# The potential fuel economy due to hybrid-drive buses use: the case of Brazilian urban transit corridors

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## Abstract

Studies carried out by COPPE/UFRJ have shown the diesel fuel potential reduction through the use of hybrid urban buses (D'Agosto & Ribeiro, 2003). Field research on the energy efficiency curve indicates that fuel economy is higher when the average speed is 15–25km/h, which happens in some transport corridors, such as São Paulo Metropolitan Area, where this kind of vehicle has been used since 2001. Based on such considerations, this paper presents data on the principal urban corridors which are considered to be potential users of hybrid drive technology. The match between the energy efficiency curve for hybrid buses and the corridor average speed enables the identification of the areas which show the best potential for this technology and where best gains are expected.
*Keywords: hybrid drive buses, fuel economy, green house gases emissions.*

## 1 Introduction

Public transport in Brazilian cities accounts for 29% of the total trips, in which 94% of them are carried out by bus. A fleet of 55 thousand buses, which run approximately 250 million kilometer per month is responsible for transporting more than 550 million passengers a month. Such a large fleet consumes more than 60 million liters of diesel oil, representing 16.5% of the total operational cost. One should notice that in the last 8 years the diesel cost has raised 61.5% [1], what makes the improvement of bus fuel economy a key issue to be addressed.

Studies carried out by COPPE/UFRJ have shown the diesel fuel potential reduction through the use of hybrid urban buses [2]. Field research on energy efficiency curve (km/l), as a function of traffic average speed (km/h), indicates that fuel economy improvement is higher when average speed is into 15 to 25 km/h interval, what usually happens is some transport corridor, as in São Paulo Metropolitan Area, where this kind of vehicles has been used since 2001.

Based on such consideration, this paper presents data on the principal urban corridors which are considered to be potential for the use of hybrid-drive technology signaling for fuel economy. The match between the energy efficiency curve for hybrid buses and the corridor average speed enables the identification of the ones which show the best potential for fuel economy improvement.

Besides the São Paulo Metropolitan Area corridor in which hybrid buses are already in use, cities like Porto Alegre, Curitiba, Belo Horizonte, Brasilia and Goiania, present average speed higher than 20km/h corridors, which are best choices for such technology, enabling a potential fuel economy of 30%. This fuel reduction amount displays an expectative of reducing operational cost as well as reduction of local and global atmospheric pollutants.

## 2 Hybrid-drive technology and fuel economy improvement

Brazil has developed hybrid drives for buses. The models shown in Table 1 are already in operation [3]. From the options listed in Table 1, the Padron H model (Padron model featuring a hybrid drive system) meets the specifications established during the 80's by the Ministry of Transport, as best adapted to urban passenger transportation. The Padron model consists of large and high capacity buses, with a rational internal layout that streamlines passenger boarding and alighting procedures and offers better on-board accommodation, equipped with two or three double doors and a weight/capacity ratio optimized for urban traffic [4]. If a conventional drive system is used the bus is denominated as Padron C bus.

Table 1: Brazilian hybrid-drive buses' specifications.

| Name | External Dimensions | | | | Capacity | | Performance | | |
|---|---|---|---|---|---|---|---|---|---|
| | L [m] | W [m] | H [m] | Tare [kg] | Seated | Standing | $S_{max}$ [km/h] | $Pot_n$. [kW] | $Pot_{MG}$ [hp] |
| Articulated | 18.15 | 2.60 | 3.40 | 18,000 | 57 | 113 | 60 | 360 | 150 |
| *Padron H* | 12.00 | 2.60 | 3.40 | 12,000 | 36 | 64 | 60 | 240 | 80 |
| Microbus | 8.00 | 2.20 | 2.70 | 7,000 | 25 | - | 80 | 150 | 50 |

Notes - L: length; W: width; H: height; $S_{max}$: maximum speed, $Pot_n$.: rated power of electric motor; $Pot_{MG}$: rated power of motor generator group. Source: [3].

As hybrid buses offer operating advantages over conventional diesel buses, including smoother and quicker acceleration, more efficient braking, improved fuel savings and reduced emissions [5] [6] [7], a series of trials were run by the research team of the Transportation Engineering Program at the Rio de Janeiro Federal University, in order to ascertain the potential for reducing diesel oil consumption and $CO_2$ emissions through the use of Brazilian-made hybrid buses.

The fuel savings trial was carried out on the Sao Bernardo – Ferrazopolis stretch of Sao Mateus — Jabaquara Metropolitan Corridor. The bus-way used for this trial was mapped using a GPS device. It has a flat surface paved with concrete blocks in flawless condition throughout its entire length. The road configuration consists of lanes traveling in the same direction with traffic lights at the crossroads. They are separated longitudinally from oncoming traffic and constitute a 7.25-km closed circuit. There are seven stops both ways for passenger boarding and alighting.

For each vehicle loading condition (loaded and unloaded) the circuit was run at least five times. In order to measure fuel consumption, a properly calibrated flow-meter was fitted to the vehicle engine fuel-feed system. Fuel consumption and time were noted at each stop in order to obtain a mass of fuel consumption data based on the trial duration, which could be rated to the distance covered as average speed.

The fuel consumption data surveys for the Padron H and Padron C buses (the latter used as a benchmark) were carried out simultaneously, with each vehicle accompanying its counterpart as leader and follower. This was intended to minimize differences in the traffic conditions. At the end of each cycle, the vehicles switched positions, taking turns to drive as the lead vehicle.

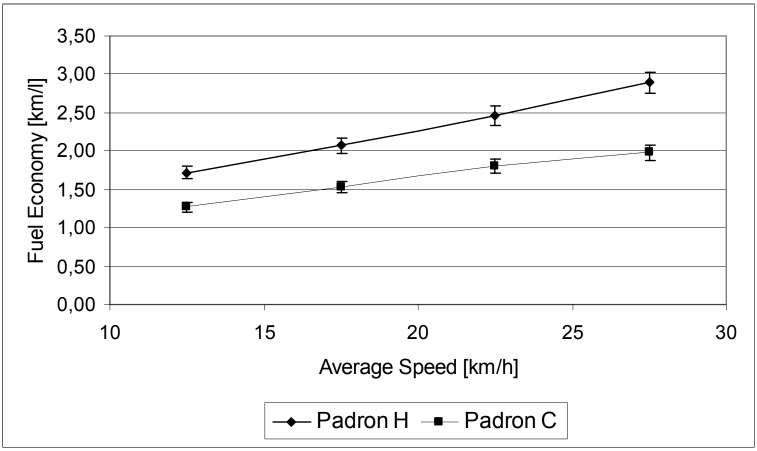


Figure 1: Fuel economy comparison: Padron H x Padron C buses.

Figure 1 illustrates the results obtained in fuel savings trials for the loaded condition. The analysis of the findings indicates that, the Padron H vehicle was at least 23.33% more fuel-efficient than its Padron C counterpart for the operating conditions established in the trials. This occurred for average speeds ranging from 20 to 24.9 km/h with a loaded vehicle.

Table 2 presents an approximate relationship between traffic conditions and average speed intervals. It considers that average speed models stopping frequency and idling time [8]. The results in Figure 1 can be taken advantage of to extend the fuel consumption reduction when using of hybrid drive buses to different traffic conditions.

The fuel economy can be estimated from the use of Figure 1 and Table 2 and the real amount of fuel consumption reduction will depend on the possibility of using the regenerative brake system, assuming soft braking and engine off when idling, maximizing fuel economy in bus stops.

Table 2: Estimated relation between traffic condition and average speed.

| Traffic flow | Average speed[km/h] |
|---|---|
| Common lane | 5 to 15 |
| Buslane | 15 to 25 |
| Busway | Over 25 |

To take maximum advantage of the regenerative brake system, the traffic condition on common lane is not necessarily the most appropriate, because it imposes abrupt and fickle braking, what hinders the conversion of kinetic energy into electricity. Thus, the best fuel economies occur for average speed of 15–25 km/h (buslanes). However, for the best results in fuel economy the ideal would be to design the hybrid drive vehicle to specific traffic conditions.

The reduction in diesel oil consumption resulted in a proportional drop in carbon dioxide ($CO_2$) emissions, meaning that each liter of diesel oil saved avoids the emission of some 2.6 kg of $CO_2$ (taking the specific mass of diesel oil as 0.83 kg/l and the $CO_2$ emission factor as 3,188 g/kg). The total emissions reduction will depend on the distance traveled by the vehicles and their average speed over each section, being calculated specifically for each application.

## 3 Brazilian bus corridor operation profile

Some 16% of the urban bus fleet in 27 Brazilian State Capitals already consists of Padron vehicles. However, this specification is applicable to the operation of some of the remainder of this fleet, which today consists of smaller, lower capacity buses (75 passengers) known as Conventional Urban Buses (CUB) [9].

Due to the size, capacity and performance of the Padron bus when compared to CUB models, these vehicles are particularly suitable for operations in Bus Rapid Transit (BRT) Systems, defined as high-quality, customer-oriented transit facilities that deliver fast, comfortable and low-cost urban mobility [5]. BRT is an evolution of the bus-lane and bus-way concepts, which propose to upgrade the performance of bus transportation systems through assigning priority to bus traffic by physically separating bus lanes from regular traffic and considering the use of specially designed buses. Becoming widespread in Latin America, this type of operation is already operating successfully in some Brazilian cities

[5] [9] where heavy constraints on investments in mass transportation systems leads to the use of buses as an important alternative to rail systems for providing rapid transit.

The BRT concept also involves the use of environmentally-friendly vehicles [5] which makes the hybrid-drive Padron bus called Padron H from now on an appropriate choice, as it can meet these demands with no loss of flexibility, in contrast to the articulated or bi-articulated models.

Besides the São Paulo Metropolitan Area corridors in which hybrid drive buses are already in use, cities like Aracaju, Belo Horizonte, Campinas, Campo Grande, Cuiaba, Curitiba, Fortaleza, Goiania, Porto Alegre, Sao Luis and Uberlandia operate bus corridors as presented in Table 3 [9]. Those cities were chosen as potential places to use hybrid-drive technology since they operate a large fleet (over a hundred) of Padron C buses and small fleet renewable rates (average vehicle age of five years).

Table 3: Brazilian bus corridor operational profile.

| City | Padron C [units] | Average Speed [km/h] | Age [years] | Mileage [km/vehicle-year] | Occupation rate |
|---|---|---|---|---|---|
| Aracaju | 248 | 20 | 6,5 | 81.584 | 76% |
| Belo Horizonte | 1077 | 19 | 4 | 86.787 | 67% |
| Campinas | 380 | 19,5 | 5,7 | 75.747 | 72% |
| Campo Grande | 105 | 17 | 4 | 63.598 | 83% |
| Cuiabá | 188 | 21 | 4,5 | 81.351 | 73% |
| Curitiba | 570 | 19,5 | 5,6 | 61.563 | 64% |
| Fortaleza | 196 | 20 | 6,5 | 75.134 | 71% |
| Goiânia | 746 | 22 | 6,2 | 59.187 | 78% |
| Porto Alegre | 661 | 20 | 4 | 57.040 | 70% |
| São Luís | 298 | 21 | 5,5 | 106.523 | 80% |
| São Paulo | 445 | 13,5 | 5,9 | 64.267 | 68% |
| Uberlândia | 192 | 22 | 4 | 74.243 | 82% |

## 4 Fuel savings (FS) and $CO_2$ emission reduction ($ERCO_2$) estimates

From the original data processed and presented on Figure 1 it is possible to estimate the fuel economy (FE) curve for Padron H and Padron C buses as a quadratic function of average speed (AS) in km/h as shown in equations 1 and 2. Those functions were determined for occupation rate of 75%.

$$FE_{PADRO\ H}\ [km/l] = -0{,}0009.(AS)^2 + 0{,}0843.AS + 0{,}3479 - R2 = 0{,}9974 \qquad (1)$$

$$FE_{PADRO\ C}\ [km/l] = -0{,}00022.(AS)^2 + 0{,}1478.AS + 0{,}196 - R2 = 0{,}9907 \qquad (2)$$

Equations to represent fuel savings (FS) and $CO_2$ emission reductions ($ERCO_2$) are obtained from equations 1 and 2 as shown in equation 3 and 4.

$$FS\ [liters] = N_{PADRON\ H}\ .\ ML\ .\ (1/FE_{PADRON\ C} - 1/FE_{PADRON\ H}) \qquad (3)$$

$$ERCO_2\ [t] = 2{,}6\ .\ FS/1.000 \qquad (4)$$

where: $N_{PADRON\ H}$ – is the number of Padron H vehicles in operation each year
ML – is the annual mileage [km/year] of each Padron H vehicle

Using the previous equations, the average speed and the mileage estimates for each city from Table 3 it is possible to obtain FS. The number of Padron H vehicles in operation each year is a function of the substitution rate considering five-year time to complete turns over. Figures 2 and 3 present FS and $ERCO_2$ for each city in five years time.

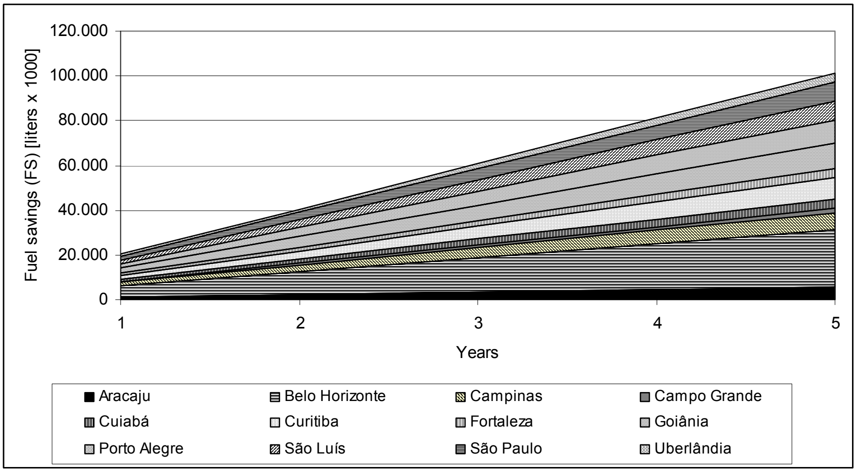


Figure 2: Fuel savings (FS) for each city.

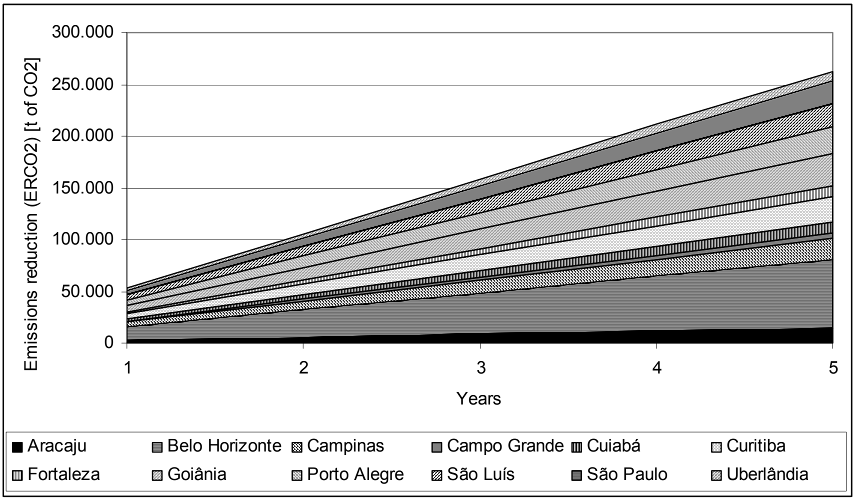


Figure 3: Emissions reduction ($ERCO_2$).

The average fuel savings considering the 12 cities along 5 years time is 60,841 thousand liters/year and the total savings are 304,206 thousand liters. The reduction on $CO_2$ emission is proportional to the fuel savings. The average reduction is 158,187 t/year and the total reduction is 790,935 t.

Belo Horizonte (greatest fleet) represents 25% of the total savings while Campo Grande (smallest fleet) is responsible for less then 2%. Goiania, Porto Alegre and Curitiba also have good potential for fuel savings, representing respectively 11.6%, 10%and 9.5% of the total.

To reach those values it would be necessary a fleet of 5,106 hybrid-drive buses at a substitution rate of 1,026 vehicles/year. The additional investment in the fleet would be US$ 15.39 million, assuming the Padron H bus has an additional cost of 30% [3]. Taking the current price of diesel oil as US$ 0.35, the costs savings are around US$ 21.29 million, enough to exceed the additional investment.

## 5 Final comments and recommendations

The use of hybrid-drive buses is a good option to save fuel and reduce $CO_2$ emissions on Brazilian bus corridors and the cost savings are more than enough to exceed the additional investment in this new technology.

The gains depend on the bus fleet and annual mileage and is a function of fuel economy. Belo Horizonte has the greatest Padron C bus fleet and the best potential to use Padron H buses.

This work uses a simple model to estimate fuel economy as a function of average speed considering occupation rate of 75%. In real operation the average speed and occupation rate can vary along the years, modifying the estimated values.

The bus fleet substitution was restricted to Padron C vehicles and it was not considered fleet enlargement along the years. A better value of fuel saving and reduction of $CO_2$ emissions would be obtained if part of CUB buses should be replaced for Padron H buses.

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