

ANALYSIS OF POTENTIAL GAIN FROM USING HYBRID VEHICLES IN PUBLIC TRANSPORTATION

İrem DÜZDAR¹ and Özay ÖZAYDIN²

Abstract: In the last two decades, the pollution in major cities was a growing concern. A significantly large contribution was made by road transportation sources to this problem. EU regulations on emissions and improvements in fuel quality sustained an improvement in air quality through reduction in pollutants. Latest trend taking the environmental issues into consideration in consumer car industry is hybrid vehicles, which use a conventional inner combustion engine using petroleum or diesel fuel, alongside with an electric engine, selectively using the necessary one depending on the current speed and power needs. As the vehicles equipped with this technology create less emission and consume less fuel, investigation of the potential gain when used public transportation is inevitable. In this study, a comparison-based study will be done between traditional busses using fossil fuel and new technology busses that the Istanbul Municipality selected as candidate fleet, utilizing energy, finance, environment and social responsibility aspects.

Keywords: Public transportation, Hybrid vehicles, Environment

I. INTRODUCTION

Public transport, public transportation, public transit or mass transits are transport systems that transport members of the general public, usually charging set fares. The terms generally taken to include rail and bus services, and wider definitions might include scheduled airline services, ferries, and taxicab services. A restriction sometimes applied is that transit should occur in continuously shared vehicles, which would exclude taxis that are not shared-ride taxis.

Public transport may be regulated as a common carrier and usually provides scheduled service on fixed routes on a non-reservation basis, although share taxis provide an ad-hoc form of flexible public transport and demand responsive transport provides a pre-bookable form of public shared transport. Taxicabs and other vehicles for hire are generally fully flexible.

The majority of transit passengers are traveling within a local area or region between their homes and places of employment, shopping, or schools.

II. EFFECTS OF PT ON ENVIRONMENT

The people moves from one place to another all their lives for various reasons. The distance moved is getting bigger as the cities growing. And they have to use vehicles to reach their destinations. In the developed countries well educated people use the public transportation vehicles. Public transportation has many of the advantages. It is more economical for the people, for the country and for the environment. It yields less noise, less pollution, less heat emission for the atmosphere, less money for fuel and vehicle, less area for roads and parking. [1]

III. NEXT STEP: HYBRID VEHICLES

Why would anyone buy a hybrid electric vehicle (HEV)?

First mass introduction to markets happened in 1999, and was a radical change in motor vehicle technology. Currently available HEV models achieve fuel economy increases of 10-40% [2]. compared to similar-sized vehicles, with commensurate reductions in greenhouse gas emissions. Some of HEVs' benefits are collective. Millions of people buying less-polluting and more fuel-economical cars can produce cleaner air and reduce risk of climate change, but no single HEV buyer can have much impact on these problems.

¹ İrem Düzdar, Haliç University, Faculty of Engineering, Industrial Engineering Department, Bomonti, Istanbul, Turkey, jduzdar@halic.edu.tr

² Özay Özaydin, Doğuş University, Faculty of Engineering, Industrial Engineering Department, Acıbadem, Istanbul, Turkey, oozaydin@dogus.edu.tr

Further, the private benefits of HEVs are unclear; reduced expenditures on fuel are routinely shown to be less than the vehicle purchase price premium of the hybrid vehicle over an assumed non-hybrid alternative. If private benefits are illusory and if collective benefits are not achievable by individual customers, why would anyone buy an HEV? Hopes that HEVs (or any new technology that promises collective benefits) can be successfully mass-marketed depend on answers to such a question [4].

An answer

HEV not only provides its owner with transportation, but also provides symbolic meanings that owners can incorporate into better stories about themselves [3]. The symbolic meanings associated with HEVs are multiple and multi-layered, including widely recognized ideas like preserving the environment, opposing war, saving money, reducing support for oil producers, and owning the latest technology. But these denotations are linked to more personal connotations, such as concern for others, ethics, maturity, national independence, or individuality [4].

IV. HYBRID VEHICLES AS A PUBLIC TRANSPORTATION TOOL

Hybrid-electric buses are being developed to answer specific challenges faced by today's public transport operators, range, fuel economy, emissions, and safety. Today's conventional buses still exhibit relatively poor fuel economy and moderately high emission levels while today's battery-electric buses cannot handle the demands of most transit duty cycles, specifically with respect to vehicle range. Hybrid buses are being developed in response to these challenges. Many hybrid-electric vehicles have evolved over time from initial work in the electric bus arena with assistance from both government and private programs [1]. Additionally, many urban areas where transit buses operate experience air quality problems that are also driving the decision to adopt alternative technologies. These include both alternative fueled traditional buses and hybrid buses.

A hybrid vehicle can be set up as a parallel configuration, where both the electric motor and the mechanical engine can drive the wheels, or as a series configuration, where only the electric motor drives the wheels. Different advantages and tradeoffs exist for each combination of components (Table 1 and Table 2)

TABLE 1 - SERIES HYBRID [1]

Benefits	Trade-offs
Fuel cell compatible	Greater energy losses as more energy passes through the energy storage device than in parallel hybrid
Reduced emissions – engine rarely idles and tends to operate in a narrow peak efficiency band	Maximum power at high speeds may only be available with both the APU and energy storage device operating
Improved low speed acceleration – all the power is routed through the electric motor providing high torque at low speeds	Lower steady state efficiency as generator is required to convert engine energy to electric energy and back again into mechanical energy
Numerous component layout options, simpler packaging	Increased weight – smaller APU will increase reliance on batteries and may require more batteries (weight) and may shorten battery life

Most of the countries now import more than half of the oil it consumes annually. The trade imbalance created by oil imports poses a major threat to the nation's economy should foreign sources of fuel become disrupted. Governments have directed federal agencies to develop programs to reduce the nation's consumption of imported fuels. One of the primary strategies has been to support the development of advanced vehicle technologies, like hybrid-electric, that reduce fossil fuel consumption overall and can utilize domestically produced fuels such as natural gas.

TABLE 2 - SERIES HYBRID [1]

Benefits	Trade-offs
More overall power – both engine and motor can supply power simultaneously	Generator rotor must spin when using energy from engine, adding more mass and rotating inertia
Reduced weight – smaller energy storage capacity possible compared to series hybrid	Less capable of capturing all available regenerative braking energy
Greater energy efficiency during steady state operation – not all energy must go through generator and electric motor as with series hybrid	Not fuel cell compatible
Greater battery life as batteries are used primarily for regenerative braking and acceleration assist, not for primary acceleration	

A diesel engine is currently the most efficient power supply available to the transit industry. In a conventional bus, current diesel engines are about as efficient (~30% overall) as they can get, although direct fuel injection will be used in the future to force some small efficiency gains and emission reductions. The reason this increase is expected to be small for conventional buses is that engine efficiency is dominated by the operating cycle and excessive idle time and not necessarily by the peak efficiency of the engine. In a hybrid-electric vehicle, however, the engine is not coupled mechanically to the wheels and can be operated more efficiently or, in some cases, turned off completely.

In slow urban drive cycles, nearly 50% of the energy expended by the vehicle is utilized for acceleration while the remaining energy goes to auxiliary systems and road load. If all the kinetic energy could be captured it would potentially double current transit bus fuel economy? Real world system limitations usually result in a maximum capture of about 50% of the available kinetic energy during regenerative braking. By recapturing 50% of the total kinetic energy (25% of the total expended energy), fuel economy is increased by 33%. [5]

The European Commission (2001) states in their White paper (European transport policy for 2010), that logistics can contribute to one of the objectives through: reducing the environmental impact of transport (e.g. improved vehicle utilization).

Two general approaches for reducing the environmental impact can be identified. The first is to rely on new, more energy efficient technology, which for public transport has proven to be insufficient. The second is to rely on companies to restructure their processes. In the public transport literature (the micro perspective) two methods to reduce the environmental impact are to either introduce more energy efficient technology, or to organize in a different way. However, it is not enough to introduce new technology to stop the development, e.g. more energy efficient engines. There is a need for larger structural changes in public transport.

A hybrid-electric bus is defined as carrying at least two sources of energy on board the vehicle, with an electric drive to provide partial or complete drive power to the vehicle's wheels. In most cases the two sources of energy will be an electrical energy storage device and an APU (auxiliary power unit). In a conventional bus, the diesel engine generates power that is mechanically transferred to the wheels through the transmission and differential. In a hybrid-electric drive bus, the engine produces electricity and may not be coupled to the wheels. Power is electrically transmitted to the wheels by a combination of the engine generator set and traction batteries. Although simple, the components of an electric drive system may only be well understood by transit agencies that operate electric trains or trolley buses.

Owning Costs

Here we will try to provide an understanding of the cost factors involved with owning and operating hybrid electric drive buses. Since the technology is new it is impossible to use hard numbers on the cost to own and

operate these buses. Recent buyers have paid between 840.000 and 440.000 USD/bus. But in 1999 New York City Transit paid 385.000 USD/bus for 125 hybrid buses.

Fuel

By definition HEV's consumes at least two different fuels, and these different fuels costs must be considered to estimate the operating costs. One is diesel or natural gas, and the other is lead acid batteries.

TABLE 3. HYBRID BUS FUEL COSTS [1]

		Conventional Drive	Hybrid
Diesel	Fuel Cost ((\$/Gal)*1000)	720,00	720,00
	Fuel Economy (mpg*100)	350,00	450,00
	Annual\$/bus	5.554	4.320
	(\$/mile)*1000	210,00	160,00
	\$/bus life (*)	83.314	64.800
Electrical	Cost (\$/ACkWh) * 1000	80,00	80,00
	Annual MWnr/bus	0,00	2,60
	Annual/bus		208
	\$/mile		0,01
	\$/bus life (*)		3.120
Traction Batteries	Replacement Cost(\$/pack)		50.000
	Annual/bus		3.333,00
	\$/mile		0,12
	\$/bus life (*)		50.000
Total Fuel	Annual/bus	5.554	7.861
	\$/mile	0,21	0,29
	\$/bus life (*)	83.314	117.920
(*)	Based on 15 years life and 27000 miles per year.		

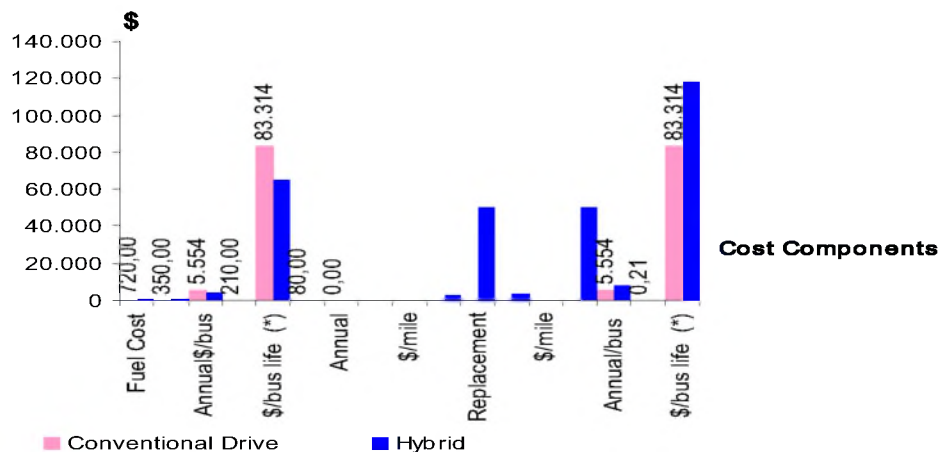


FIGURE 1. COMPARISON OF HYBRID BUS FUEL COSTS

The hybrid-electric drive definition problem is getting more unclear by the fact that the technology takes many forms and different labels to describe them. For instance, there are series and parallel hybrids, engine-dominant and battery-dominant hybrids, charge-sustaining and charge-depleting hybrids and dual-mode hybrids. All of these are currently under development and/or deployment and each has its advantages. Many perceived advantages are actually a function of the electric drive, which results in more available torque at low speed, smoother acceleration, and efficient regenerative braking. In either parallel or series

configurations the short-term benefit is increased efficiency due to the capture of kinetic energy through regenerative braking.

Hybrid-electric drive systems on transit buses are being aggressively investigated as a means of improving fuel economy, reducing emissions, and lowering maintenance and operating expenses. Several major federally funded research and development projects are testing the viability of these drive systems on buses. With the rapid pace of development and improvement of hybrid-electric drive technology, more transit agencies are being asked to evaluate the potential for hybrid-electric drive systems in their fleets. It is intended to provide transit managers with a better understanding of the technology, including benefits, challenges, and life-cycle costs.

In this paper, alternative fuels are considered for their potential to displace the oil is the main and only source of transport fuel. But we want to analyze only the hybrid electric buses among twelve different alternative fuel buses.

TABLE 4. AVERAGE VALUES OF WEIGHTS [1]

Criterion	Manufacture	Academic Institute	Research Organization	Bus Operator	Average
Energy Supply	0,0357	0,0314	0,0340	0,0249	0,0313
Energy Efficiency	0,1040	0,0943	0,1020	0,0748	0,0938
Air Pollution	0,1355	0,2090	0,1595	0,1605	0,1661
Noise Pollution	0,0452	0,0697	0,0532	0,0535	0,0554
Industrial Relationship	0,0923	0,0357	0,0480	0,0757	0,0629
Employment Cost	0,0900	0,0680	0,0343	0,1393	0,0829
Maintenance Cost	0,0300	0,0227	0,0114	0,0464	0,0276
Road Facility	0,1373	0,0953	0,1827	0,0803	0,1239
Vehicle Capability	0,0827	0,0590	0,1520	0,0283	0,0805
Speed of Traffic	0,1520	0,2420	0,1400	0,2637	0,1994
Sense of Comfort	0,0957	0,0730	0,0833	0,0523	0,0761

The evaluation of alternative-fuel buses should be considered from various aspects as; energy supply, energy efficiency, air pollution, noise pollution, industrial relationship, implementation costs, maintenance costs, capability of vehicle, road facility, speed of traffic flow, comfort. The AHP is used to determine the weights of evaluation criteria. The decision makers of the related industries as bus producers and operators assessed their subjective relative importance for each of the criteria. Table 4 shows the average values of weights. Then the next step is to evaluate the alternatives.

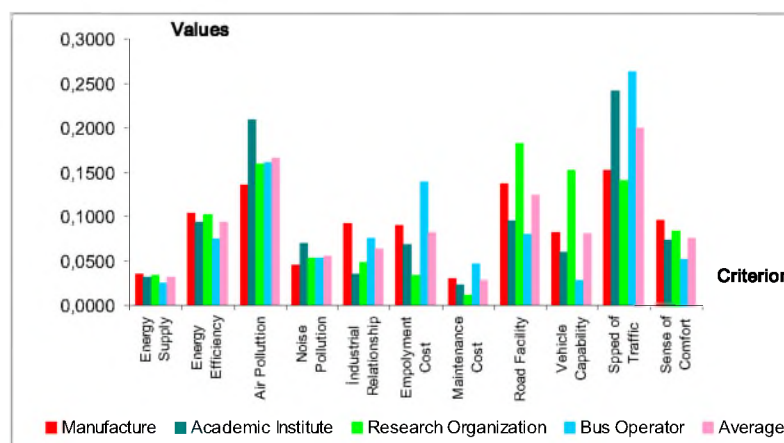


FIGURE 2. COMPARISON OF CRITERIA VALUES

TABLE 5. VALUES OF CRITERION FUNCTIONS [1]

Alternatives	Energy Supply	Energy Eff.	Air Poll.	Noise Poll.	Ind. Rel.	Empoly. Cost	Maint. Cost	Road Facility	Vehicle Capab.	Speed of Traffic	Sense of Comfort
Diesel Bus	0,82	0,59	0,18	0,42	0,58	0,36	0,49	0,79	0,81	0,82	0,56
Hybrid-Gas	0,77	0,63	0,63	0,52	0,66	0,63	0,65	0,67	0,70	0,80	0,74
Hybrid-Diesel	0,77	0,63	0,51	0,58	0,66	0,63	0,65	0,67	0,70	0,80	0,74
Hybrid-CNG	0,77	0,73	0,80	0,48	0,63	0,66	0,65	0,67	0,71	0,62	0,78
Hybrid-LPG	0,77	0,73	0,80	0,48	0,63	0,66	0,65	0,67	0,71	0,62	0,78

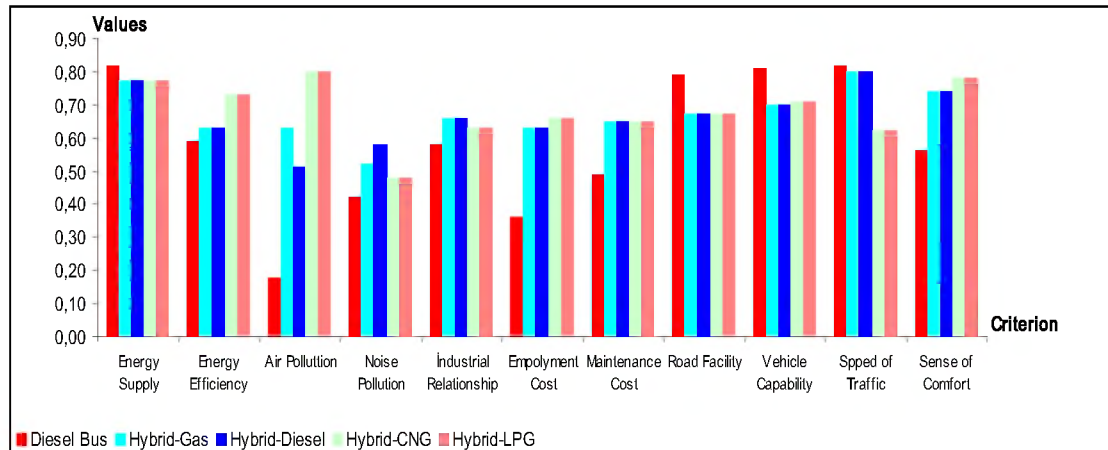


FIGURE 3. COMPARISON OF CRITERION FUNCTIONS

The major force behind the development of hybrid drive buses is emissions reduction. Hybrid buses are cleaner and emit fewer grams of pollutants per mile than conventional diesel buses. Hybrids have been shown to reduce particulates and NOx by as much as 50% during testing. Hybrid buses may be very desirable for highly industrialized countries [5].

TABLE 6. HYBRID BUS EMISSION CREDITS [1]

	Conventional Drive	Hybrid
PM g/mile	0,24	0,12
ton/year/bus	0,01	0,00
ton/year/100 buses	0,71	0,36
NOx g/mile	30,10	19,20
ton/year/bus	0,89	0,57
ton/year/100 buses	89,40	57,20
VOC g/mile	0,14	0,08
ton/year/bus	0,00	0,00
ton/year/100 buses	0,42	0,24
CO g/mile	3,00	0,10
ton/year/bus	0,09	0,00
ton/year/100 buses	8,91	0,30
CO ₂ g/mile	2.779,00	2.262,00
ton/year/bus	82,54	37,18
ton/year/100 buses	8.253,63	6.718,14

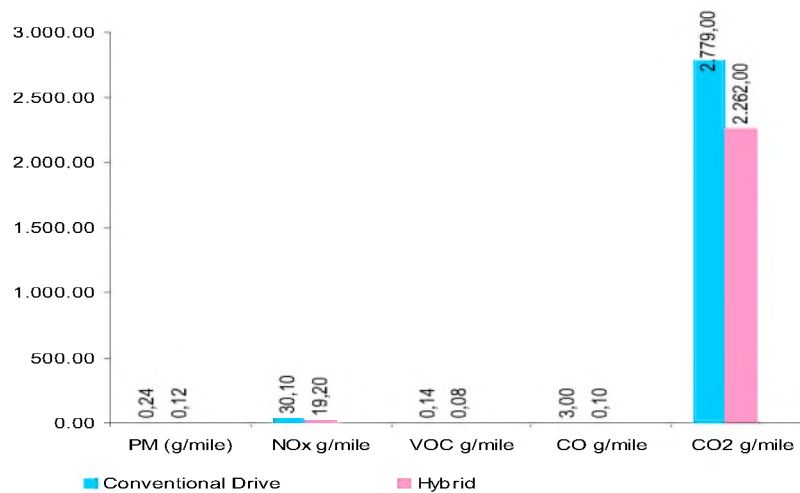


FIGURE 4. COMPARISON OF EMISSION CREDITS

Dual mode hybrids may allow limited zero emission range for operation in highly sensitive areas. For example, crowded downtown, tourist or historic areas might particularly benefit from pure electric (zero emission) propulsion mode of operation for short distances. In Boston, a new underground bus transit way is being constructed that will require buses to travel a 1.1 mile tunnel without burning fuel. Dual-mode hybrid buses might be particularly well suited to this type of application.

The major impetus behind alternative fuels is interest in reducing harmful emissions, improving public health, and conserving energy. Political, social, and environmental pressures are being placed on transit agencies to adopt alternative fuels and technologies including hybrid-electric drive.

Normal operating conditions for diesel buses range from 10°C to 85° C. Hybrid buses can perform in similarly demanding conditions; however, this will likely require some type of thermal management of the batteries. Lead acid batteries become less efficient when ambient temperatures drop below 45° C while other batteries such as nickel metal hydride may require active cooling at warmer temperatures. Regardless, hybrid drive system developers are designing thermal management into their battery management systems.

Hybrid transit bus maintenance costs are not well understood at this time. There is not yet enough operating experience with hybrids to realistically quantify the hours and costs associated with maintaining them. In practice, transit agencies experimenting with early hybrid prototypes report higher than normal maintenance costs which are typical for a new technology.

Hybrid technology can also have noise reduction benefits over conventional buses. Diesel bus noise standards typically specify that noise levels not exceed 83 dBA at any seat location in the bus at 50 km/h. Comparative noise data for hybrid bus was not available, but hybrid buses are quieter than standard diesel buses in service.

V. RESULTS

Hybrid-electric drive technology introduces new opportunities and challenges in bus operation and maintenance. Hybrid drive offers operational advantages such as smoother and quicker acceleration, more efficient braking, improved fuel economy, and reduced emissions. Maintenance requirements may initially increase due to energy storage system requirements; however, these may go away once the technology develops. In the long term, hybrid bus maintenance may be less difficult than conventional mechanical technology due to savings associated with transmission and brakes. Infrastructure modifications are expected to be minor. Mechanical and safety retraining is needed in light of high voltage components. Transit providers must understand the issues and risks involved in deploying hybrid drive technology.

Successful introduction of a new technology into the bus fleet ultimately depends on both the commitment from management and a successful management plan. Hybrid drive will present public transportation managers with new challenges in the areas of operation, maintenance, labor, cost, and public relations. A management plan must address each of these issues and receive the full support of the agency's leadership. Addressing the nuts and bolts of infrastructure, hardware, and operating schedules will ensure success. Other human factors must be addressed as well, such as driver and mechanic acceptance. Employee acceptance can be won through careful training and rewards. Customer acceptance and public relations must also be carefully addressed. Hybrid technology may win supporters among public transportation users, elected officials and environmental constituencies for being quieter, smoother, and better for the environment.

REFERENCES

- [1] Transportation Research Board National Research Council. (2000). *Hybrid-Electric Transit Buses: Status, Issues, and Benefits*. TCRP Report 59, National Academy Press, Washington, D.C.
- [2] US Department of Energy. (2007). *Fuel Economy Guide*. Report DOE/EE*0314, Office of Energy Efficiency and Renewable Energy, Washington, DC.
- [3] Kurani, K., Turrentine, T., & Heffner, R. (2006). Narrative self-identity and societal goals: automotive fuel economy and global warming policy. In D. Sperling, J. Cannon, & J. Cannon (Ed.), *Driving Climate Change*. Burlington: Elsevier.
- [4] Heffner, R. R., Kurani, K. S., & Turrentine, T. S. (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research Part D*, 12, 396-413.
- [5] Environmental and Energy Study Institute. (2007). *Hybrid Buses Costs and Benefits*. Washington, D.C.