ENVIRONMENTAL STRATEGY FOR ENERGY: HYDROGEN FUEL CELL BUS FOR BRAZIL

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Abstract

The São Paulo Metropolitan Region (SPMR) in the State of São Paulo, Brazil, is one of the most densely populated urban regions in the world and pollutants originated in the exhaust of vehicles heavily affect it. The addition of ethanol to gasoline (>20%), the use of cars running on pure alcohol, the restrictions in the circulation of vehicles and the utilization of electronic fuel injection and catalyst, have made the problem of pollution to get better levels. But this is not enough, and these measurements cannot be applied to the 25,000 buses running on diesel. Also, it is estimated that about 400,000 trucks, also running on diesel, circulate in the region. This points to the SPMR as an ideal place for the introduction and testing of new technologies for vehicular pollution reduction.
In order to launch a fuel cell bus project using hydrogen produced by electrolysis, Brazil formed a team integrated by the Ministry of Mines and Energy, Empresa Metropolitana de Transportes Urbanos de São Paulo S.A. – EMTU (metropolitan bus authority) and University of São Paulo - USP. The project is being financed by the Global Environment Facility, under United Nations Development Program implementation. The main objectives of the Brazilian Project are: i) to demonstrate the feasibility of the introduction of fuel cell buses in the existing urban transportation infrastructure, ii) to decrease the present cost of the fuel cell bus by promoting their mass production and generalized use, and iii) to set the basis for the introduction of this type of clean bus.
The different phases of the Brazilian project are:

Phase 1: Pre-feasibility study and proposed strategy
Phase 2: Running a fleet of 8 fuel cell buses
Phase 3: Scale up a facility for 200 buses operating from a single garage
Phase 4: Commercial and industrial roll out.

Phase 1 of the Project started in December/1997 and it is already concluded. The Phase 2 has started on November 2001.

1. Introduction

Bus transport is a major factor in passenger transport in Brazil, as it is in most emergent economies. Brazil is one of the world's largest bus markets. With its large internal market plus some exports, Brazil is also one of the world's largest bus manufacturers. The Brazilian urban bus fleet is large and continues to grow. The São Paulo Metropolitan Region (SPMR) is the largest urban concentration in the country and one of the largest in the world. It relies heavily on public transportation, particularly buses. There are some 25,000 buses in service in the SPMR.

The São Paulo Metropolitan Region also suffers from some of the world's worst air pollution problems. Air quality drops below minimum acceptable standards for several days a year. Motor vehicles are responsible for 90% of toxic pollutants released into the atmosphere. Buses, the majority of which powered by diesel engines, are major contributors to air pollution. In addition to toxic pollutants, diesel buses in SPMR release more than 1.5 billion tons of carbon dioxide annually. Carbon dioxide is considered to be one of the major contributors to the global greenhouse effect.

The São Paulo State Government is committed to extending the use of renewable, non-polluting energy resources for powering public transportation in SPMR. As part of this, both SPTrans (São Paulo Transporte) and EMTU(Empresa Metropolitana de Transportes Urbanos de São Paulo) operate extensive electric trolley-bus networks, both on city streets and within the dedicated corridors (some 600 trolley-buses). Large-scale further extension of these networks is inhibited, however, by the heavy fixed costs of the overhead lines. Although the costs of these can be economically justified on routes with a high density of traffic, reliance on these overhead lines inherently limits the flexibility of operation.

An up-and-coming technology has the potential to provide transportation with zero pollutants and carbon dioxide emissions: fuel cells powered by hydrogen produced from renewable energy sources. Urban buses are a natural early market entry point for this technology. Several fuel cell buses have already been built, demonstrated and put in service in North America and Europe. Some automotive companies have plans for near-term commercialization of this technology.

Fuel cell buses are an attractive proposition for Brazil's cities. The environmental benefits of replacing polluting diesel buses by non-polluting hydrogen fuel cell buses will be significant. They will make a significant contribution to reducing pollution levels in a heavily populated urban area. They will also constitute a significant first step toward reducing emissions of carbon dioxide from transportation sources, one of the biggest contributors to the global greenhouse effect, and its threatening consequences.

2. São Paulo Metropolitan Region

2.1 Transport system

Brazil's largest urban region, the São Paulo Metropolitan Region (SPMR), is composed of 39 municipalities and has a population of 17,8 million. It relies heavily on public transport and on buses in particular, with the following breakdown of journeys:

Walking 34% (10 million daily person-trips)
Private car 33% (9.6 million daily person-trips)
Bus 25% (7.7 million daily person-trips)
Commuter rail and Metro 8% (2.4 million daily person-trips)

The large share of journeys made by car and on foot suggests a potential for further expansion of public transport, notably by bus and by efficient integration of the different transport modes. Also, the intensive use of private cars shows the necessity of quality improvements in the buses and the public transportation services. The SPMR has a well-developed, integrated public transport system, for which further major extensions are planned, under the PITU 2020 (Plano Integrado de Transportes Urbanos) long-range transport plan. Public bus operations are dominated by SPTrans, managing service contractors within the city of São Paulo, and EMTU, managing the metropolitan bus system.

2.2 EMTU (Empresa Metropolitana de Transportes Urbanos de São Paulo S/A) São Paulo State Bus Authority

The EMTU is a São Paulo State Government Company, responding to the Secretariat of Metropolitan Transport, responsible for the bus lines planning, management and inspection in the SPMR and Baixada Santista Metropolitan Region (BSMR).

EMTU has created a network of dedicated bus/trolley-bus corridors, as a cost-effective alternative to fixed rail systems, where traffic density does not justify these. The first Metropolitan Corridor is already running and it links 5 cities. Since 1997 a private company, under EMTU concession, operates it. This system is composed by 11 lines, almost 200 buses and transports 6 million passengers/month, running in 33 km extension, 9 terminals, including 22 km operated by trolley-buses. Additional 11 km are now under construction.

In bidding process for new concessions, the EMTU is adopting a strategy to support the use of environmental friendly technology by rationalizing the transport system and creating an environmental policy:

- Environmental Policy: established targets of bus emissions, to be achieved in middle term by the private buses operators, decreasing the limits of acceptable levels;
- System Improvements: to rationalize the operation of the metropolitan bus system by the construction of new terminals and fully or partly segregated lanes. It follows the "Trunk-Feeder" bus concept, that foresees system of low capacity feeding system of medium capacity. It makes possible to increase the buses speed, to reduce the number of buses running and to increase the demand. All these factors can support higher investments in advanced buses.

According to EMTU's tradition in new technology development, this Company has experienced some Natural Gas and Ethanol fueled buses, since 1992 and 1997, respectively.

Now, it is time to improve the emission control in the transportation sector, and we think that fuel cell buses must be implemented in the medium term. This requires strong efforts to develop the hydrogen fuel cell technology and its implementation.

3. The Project: Hydrogen Fuel Cell Bus for Brazil

Regarding the remodeling of the transportation systems, energy conservation and conversion efficiency, emission reductions, public comfort and mobility, the Brazilian Government through the MME - Ministry of Mines and Energy and the EMTU have decided to support a Program on behalf of developing the hydrogen fuel cell bus alternative, to stimulate the development and utilization of fuel cell buses. As part of such a Program, this Project will support a significant operational test of fuel cell buses in the SPMR obtaining and operating 8 fuel cell buses - FCBs, to evaluate and to establish the minimum technical requirements for high vehicle durability, making the FCBs economically competitive, and providing feedback to the technology developers to gain meaningful experience in the operation and management of buses powered by fuel cell drive trains.

This program has been financed by the UNDP/GEF (United Nations Development Programme/Global Environment Facility), Brazilian Federal Government (FINEP – Projects and Studies Financing) and EMTU.

3.1 Development objective and expected optimized costs

The development objective of the Project is to reduce, in the future, GHG emissions through the introduction of a new energy source and propulsion technology for urban buses based upon fuel cells operating on hydrogen. This Project is designed to initiate and accelerate the process of the development and commercialization of fuel cell buses in Brazil. Together with similar future initiatives in other countries, it is intended to provide a major push to the accelerated development of relatively clean technology in the mega-cities of developing countries.

Over the longer term, assuming that this Project and its successors perform as designed, this Project will lead to an increased production in fuel cell propelled buses, and eventually, the reduction in their costs to the point where they will become commercially competitive with conventional diesel buses.

The FCBs cost hardly will be lower than the present used Diesel buses in Brazil, because these buses do not have the necessary quality requirements and do not compare to bus international standards and costs. On the other hand, to assure future viability, the FCBs cannot be more expensive than the present Brazilian trolley-buses, which comply with the best international quality standards and are much less expensive.

Considering the possibility of having a joint venture between a fuel cell system and Brazilian bus manufacturers, it was assumed that the future cost of a Brazilian FCB might be similar to the sum of the costs of a Brazilian trolley-bus and an international fuel cell system.

Based on such considerations, some basic requirements were determined to assure economic competitiveness, to be pursued in this fuel cell bus Project:

- 20 years or 1.0 million km is the minimum durability requirement, to allow higher initial investments amortization;
- vehicle manufacturers might participate in the Brazilian FCBs construction in order to bring their costs to competitive levels.

3.2 The overall hydrogen fuel cell bus program

This Project is the second step - Phase II - of a complete program – Environmental Strategy for Energy: Hydrogen Fuel Cell Buses for Brazil, the phases of which are summarized in the Figure 1 below:

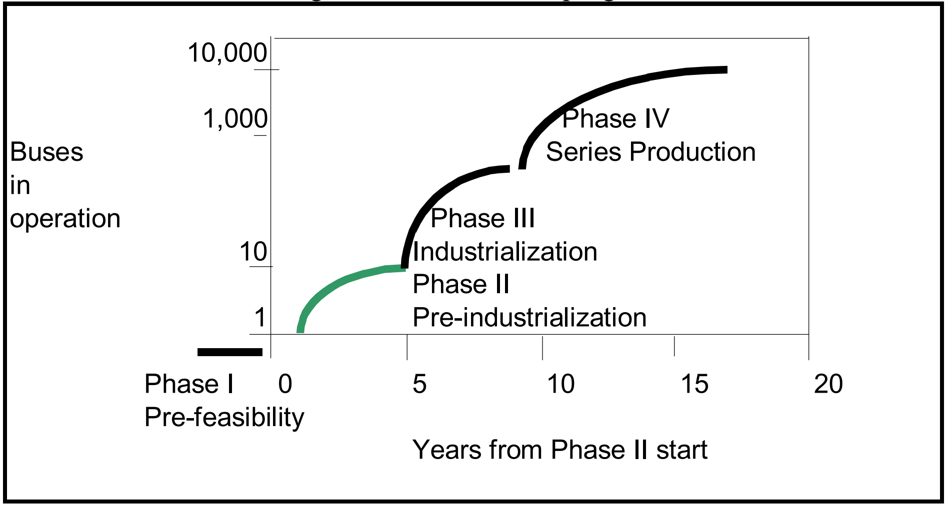
a) The Phase I feasibility study and Proposal for Phase II has been completed.

b) Phase II – the subject of this Project - involves running a fleet of 8 buses from EMTU's garage in the SPMR for 4 years in order to obtain 1,000,000 vehicle-km of experience. This is not a Project to be considered purely in isolation as a technology demonstrator. Its outputs will include both the preparation of the local operating infrastructure for Phase III and invaluable feedback into product development;

c) Phase III will involve converting a complete bus garage to operating fuel cell electric buses, with a fleet of some 200 buses. The SPMR has 52 garages in its network, ranging in size from 50 to 650 buses. 33 of these garages are in the range of 100-300 buses. Buses supplied for Phase III are expected to be built in Brazil, by adaptation of a Brazilian trolley-bus chassis, in order to take advantage of existing national capabilities.

d) Phase IV will involve wider deployment in the SPMR and other Brazilian metropolitan areas, series production of the buses on a commercial basis, and the start of exports to Latin America and other regions and/or licensed production outside Brazil. In this stage, it is expected that fuel-cell buses should be economically competitive with diesel buses on a life-cycle basis.

Figure 1: Phases of the program



Source: Phase I final report

3.3 Size, duration and location of the Project (Phase II)

The size, duration and location of the Project are dictated by the need to ensure statistically valid results:

1) 1 million vehicle-kilometers is the minimum cumulative volume of operation needed to ensure that all likely failures in service are encountered, their causes understood and remedied, and opportunities to reduce costs and increase reliability and durability are identified – the life expectancy for an electric-drive bus being 15-20 years and 1.5 million kilometers, which is currently practiced in Brazil;
2) Diesel buses in the SPMR run an average of 84,000 km per year. It is prudent to assume half of this, i.e. 42,000 km per year, with a new driveline technology and the need to familiarize operators and maintenance personnel with it. It is assumed that the availability of the buses will increase from 50% of the availability of a diesel bus in the first year to 60% and 70% of the availability in the second, third and subsequent years of operation;
3) Achieving 1 million vehicle-km therefore requires 27 vehicle-years of operation;
4) Fulfilling this in 1 year with 27 buses would be extravagantly expensive in capital costs and unachievable until bus production could be ramped up (requiring other markets to be exploited beforehand). Individual buses would not remain in operation long enough for all potential faults to be detected;
5) Spreading the experience over several years (3 buses for 9 years, for example) would be an impractical length for a trial period. The feedback from operations would mainly come too late to influence the design and updating of the technology by the producers of fuel cell engines, thereby making Project's outputs irrelevant to the rest of the program;
6) 3 buses over 3 years will not give adequate results, as these buses will still have semi-prototype engines, which will vary in characteristics from one to the other one. A minimum sample size of 8 is needed to ensure the statistical validity of the experimental results and the coverage of 1 million km, at least;
7) The 8 buses need to be in the hands of 1 operator, in order to ensure consistency of measurements and results. São Paulo contains more than enough opportunities to test the buses in different conditions: corridors and city streets; continuous operation and stop-and-go; fully and partly loaded; flat terrain and steep hills. Dispersing them among more than one city will both compromise the integrity of the test program and duplicate the investments in fuelling infrastructure and training; and
8) São Paulo also has the best-qualified bus operator, EMTU/SP, and a substantial

government/academic technology infrastructure.

The best compromise between effectiveness and cost-effectiveness--taking into account the objectives of the Project and the delivery capability of the suppliers canvassed--is therefore to run an initial batch of 3 buses for 4 years, (anticipating one rehabilitation of the fuel-cells to extend their useful life), and a second batch of 5 buses for the last 3 of these 4 years.

Therefore, this procedure has the following advantages:

1) to accumulate over 1 million km, the minimum timelife required for future buses, which is a very good target for evaluating MTBF (minimum time between failures) and FMA (failure mode analysis), at the end of the 4th operational year;
2) to make each bus run a total of 80,000 to 120,000 km, which is 2 or 3 times the objective for MTBF, and therefore sufficient to detect likely failure modes; and
3) to identify bus and driveline design and manufacturing problems.

3.4 Project fuel supply

Compressed hydrogen is best suitable than on-board liquid fuel reforming for urban buses, since their operation is centralized in a few garages.

Purchasing hydrogen from third parties could be an option, however it is out of consideration in this Project. This hydrogen presents the risk of contamination problems in the expensive prototypes of fuel cell and is not renewable, in Brazil, thus, it is not recommendable from the greenhouse effect point of view. It may be considered in the future, if hydrogen producers decide to include renewable resources in their processes under competitive costs.

Producing hydrogen from ethanol/biomass reforming may be a good option in the future, but it is not feasible now. Thus, it is not recommendable for this Project.

Thus, the most promising alternative is the hydrogen production from water electrolysis. Considering a production plant running 20 hours per day during the off-peak period, this process is less expensive than the other ones. In addition, renewable hydroelectric power is available in Brazil (92% of electricity generation is from hydro-power), the electrolysis technology is already well known and commercially available, as well as this process assures contaminant-free hydrogen at competitive fuel costs.

3.5 Benefits of hydrogen fuel cell urban buses

The Project will demonstrate significant additional local benefits in terms of reduced emission of pollutants dangerous to human health and habitat. In particular, the Project will reduce the emission of NOx, SOx, CO, HC and particulate, as detailed in the incremental cost matrix. As detailed in the text, there are also significant benefits to the global community, the automotive industry, and the technology providers.

Although the boundary for this immediate Project is the Brazilian urban transport sector, the Project will support and draw upon resources from the global automotive industry. It should also provide important feedback for public transport agencies in other parts of the developing world. One of UNDP GEF's roles is to ensure that the information gathered and experience gained should be shared across national and commercial boundaries. In that context, this Project is important internationally for the experience that will be gained and shared.

4. References

UNDP, United Nations Development Programme (1999), *Environmental Strategy for Energy: Hydrogen Fuel Cel buses for Brazil*, Pre-feasibility Study, São Paulo.

UNDP, United Nations Development Programme (1999), *Environmental Strategy for Energy: Hydrogen Fuel Cel buses for Brazil*, Project Document BRA/99/G32, São Paulo.