Fuel consumption cost of a 100 bus fleet for 12 years:

$$FCC\ (₺\ /\ 12\ \text{years-100 bus fleet}) = FCC\left(\frac{₺}{year}\right) \times n \times T$$

FC : Fuel Consumption
X : Total Travel Distance
FCC : Fuel Consumption Cost
FP : Fuel Price
n : Bus number
T : Year

III. Results and Discussion

Results of this study is presented in Table 1. Only vehicle purchase costs used in the calculation of investment costs. In this case, all of the buses are assumed to be 12 m length. The reason is that the absence of 12 m diesel hybrid electric buses in operation in Turkey. The assumed purchase costs of the diesel and diesel hybrid buses respectively for a 40-foot diesel was $ 300.000 and for a 40-foot diesel hybrid electric bus was $ 500.000. CNG bus purchase cost assumed more than $ 50,000 in the case of the purchase cost of a diesel bus and thus $ 350,000.

This study compared diesel hybrid, diesel and CNG vehicles in terms of life-cycle cost and it was found that diesel vehicles has slightly higher life-cycle cost in comparison with diesel hybrid vehicles. Although diesel hybrid vehicles have 30% better fuel economy than diesel vehicles, there is no difference between diesel hybrid and diesel vehicles because of the high life-cycle cost of diesel hybrid vehicles. CNG vehicles have the lowest life-cycle cost because fuel cost in the CNG vehicles is less than diesel fuel cost. The high initial purchase cost of these vehicles is expensive and makes no difference between CNG vehicles and diesel vehicles. Overall, diesel hybrid vehicles are slightly economical compared to diesel and CNG vehicles in terms of life-cycle cost. This research also showed that CNG vehicles are more economical in terms of technology but they depend on outside and diminishing fuel sources. Moreover, the importance of hybrid vehicle is getting increased because of improved fuel economy, decreased emissions and reduced our dependence on petroleum. These properties makes hybrid vehicles are better than conventional vehicles. In addition, better fuel economy and less usage of fuels bring more economical solution for transportation industry. The optimization of hybrid vehicles based on the vehicles road, the knowledge of the average of speed, places and stop sequence on the road should be taken into consideration to maximize yield of hybrid cars.

Table 1. Calculated costs of different vehicle types for Turkey

	CNG	Diesel	Diesel Hybri
Purchase cost per bus	TRL 624,925	TRL 535,650	TRL 892,75
Fuel consumption cost per bus per 60,000 km	TRL 472,320	TRL 1,437,624	TRL 968,25
Purchase cost per a 100 bus fleet	TRL 62,492,500	TRL 53,565,000	TRL 89,275,0
Fuel consumption cost per a 100 bus fleet per 60,000 km	TRL 47,232,000	TRL 143,762,400	TRL 96,825,6
Life cycle cost per a 100 bus fleet	TRL 109,724,500	TRL 197,324,400	TRL 186,100,

Hybrid vehicles, especially in cities which have heavy traffic because of starting and stopping in traffic jams, can capture part of the braking energy, store it and use it to provide traction through an electric motor. This system is called regenerative break system and thanks to this system, hybrid vehicles provide better fuel economy and less gas emissions. According to results of this study, hybrid vehicles have lower fuelling cost and reduced fuel consumption. Therefore it is a valuable vehicle for Turkey which has expensive oil costs. However it has high initial cost and after purchasing combining two power trains is complex and components are not available in the local market and not easily accessible in international market. Fuel costs represent the major part of transportation industries' operating cost.

Diesel vehicles lost energy as heat during braking. The reduced energy losses and improved fuel economy makes hybrid vehicles cleaner, more efficient and economical than diesel cars in the transportation industries. The loss of energy is minimized in hybrid vehicles because of the power sources which are working in optimum level. Therefore, hybrid vehicles is more energy efficient than diesel vehicles. The extent of hybrid component is very crucial to obtain high yield on the energy efficient in the hybrid vehicles. Parallel hybrid systems can reduce the associated energy losses by using the electrical storage device which is located between internal combustion engine and transmission box to either absorb or increase the output of the engine. However, the loss of energy is not efficient in the parallel hybrid systems due to small size of the electrical storage device. This device cannot be very efficient especially in heavy traffic in the cities because of starting and stopping in traffic jams. On the other hand, hybrid system is more efficient in heavy traffic in the cities because of reduced energy losses using the electrical storage device which can store more energy compared to parallel hybrid systems. Hence, hybrid vehicles are recommended for heavy traffic in the cities. A summary of the systems are given in Fig. 1.

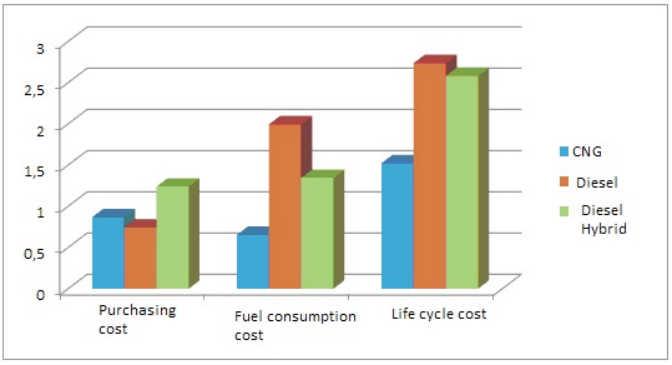

Fig. 1. Life cycle cost of a bus per km (60.000 km)

Some researchers have studies on life cycle cost of abovementioned bus types [9, 10]. According to these studies, a bus 12-year life cycle cost (LCC) analysis for a fleet of size of 100 buses was performed based on information available in the literature, manufacturers' specifications, and fuel economy data gathered by West Virginia University [9,10]. Only technology-dependent factors relevant to bus propulsion were considered; driver and management cost were excluded. Buses were assumed to operate at a national average speed of 20.43 km/h, to travel for about 51.500 km per year, and to seat 40 passengers for the purposes of calculation [11]. According to results of this study, total cost of 12 years operated 100 fleet hybrid electric vehicles is approximately 0.4$ per mile higher than CNG and diesel vehicles since capital and operation cost is higher than other vehicle types. However energy cost is between diesel and energy vehicles. Furthermore the study [9] presents estimates greenhouse gas emissions for city bus for 2007. Tailpipe emissions (particulate matter (PM), nitrogen oxides (NO_x) and greenhouse gas (CO_2) and fuel economy estimations were based on recent emissions and fuel economy studies, and adjusted with best engineering approach. For simple presentation of emissions and fuel economy by the three typical bus fleets (diesel, CNG and hybrid buses), the results given in the WVU study are appropriately processed. Hybrid vehicles produce approximately 4 units less CO_2 emissions per km when compared to Diesel and CNG vehicles. NOx emissions are not differ slightly according to vehicle types. However PM emissions of Hybrid vehicles are lowest within CNG and Diesel vehicles. Also diesel hybrid bus fuel economy is better than the diesel bus fuel economy.

IV. References

[1] A. Toro, P. Delzanno, Fuel cell stack and fuel cell powertrain for automotive application, in: Society of Automotive Engineers Special Publication SP-1827, 2004, pp. 11–19.

[2] P. Corbo, F.E. Corcione, F. Migliardini, O. Veneri, Experimental study of a fuel cell power train for road transport application, Journal of Power Sources 145 (2005) 610–619.

[3] Živanović, Z. ve Nikolić, Z., 2012. *The application of electric drive technologies in city buses*. New Generation of Electric Vehicles, DOI:10.5772/51770.(http://www.intechopen.com/books/new-generation-of-electric-vehicles/the-application-of-electric-drive-technologies-in-city-buses)

[4] Hallmark, Shauna., Wang, B., Oui, Y., ve Sperry, B., 2012. Assessing the costs for hybrid versus regular transit buses. *TECH BRIEF IOWA State University*. PP.1-6.

[5] Transport Canada. Hybrid Buses. http://www.tc.gc.ca/eng/programs/environment-utsp-casestudy-cs71e-hybridbuses-272.htm.Accessed Dec.2011.

[6] Battelle (August 2002). Technical Assessment of Advanced Transit Bus Propulsion Systems. For the Dallas Area Rapid Transit. Dallas, Texas.

[7] Clark, N., N. Borrell, R. Enrique, D. L. McKain, V. Paramo, W. Hugo, W. Vergara, R. A. Barnett, M. Gautam, G. Thompson, D. W. Lyons, and L. Schipper (2006). "Evaluation of Emissions from New and In-Use Transit Buses in Mexico City, Mexico. Journal of the Transportation Research Record. Vol. 1987. pp. 42-53.

[8] Battery Hybrid and Fuel Cell Electric Vehicles are the keys to a sustainable mobility, AVERE, European Association for Battery. (2010). Hybrid and Fuel Cell Electric Vehi cles, http://www.avere.org/www/Images/files/about_ev/Brochure.pdf, accessed 2 November, 2011.

[9] Nigel, N. C, Feng, Z. W, Scott, W, & Donald, W. L. (2007). Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation. U.S. Department of Transportation Federal Transit Administration, FTA-WV-26-7004.2007.1, Final Report, accessed 27 August 2010, http://www.fta.dot.gov/documents/WVU_FTA_LCC_Final_Report_07-23-2007.pdf.

[10] Nigel, N. C, Feng, Z. W, Scott, W., & Donald, W. L. (2008). Additional Transit Bus Life Cycle Cost Scenarios Based on Current and Future Fuel Prices. U.S. Department of Transportation Federal Transit Administration, FTA-WV-26 7006.2008.1, Final Report, accessed 27 August 2010, http://www.fta.dot.gov/documents/,WVU_FTA_LCC_Second_Report_11-03-2008.pdf.

[11] Zivanovic, Z., Jovanovic, Z., & Sakota, Z. (2011). A Comparative Analysis of CNG and Hybrid Buses vs Diesel Buses. 10th Anniversary International Conference on Accomplishments in Electrical and Mechanical Engineering and Information Technology, DEMI, Proceedings, 607-612.

[12] Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation, U.S. Department of Transportation, Federal Transit Administration, FTA-WV-26-7004.2007.1, July 2007: http://www.fta.dot.gov/documents/WVU_FTA_LCC_Final_Report_07-23-2007.pdf

[13] Hallmark, Shauna., Wang, B., Oui, Y., ve Sperry, B., 2012. Assessing the costs for hybrid versus regular transit buses. TECH BRIEF IOWA State University. PP.1-6.

[14] Callaghan, L. ve Lynch, S., 2005. Analysis of Electric Drive Technologies for Transit Applications: Battery-Electric, Hybrid Electric and Fuel Cells. *U.S. Department of Transportation Federal Transit Administration Final Report*. U.S: Department of Transportation FTA-MA-26-7100-05.1.