Married by Transit. Source: TransMilenio website.

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Trolleybus and TransMilenio: Economic, Environmental and Equity Benefits

This paper seeks to examine the potential to use electric trolleybuses in the TransMilenio Bus Rapid Transit system of Bogotá, Colombia: to what degree can trolleybuses be used operationally; what would be the economic characteristics compared to the de facto diesel choice (to what degree would such a system make economic sense); what are the political barriers to adoption; what public health arguments exist; and what might the environmental benefits be (including air quality and greenhouse gas emissions)?

TransMilenio and its Context

The political history of TransMilenio (TM) is a remarkable one, and one which relates directly to the question of how decisions such as those explored in this paper, are made. TM is the most prominent and internationally best-known result of a period of focused attention in Bogotá on reducing automobile use and increasing public space and public equity for the poor (about half the households of Bogotá make $4-$6 USD/day). With this core goal of equity, Mayor Enrique Peñalosa (and other mayors before him and since) took significant steps to reduce capacity for automobiles in the city and open public space.[1]

The TM system was established in record time, opening in January 2001, but with little public input.[2] Even as the system expansion steamrolls forward today under the reign of a new Mayor (ironically, oft destroying housing in swaths in part to *preserve* automobile lane capacity,[3] a reversal of Peñalosa's goals and principles and despite claims that Bogotá is using TM to reduce automobile

[1] Peñalosa, ITDP presentation.
[2] CP 219 lecture discussion with Bogotan, María Catalina Ochoa.
[3] Miranda, TransMilenio tour.

use) with predictable effects on land values, housing demand, and further displacement, the system is considered wildly popular amongst the public, who view it as a major improvement to their lives and to the city as a whole; for instance, on average, due to greatly increased travel times which came with TM's efficiencies, "passengers have gained 300 hours per year to themselves."[4] TM replaces dangerous, noisy, highly polluting and aged privately run buses – at a reported rate of 7.7 for each articulated bus during its second phase, up from 2.7 each during phase I after the "scrapping ratio was made a part of the competition qualification."[5]

TM is fast, clean, attractive, and relatively crime free – everything the buses it is replacing are not – although it does cost some pennies more on average, no small thing for many Bogotans, and suffers from overcrowding on many runs. TM has brought fame and high regard to Bogotá, a refreshing change given the world's impression that Bogotá is a dangerous place, ripped by rampant homicide, "narcoterrorism" and civil war. "Over 1000 city officials from approximately 50 countries have visited Bogota in the past few years" (as of November 2005).[6]

TM, by one before and after study, had broad ranging benefits including air pollution, "human diversity" (accessibility), noise (slightly), and as shown in Figure 1, below: collisions, abuse, injury, mortality and robbery all declined.[7]

[4] *Ibid.*
[5] Castro, p. 50.
[6] Wright, p. 699.
[7] Habib Mustafá, Yusif, et al.

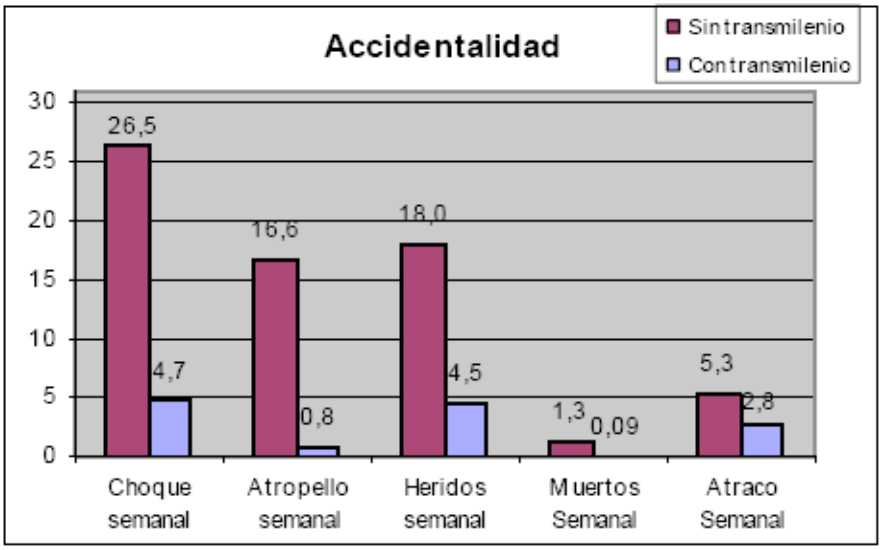

Figure 1. Accidents before and after TransMilenio (red and blue bars, respectively) for weekly incidents of Collision, Abuse, Injury, Mortality and Hold-ups.[8]

To be critical, some of these gains could be due to other policies (although the dramatic reductions over one year's time seems highly indicative of a TM effect). For example, since 1996, roadway mortality has dropped steadily from 1301 to 585 in 2003 during a period of "major prehospital attention" and the "implementation of the Zanahoria law,"[9] or "carrot law," which prohibited liquor sales after 1 AM.[10] The ITDP reports the rather dubiously combined metric that "air and noise pollution have been reduced by 30%."[11]

The Trolleybus and Bogotá

Bogotá is a model for public transport provision, given the success of its TransMilenio (TM) system, a diesel-powered Bus Rapid Transit system in the high-altitude (2640 meters) capital of Bogotá, Colombia in South America.

[8] *Ibid.* p. 2.
[9] Montezuma, slide 26.
[10] Ordóñez.
[11] *Ibid.*

However, Bogotá is also an incredibly polluted city, the 5th worst of 37 Latin American cities compared by Bogotá's Ministry of the Environment,[12] and public transport provides a lion's share of many of the pollutants, exacerbated by geography and the subsidization of low-grade, high-sulfur diesel #2.[13] Health harms from pollution are thus deplorable.[14]

At the same time, Bogotá has a wealth of electricity provided by hydropower, and is rich with oil as well. Can the TransMilenio system adopt trolleybus technology[15] for some or all of its operation, thus substituting renewable hydro power for diesel? If so, what would be the benefits and drawbacks of such a choice? Moreover, can a developing country put long-term sustainability first, if the up-front cost is more? Bogotá has already made significant progress with its campaigns to reduce automobile impacts for equity.

Health and environmental benefits, as well as economic benefits, suggest that trolleybuses would make very good sense. Barriers include higher initial capital costs, operational limitations of a fixed-guideway system, institutional barriers to adopting new technology, and political barriers to reducing fossil fuel use.

Trolleybuses are particularly well-suited to hilly terrain and high passenger loads, both of which can be found in parts of Bogotá, where the cityscape climbs up the mountains from the valleys below. This principle is part of why both San Francisco and Seattle have been not only actively maintaining but expanding their trolleybus service.[16]

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[12] Ministry of the Environment.
[13] *Ibid.*
[14] Onursal, B. and Gautam, S.P.
[15] A trolleybus is "basically, electric traction without tracks"(Peschkes, p. 9).
[16] Natvig;

Hydropower is considered the most carbon-neutral means of powering a transportation system, and it is most efficient when directly powering rail or trolleybuses by electric traction. If electric-powered buses (trolleybus technology) can be employed in any part of the TM system, including feeder lines, Bogotá could potentially gain carbon credits in addition to reaping the many health benefits of electrified bus lines: reducing noise and air pollution as well as infrastructure-degrading, resident-agitating vibration.

Electric trolleybus systems, once common, are making a comeback, not just in San Francisco and Seattle but with new Bus Rapid Transit (BRT) systems in Quito, Ecuador and Mérida, Venezuela, countries bordering Colombia.

Political history and political potential

Prior to TMs implementation, there were no fewer than twelve concerted attempts to establish a metro rail system in Bogotá. The advent of TM, it is said, closed the door on that option and settled the debate forever.

Arturo Goméz, a professor of Civil Engineering in Bogotá and a consultant assisting with a new trolleybus BRT system in Venezuela, says rail is out of the question here: "a rail-based system ought to provide the flexibility of TM, in which most people use express buses and save large amounts of time. Metros, for example, stop at all stations, and thus, will lower the level of service for these users. And given the large passenger demand, passengers would not go more comfortably in a metro."[17]

There remains a sizeable political camp which would prefer a rail system instead. "The National Image of Bogotá" is that "Bogotá needs a Metro,"[18] reports the executive director of La Fundación Ciudad Humana (Human City

[17] Goméz, personal email.
[18] Montezuma, slide 11.

Foundation) in a presentation announcing his book debunking the global myths regarding the Bogotá transformation to-date. In fact, the city officially plans that "high demand busways will be replaced by Heavy Rail when demand reaches system capacity (estimated at 45,000 pphpd)," although there is no funding identified.[19] It's noteworthy that Bogotá was able to build 40 km of the TM system without taking any loans.[20]

The trolleybus is in many senses a compromise between rail and bus: more flexible than underground rail, but with much of the comfort, air and noise pollution benefits of rail. Perhaps a potential for adoption lies in its potential to satisfy both camps: BRT with the trappings of LRT.

One source for the passion over rail stems from an outrage at feeling that previous rail systems were taken from the public by private interests who wished to establish greater market share for petroleum and its automobile and bus vehicles, a view which also exists for the trolleybus worldwide (as well as for the electric car[21] and the bicycle[22]).

The documented phenomenon in which motor interests bought up and shut down existing transit systems in the United States (General Motors was convicted of conspiracy in one case), was not an isolated phenomenon in the world; "this same practice was suffered throughout Latin America, and it happened right here in Colombia," decried a frustrated Gustavo Calderón

[19] National BRT Institute, p. 56.
[20] ITDP, p. 20.
[21] Paine, film, "Who Killed the Electric Car?"
[22] Meggs, *Wherever the Wheel?*

Herrera of the Fundación Colombiana de Peatones,[23] while moderating a panel at the Towards Carfree Cities Conference VI on September 20, 2006 in Bogotá.[24]

Yet Oscar Diaz of ITDP, known as former Mayor Enrique Peñalosa's "right hand man,"[25] downplays the rail enthusiasts and lumps "private car owners" with them, calling rail advocates "other obscure interests."[26]

Trolleybuses, despite their similarity to petroleum-based buses, were no exception from the motor-monopolization effort, as Carl Natvig of SF Muni (which operates the largest trolleybus system in North America) attested in 1978:

> The trolley coach has survived in San Francisco while being abandoned for motor buses in most other systems partly because Muni did not fall under the influence of the motor interests as did others and partly because of the great longevity of trolley coaches themselves which allowed them to last into the new era of environmental awareness.[27]

The trolleybus is thus dubbed a "neglected mode in U.S. planning."[28] Given the magnitude of motor influence in the United States and abroad, the fact that this methodology would recur internationally should be no surprise; GM yearly financial operations, for example, has been larger than the GNP of the 6th largest country in the world,[29] considerable influence.

In 1966, Italy had up to 5 times more trolleybus lines than today, at 1,121 km, when it suffered "the first suppression…the main reason was that buses were considered more suitable to the new traffic conditions."[30] Yet today, Italy is actively seeking to establish trolleybus systems in a number of cities due to their

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[23] Colombian Pedestrian Foundation. http:// www.geocities.com/peatones/
[24] TCFC VI. September 20, 2006.
[25] Peterson, Lisa. Former ITDP employee (Penalosa sits on the Board, and Gomez works at ITDP). Personal interview, Dec. 2006.
[26] Diaz.
[27] Natvig, 1978, *Summary*.
[28] Rafter.
[29] Klein and Olsen, *Taken for a Ride*.
[30] Galaverna, p. 14.

many benefits, a trend that is expected to "remain constant or increase in the next few years" for quality of life reasons, particularly due to air pollution benefits, despite a perception that trolleybuses cost more to purchase and operate.[31] Given the findings of SF Muni and others that the total cost of trolleybuses less expensive than diesel buses on heavily used lines (see below), the Italian perception may be distorted by how few systems remain (and more).

Brazil, as well, has a story to tell; simply the Abstract of Waldemar Stiel's transit history tome employs, again, the word "suppression" to describe the history of "electric city cars and electric bus transportation systems in 85 Brazilian cities" including the "start, development and *suppression* of each system." (emphasis mine).[32] This despite known benefits; Stiel published in 1984: "A trolébus saves, in a year of operation, 47 thousand liters of diesel and avoids the atmospheric pollution equivalent of three tons of carbon monoxide."[33]

That the trolleybus may be in the camp of the bicycle as a "forgotten mode,"[34] is exemplified by their near total exclusion from a fancy bus information website dedicated to clean air in Latin America.[35]

All this suggests the possibility that corruption may be playing an important role in public policy decisions. Corruption is "operationally defined" by Transparency International (TI, a group which actively monitors and studies corruption around the globe), as "the misuse of entrusted power for private gain." Colombia had a low 3.2 score (from 1 to 10, with 10 being best) on the Corruptions Perception Index (CPI) released by TI in 2000, ranking 59th in the

[31] *Ibid.,* p. 21.
[32] Stiel, Abstract.
[33] *Ibid.,* p. 464, with translation from Portuguese checked by http://www.freetranslation.com/
[34] Wilkinson, B. 1997. "Nonmotorized transportation: The forgotten modes."
[35] Clean Air Initiative in Latin American Cities, http://www.cleanairnet.org/infopool/1411/propertyvalue-17726.html

world of that year's assessed countries, at approximately the time when the TM project began in earnest.[36] This ranks Colombia just below México and just ahead of Ethiopia, Thailand and China (based on a relatively high number of surveys (8) used during the preceding two years, 1998 and 1999).[37] Two years later, Columbia's index had climbed slightly, with a score of 3.6 over more surveys (10). Today, TI rates Colombia at a CPI of 4.0.[38]

One agency representative for a Trolleybus system who did not wish to be identified asserted the reason trolleybus and rail options were not incorporated in this case, would most likely be due to corruption. "There is a lot of money to be made selling the parts for diesel buses which don't last as long, and selling the fuel…furthermore, given the potential demand in Bogotá, they should have been able to get a capital loan for a rail system through a rail company; at least, that used to be done in the past."

In fact, Bogotá once had some trolleybuses: "During the 1990s trolleybus systems closed in a few places such as Montevideo and Bogotá, either because of power costs or the mismanagement of public funds. Bogotá purchased 180 new trolleybuses from Romania in 1982-1985, then changed its mind, pulled down its wires and allowed hundreds of new, unused vehicles to rot in a field. Tram and trolleybus systems in the United States were purchased by a General Motors affiliate that replaced all electric vehicles with General motors buses that burned fossil fuel."[39] This story is reminiscent of the Red Lines in Los Angeles, although there "5 gallons of kerosene per car" were applied and the trains were burned.[40]

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[36] TransMilenio went into operation in January 2001.
[37] http://ww1.transparency.org/cpi/2000/cpi2000.html
[38] 2005 CPI. http://ww1.transparency.org/cpi/2005/cpi2005.sources.en.html
[39] http://www.merida360.com/mrd-city/trolmerida/tesis01-allen-engl.html
[40] Klein and Olsen.

What, besides corruption, can account for allowing 180 new trolleybuses to rot in a field?

On the flip side, Darío Hidalgo, one of the most published experts on TransMilenio, told me in an interview that his impression is that Trolleybus systems are an excuse for consultants to make lots of money from the overhead wire infrastructure.[41] Over-inflating trolleybus costs could kill the potential for their adoption, while making money. Corruption can cut in every direction.

There are still other potential explanations for the choice of diesel buses: although Paolo Custódio, in a guest lecture at UC Berkeley, decried the lies of consultants generally, and attested to the rush to implement the TM system. Yet he said, "sometimes you have to push something through, or nothing will ever get done."[42] Mayors in Colombia need to prove themselves during a mere three-year term, in order to make their mark and shoot for the presidency, and the primary metric for success is capital achievements.[43] A rail system can take three years simply for construction,[44] whereas TM took less than 18 months.

"There are so many plans in Latin America, million dollar plans, which sit on shelves. I can take one look at a mayor and know if he's going to accomplish anything at all. Most will not."[45]

The TransMilenio project happened over the protests of private bus owners who stood to lose their businesses (and many did), and by the same method, threatened to reduce fossil fuel consumption while providing better alternatives to the private automobile (which has undoubtedly happened, and

[41] Hidalgo, Sept. 20, 2006.
[42] Custodio, 2006.
[43] Class discussions, CP 219.
[44] ITDP, p. 20.
[45] Hidalgo, personal interview.

TM claims that 9% of the riders of TM previously drove for the same trips). TM may have been the sole achievable method of moving towards a better system.

A rail system, while providing energy savings and possibly long-term cost benefits, as well as quality of life benefits, particularly if it were constructed underground, may well have, by the same token, meant that the reduction of automobile capacity and the retirement of polluting older private buses would have been slower and much less complete, although the potential for increasing public space would have been larger.

Have Trolleybuses Been Considered?

Rotting fields of buses notwithstanding, TransMilenio reportedly has a basic study of the feasibility of trolleybuses, created during the extremely rushed period of Phase I, in which a basic economic costs analysis was done for trolleybus technology. This is called the "MacKenzie Report."[46] The report ignored issues of public health and the environment, and evidently was neither a completely detailed technical analysis nor a long-term cost analysis.[47]

Other bus alternatives

This paper does not deal in any detail with other bus locomotion alternatives. While both fuel cell and battery-powered electric buses exist, they are not economical on a commercial scale. Many experts believe that this will not change in the near future.[48] A brief carbon comparison is made below, which is also not favorable to their adoption in light of the proven trolleybus.

[46] Hidalgo, personal interview, Sept. 20, 2006.
[47] Unfortunately, although TransMilenio staff promised that this report would be provided, it has not despite a concerted email and telephone effort on the part of this author over the past 12 weeks since the promise was made in person during the Towards Carfree Cities Conference VI tour of TransMilenio in Bogotá, Sept. 23, 2006.
[48] Delucchi and Lipman; Pro, Hammerschlag, and Mazza.

Capital and Operational Costs

Phase 1 of TransMilenio is said to have cost $5.2M USD/km, about half of the capital cost of Quito's trolleybus system, at $10.3M USD/km.[49] It is interesting that the fares have an reverse relationship, yet farebox returns pay for each systems operational costs: Quito's fare is US $0.25 while Bogotá's is US $0.40, even though the TM system carries over twice as many pass/hr/dir.[50]

"The overwhelming popularity of the Quito trolley-bus has exceeded expectations and in a sense created an unexpected problem. With over 200,000 commuters now using the system daily, its maximum capacity has been reached, and thus prompted calls for further expansion. The municipality plans to deliver an additional 73 km of busways by 2006." However, "for cost reasons, Quito's new Eco-Via line utilizes Euro II diesel buses rather than continue with electric trolley technology."[51] Quito was unavailable for comment today. Yet the trolleybus system delivers at a cost of only twenty US cents per passenger, half that of TransMilenio, Their BRT stations are reportedly US $35,000.[52]

For buses alone, in Italy, "trolleybus purchase price is 1.5 or 2 times as high as the bus one…[but] on the contrary, the trolleybus life-cycle is nearly twice as long as a bus normal life-cycle and the vehicle maintenance costs and the energy consumption ones are lower."[53]

Carl Natvig of SF Muni attests to this, saying SF Muni's diesel buses last at best 12 years while electrics last 18 – and the electrics carry more people, and are

[49] ITDP, p. 5.
[50] Wright, ITDP, p. 33.
[51] ITDP, p. 7.
[52] *Ibid,* p. 23..
[53] Galaverna, p. 19.

in use more hours.[54] Although the lifecycle numbers Muni uses are the same as those which the FHA uses for funding of replacements (a metric meant to correspond to the point at which it makes economic sense to replace buses due to rising maintenance costs), Natvig says.

"[Trolleybuses] are reinvented every time a transit property buys some. There is no typical mile of trolley overhead to cost out. Every mile built in a city is unique,"[55] says Michael Vooris, Transit Fleet Procurement Supervisor for Seattle. Vooris also advises, "You have the largest [trolleybus] system in N.A. across the Bay from you. Have you talked to them?"

In fact, SF Muni does have a cost per mile estimate for their new system plans: $8.319 M USD per mile (or, $5.169M USD per km, less than TransMilenio Phase 1 at $8.3M/km – although a major difference is that this price (2002 dollars versus 2003 for TM cost) does not include a BRT system, nor does it include buses, unlike the TM cost. Higher U.S. labor costs are, of course, included.[56] At the same time, TM Phase II costs have doubled, to $15.2M/km.[57]

In Venezuela, the worst cost data emerges: "Each articulated bus was US$ 1 million, instead of US 250,000 for a TM articulated bus."[58] Could this high cost be attributed to uncertainty in reinventing trolleybuses? Escalating copper prices increasing the cost of electric motors? It's worth noting that Colombia has valuable copper resources which might be an asset in reducing bus price.

[54] Although Federal bus life standards don't make sense in some cases, Natvig says here they match reality, for the diesels because of the high loads, long hours and hills the buses, and literally are through at 12 yrs.
[55] Voris.
[56] SF Muni. 2002, p. 38.
[57] National BRT Institute, p. 35.
[58] Gómez.

Maintenance costs for overhead wires in San Francisco add $2.50 - $3 USD per hour of operation, a cost made up primarily of maintenance.[59] Labor costs in Bogotá are considerably cheaper than in the United States.

Perhaps the most optimistic cost estimate comes from Europe, where a complete package including everything from "Consultancy and design" to "Marketing/contingency," with all the substations and overhead wiring in between; stops and shelters; 25 stylin' 140-passenger buses included; with a 50 km radiating five-route system; intelligent traffic control provided; 10-minute peak headways on all routes; and an initial system capacity of 20,000 passengers an hour, comes to a mere $54.4M USD, just $1.088M USD/km.[60] Someone, somewhere, is not being consistent. (Optimism bias, or strategic misrepresentation?)

Air Pollution and TransMilenio

A trolleybus system has the tremendous benefit of injecting essentially zero emissions into the air at the vehicle, greatly reducing the human health impacts of pollution. Yet TransMilenio itself, in replacing up to 7.7 old and highly polluting buses per new articulated bus, is associated with improved air quality in highly polluted Bogotá.

> "TransMilenio has had a positive impact on air quality in the vicinity of Caracas Avenue, with a 43 percent reduction in sulphur dioxide, an 18 percent reduction in nitrogen dioxide, and a 12 percent reduction in particulate matter."[61]

Another study found even better results for SO2, and similar results for PM-10, however the maximum for NO2 was up from 146 to 175 (Figure 2).

[59] Natvig, interview, Nov. 29, 2006.
[60] Williams, p. 480.
[61] National BRT Institute, p. x.

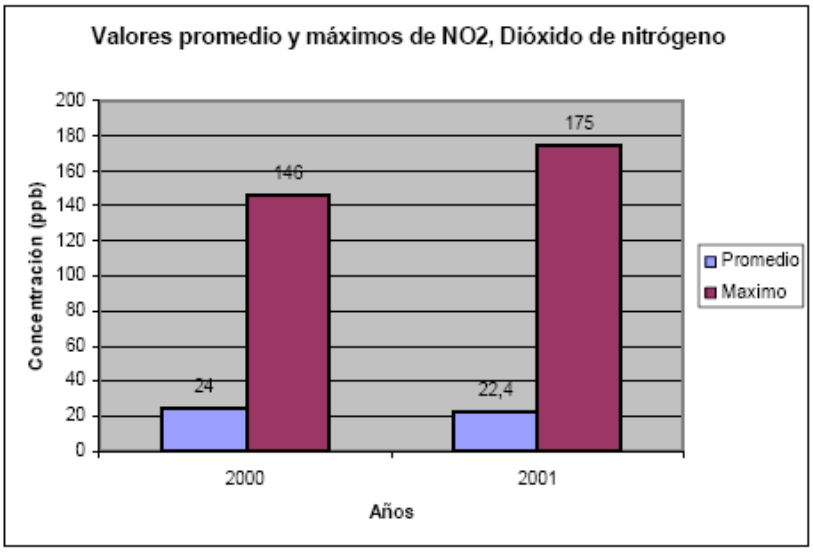

Figure 2. Minimum and maximum (blue and red) levels for NO2 in ppb, before and after TM.[62]

At the same time, the city's air pollution has worsened, even during a period when private automobile transport has improved.

> "For the city as a whole, particulate matter has increased by 12 percent and sulphur dioxide has increased by 15 percent, while nitrogen dioxide, carbon monoxide, and ozone have been reduced. Overall, this suggests that, while TM may have induced localized reductions in air pollution, this is unlikely to have translated into citywide air quality improvements."[63]

One possible explanation for this is the fact that the Bogotan economy has been on the rise, and pollution is associated with economic growth.[64] The Colombian economy has been growing at a strong 5.2% (real growth rate, 2005 estimate).[65] Another possible explanation, which I found no support for to-date, is the idea that expansion of TransMilenio has pushed some traffic onto alternate routes, creating more congestion and therefore increased pollution on those routes. There certainly is tremendous congestion on many other routes. However, at

[62] Habib Mustafá, Yusif, et al, p. 3.
[63] *Ibid.*
[64] DAMA.
[65] CIA World Factbook.

least for public transport users, "Overall, it is estimated that TransMilenio has reduced average travel time in the city by 13 minutes per trip."[66]

Energy and TransMilenio

Rising oil prices and the energy efficiency of trolleybuses adds to their argument as a good choice. In San Francisco, trolleybus operating energy costs less than $2.20/hour, versus a best case for hybrid diesel of $6/hour.[67]

Colombia exported 1.082 billion kWh of hydroelectric power (2.15% of total production) in 2003 and used 270,000 bbl/day of oil (2003 est.), 52.7% of its extraction.[68] Long-term availability of fossil fuels are far from assured, and recent trends in price volatility and price spikes, will pose serious problems for delivering basic services. The price of oil has gone up 2.5 times since TransMilenio opened, from $24.11 a barrel in Jan. 2001 to $58.86 today.[69]

"Just as a start one main concern in the past has been the high cost of this option [of trolleybuses], however with rising oil prices it becomes an option."[70]

Although Colombia is enjoying an economic boost due to oil prices, long-term sustainability indicators suggest that this will not continue. Whereas California floated out of a Dot Com boom directly into an energy crisis, prompting outrage that temporary wealth had been squandered, Colombia still has a window of opportunity to invest in the future with the wealth of today.

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[66] BRT Institute, p. 14.
[67] Natvig interview.
[68] CIA World Factbook, Colombia, https://www.cia.gov/cia/publications/factbook/geos/co.html. This researcher is surprised that each time he looks at the Factbook, the numbers seem to have changed significantly. First it appeared Colombia exported 50% of its hydro and imported 50% of its petroleum. Now it says something quite different. Was this optimism bias, carelessness, or did something big change when it was updated Nov. 30?
[69] Calculated from EIA, Colombia Spot Prices. http://tonto.eia.doe.gov/dnav/pet/hist/wepccoclw.htm
[70] Echeverri, Germán Camilo Lleras.

Oil is a finite resource, and many authorities believe world oil extrction will soon "peak," resulting in an inexorable, permanent decline, the first time in world history for this now essential resource; on average, its availability has been permanently on the rise.[71] Individual countries peak at different times.

Colombian petroleum extraction has already "reached a peak of 816 kb/d in 1999 at the midpoint of depletion. It has since declined to 520 kb/d giving a current depletion rate of just under 5% a year."[72]

A constant decline of what is currently 5% per year (25,620 kb/d) means that in only 7.5 years (mid-2014), at 2003 consumption rates of 270,000 kb/d,[73] Colombia will become a be a net importer. If the rate of 5%, rather than the amount that is 5% (low bound), remains constant, then the switch to importer begins in 2062, a much longer horizon. Given that world demand for oil is increasing at 2.8% per year for South America,[74] that picture is too rosy. Correcting for projected demand increase, Colombia becomes a net importer in 2013. (Already, Colombia is straining for supply as "refining capacity cannot satisfy domestic demand, so some refined products, especially gasoline, must be imported."[75] Furthermore, current decline of reserves is not a luxury to be counted on; an EIA and another estimate anticipate 8% world "rapid decline."[76]

At that point, costs for all things may escalate dramatically as oil is a key part of most modern processes, something that should be taken into account when pricing lifetime costs of transit systems (see costs section, below). One way

[71] Hirsch Report, SAIC.
[72] Sousa.
[73] CIA World Factbook.
[74] EIA, International Energy Outlook 2006. http://www.eia.doe.gov/oiaf/ieo/highlights.html
[75] http://www.javier.net/colombia/index.php?option=com_content&task=view&id=6&Itemid=30
[76] Hirsh, slide 17.

to attack this projection is efficiency, and another is by alternatives such as the hydro-electric-powered trolleybus.

Neighboring Venezuela used its oil profit boost to invest in Trolleybuses. Arturo Ardila Gómez has been "participating in a consultancy for a project that is similar to TM, in Mérida, Venezuela, where they are going to use trolleybuses…estimates indicate that the fare will not even cover operational costs of the trolleys. But Venezuela has got oil to cover these and many other needs."[77]

The Trolleybus and TransMilenio

Although trolleybuses can substitute in many cases for diesel buses, there are many ways in which they are quite unlike their diesel counterparts – and mostly for the better. They run on electricity, which is the only energy which can be generated from every other sort of energy, including renewable sources such as wind, hydro, and solar, giving great long-term versatility and sustainability potential. Trolleybuses are dramatically more silent, with much less vibration, than their diesel counterparts. Although they cost more, even 2-4 times as much by some estimates, they are considered to last twice as long. They are more lightweight, contributing to energy savings and reduced roadway damage; have more capacity; are considered more comfortable and pleasant to ride and so attract more ridership; fare much better on hills; have higher acceleration so can reduce fleet size and increase route speeds; save energy per passenger as compared to diesel (benefiting from high efficiencies and regenerative braking in addition to weight savings), and have fewer maintenance demands as vehicles – however, they also require an extensive infrastructure of suspended electric

[77] Gómez.

cables (one positive, one negative), and substations to maintain voltage. This, combined with higher bus cost, makes the barrier to entry considerably higher than that of diesel buses; however, the long-term economic benefits, even without the public health benefits of reduced noise and air pollution, can outweigh upfront costs.[78]

In recovering infrastructure costs, Muni found that past 10-minute headways, amortization became favorable to electrification (cheaper than diesel), in their 2002 report as well as in an earlier report. TM never goes below this; off-peak services for TM are spaced at a maximum headway of 10 minutes," a very promising indicator for trolleybus cost competitiveness indeed.[79]

For all these foregoing reasons and more, the San Francisco Municipal Transportation Agency (Muni), which again, operates the largest trolleybus fleet in North America (carrying 250,000 riders per weekday on its 16 trolley coach lines), has a 2002 plan for maximum expansion of its trolleybus system, including the conversion of certain diesel routes to electric trolleybus operation.[80]

After that glowing review, it is only fair to describe the primary downsides of trolleybuses, principally fixed operation to overhead power lines. Besides aesthetic objections, which one hopes wouldn't be a problem for TM, particularly on the trunk lines (which are generally in the center of expressways, not exactly centers of aesthetic concern), cables need maintenance and restrict travel movement, contributing to delays. It is unclear whether trolleybuses suffer more delays due to this as service calls due to fixed operation are a small number of overall calls, and trolleybuses are more reliable than diesels.

[78] SF Muni, 2002, page 12.
[79] National BRT Institute, p. viii.
[80] SF Muni, 2002.

Furthermore, unanticipated blockages which cannot be circumvented should not be significant on dedicated busways, and there are technologies which allow buses to move independently of the cables for various amounts of time (dual-mode systems), sometimes referred to as "autonomous group" in Italy.

The "current trend is towards the use of autonomous group for all movements except for regular service along lines. Dual-mode trolleybus operation makes the installation of overhead contact line along the control section of one or more lines possible, while the installation of contact line in periphery, where the transport demand is lower and the high costs of fided installations are not justified, can be avoided."[81]

Operations: is there a Place for Trolleybuses in TransMilenio?

> "The switching is the key to it all, because that's the core of TM's success, is the high-speed passing."[82]

Although electrification is increasingly cost competitive with shorter headways, Bogotá's TM, again, has headway intensity to the extreme:

> "Two-minute headways are typical during peak periods for each service line, resulting in combined headways as low as 13 seconds at busy stations along the trunk corridors.[83]

Short headways require lots of passing, which raises serious questions as to the barriers to electrification. The biggest problem seems to be that electric buses sharing wires cannot directly pass one another. It is possible to have dual lines side by side, and it is possible to switch between them to allow passing.[84] As mentioned above, various technologies, including hybrid technology

[81] Galavera, p. 19.
[82] Golub, interview.
[83] National BRT Institute, p. viii.
[84] Natvig interviews.

(onboard diesel generator or battery) allow off-grid "dual mode" operation. This investigation found no high-speed de-cabling technologies.

Understanding the core operations of TransMilenio and the technology limits of electrification will be absolutely essential in making a determination for the potential to electrify trunk lines.[85] Even if some applications are impossible, and one hesitates to put anything beyond the reach of the operational superstars of TransMilenio; there must be ways to integrate trolleybuses. TM has not only congested areas but lesser-trafficked feeder lines; even on trunk lines, there are sometimes multiple lanes for passing, with routes segregated into express and local, with long stations which would allow space for at least some switching. Diesels commonly share trolleybus routes as back-up buses or for service where infrastructure is not available. Furthermore, phasing in trolleys is most ideal on a system in rapid expansion. TM's bus contracts turn over every 10 years, and their useful life is not expected to be much longer than that, particularly especially given their heavy loading and large daily runs. TM is adding hundreds of kilometers of routes in coming years.

Even at busy stations, it should be possible to run some lines on trolleycables. The ideal choices for these are likely non-express buses, because they make the most acceleration and deceleration movements, which produce the most pollution and waste the most energy – whereas trolleybuses recapture

[85] Unfortunately, as with other requests, no help with operational data was provided by TM staff, nor were GIS files, despite repeated promises to help. Analyzing such data for Trolleybus compatibility would have been a rewarding exercise. A last minute discovery of papers at the University of the Andes in Bogotá might have been useful. An intriguing paper with, unfortunately, illegible graphs, describes dwell times mathematically as a function of a wide variety of things including such details as weather and bicycles (improving accuracy from 53% to 66% over a past model). (Tenjo and Echeverri (translation checked by http://www.freetranslation.com/).) Another study seeks to create "two modules, one of optimization and another of simulation." (Arana Novoa, et al.)

the most energy (estimates of 30%) by regenerative breaking.[86] It is possible to create a multiple cable system, allowing side by side passing of segregated routes. This would have the advantage of significant cost savings in reduced pole infrastructure and reduced substation investments.[87] Because of the distances required to switch from one cabling system to another, extending platforms might be necessary, adding to cost and passenger walking distances. High-speed switches are available which allow crossing to another cable pair at 25 mph, with straight-through operation at 40 mph (40 and 65 kph, respectively, well above normal TM operating speeds; Express service has an average operating speed of 32 kph[88]).

The high level of coordination which would be required with increasingly complex use of trolleybus technology on heavily used routes with frequent passing behavior is particularly conceivable on the TransMilenio system, thanks to their sophisticated control system:

> Operations are managed at a control center equipped with six workstations, each able to control 80 articulated buses. Each bus has a logic unit connected with GPS, odometer, and the door opening system. The logic unit reports the bus location every 6 seconds with 2-meter (6.6 feet) precision. Control center operators have a monitoring screen for each service in schematic display and a digital map that shows the physical location of all buses in revenue service. Optimized timing of traffic signals at intersections along trunk corridors further reduces service delays. [89]

Even if we ignore trunk lines, another possibility for the trolleybus is the feeder lines. Phase II, mostly completed, includes 509 km of feeder lines, which often operate in mixed traffic in residential areas, rather than dedicated busways. Planned are 335 more articulated buses and 200 more conventional.

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[86] Personal interview with professor XXX of Toronto, after TCFC VI in Bogota.
[87] Natvig interview.
[88] National BRT Institute, p. 14.
[89] National BRT Inst. P. viii.

Finally, routes with elevation changes, again, have great promise for electrification. Muni finds that trolley buses are far superior to diesels for hill climbing for many reasons,[90] as does Seattle; "Trolley busses can climb these hills easier then standard Diesel busses."[91] The city of Bogotá is mostly flat, on a plateau, yet bordering a mountainous area with development up steep slopes on some highly trafficked routes (with stunning views, incidentally). Additionally, there is a proposed link to a neighboring city which travels over a large mountain and may be an ideal trolleybus linkage. With regenerative braking, a descending trolleybus could even be said to be pushing up an ascending bus.

Trolleybuses Excel At	Transmilenio
Hill Climbing	Some
High Passenger Loads	Yes
Rapid Acceleration between close stops	Lots

Figure 4. A few supportive considerations

BENEFITS OF ADOPTING TROLLEYBUSES

Air Pollution

"TM improved the air of the city."[92] But is that enough?

Even given that TM buses are associated with air pollution reductions, the fact remains that Bogotá is terribly polluted, and needs solutions. The Ministry of the Environment has proposed, for instance, prohibiting freight transport during the morning peak in order to mitigate the peak in air pollution from

[90] Strauss interview 1.
[91] Kavanagh Transit Systems.
[92] Montezuma, Ricardo. *The Myths and Realities of Bogotá*. Presentation at TCFC VI Conference, September 19, 2006. Slide 9. http://ciudadhumana.org/congresociudadessinautos/memorias/conferencias%20PDF/Transformaci%F3n%20Bogota%20VI%20Towars%20car%20free%20cities%20MONTEZUMA.pdf

public transport -- remarkable even for a large city where some 70% of trips are by transit. How much will that impact the economy? Is it worth an initial investment in zero emissions trolleybuses? How much pollution would be averted? One study, based in Beijing, arrived at the supportive finding that "at higher emissions reduction targets of 20-50%, electric trolley and LPG buses would be cost effective, and would partly replace diesel vehicles."[93]

TM certainly contributes to air pollution; long, loaded buses at 13 second headways – *280 buses per hour per direction*[94] *pollutes*. Granted, they have relatively consistent and high speeds, which should yield some benefits of emissions reduction.[95] Furthermore, at build-out, TM "will serve 5 million passengers per day with 388 km of busways."[96] Passengers ride on already busy expressways, immersed in pollution. At the same time, passengers have gained 300 hours per year to themselves.[97] This is time that might be spent in locations more protected from pollution. Pollution levels within vehicles can be many times higher than ambient air.[98]

Using emissions data from a study comparing 18-meter, 140-passenger articulated buses,[99] and the current daily distance traveled by TM buses (370 km/day)[100], and the number of buses (470 articulated during Phase I; we will ignore the 235 conventional buses, and the 535 new buses of Phase II for now),[101]

[93] Shrestha, pp. 9-10.
[94] Nat'l BRT Inst., p. 18.
[95] Pillot.
[96] ITDP *Sourcebook,* p. 6.
[97] *Ibid.*
[98] International Center for Technology Assessment.
[99] Williams, p. 474.
[100] National BRT Institute, p. 18.
[101] *Ibid,* p. 8.

we can arrive at an optimistic estimate for the vile contribution that TM diesels make to the ambient air (Tables 1, 2, below).

TABLE 1: **Daily System Emissions for Phase I Long Buses (470, 370 km/day/bus)**

	DIESEL		TROLLEY	
Contaminate	g/km	mt	g/km	mt
NOX	18.600	3.235	1.270	0.221
Contaminate	1.900	0.330	0.060	0.010
HC	1.340	0.233	0.000	0.000
SO2	1.440	0.250	0.620	0.108
Particulate	0.560	0.097	0.012	0.002
CO2	1.880	0.327	1.380	0.240
TOTAL		4.473		0.581

TABLE 2: **Daily System Emissions for Phase II ALL Buses (1240, 370 km/day/bus)**

	DIESEL		TROLLEY	
Contaminate	g/km	mt	g/km	mt
NOX	18.600	8.534	1.270	0.583
Contaminate	1.900	0.872	0.060	0.028
HC	1.340	0.615	0.000	0.000
SO2	1.440	0.661	0.620	0.284
Particulate	0.560	0.257	0.012	0.006
CO2	1.880	0.863	1.380	0.633
TOTAL		11.800		1.533

Based on this simple calculation, TM is contributing 7.69 times more metric tons of pollution, probably somewhere between 4.5 and 12 metric tons – and that pollution is reaching many lungs, unlike that of the trolleybuses.

This is actually optimistic for the diesels. For one, TM articulated buses hold 160 people, 20 more than the buses used in the study, which increases weight and therefore fuel burned and thus, contamination. Furthermore, although the TM buses are Euro II compliant,[102] they run much dirtier than they could on high-sulphur (1,000 ppm!) diesel, "the only thing available," a problem

[102] *Ibid*, p. 11.

"exacerbated by heavy duty performance requirements, which demand that vehicles cover 350 km (217 miles) per day, fully loaded 75 percent of the time, at high altitude.[103]

To its credit, TransMilenio does benefit from the consistency of its service, an additional explanation for any reduction of emission. TM buses travel at fairly optimum speeds, unobstructed, with signalization delays small enough due to timing that signal priority has not been needed generally.[104] Still, TM buses are only running 21 kph (local) to 32 kph (express), and emissions reductions from speed can continue to be seen until 60 or even 80 kph (not to mention, the vehicle is in the area contaminated for a shorter time).

Thus is probably an under-estimate of emissions, which needs to be taken into account when considering what the public health benefits of trolleybus substitution would be. Adjustments for all these factors (load, altitude, consistent speed, additional passengers, etc.) would give a more accurate number; a more serious study of trolleybus potential benefits should be done.

Energy and the Environment: Global Climate Change

Despite the preceding section, Lloyd Wright has completed a recent study which supports the idea that TransMilenio is a best practice in reducing air pollution, particularly with regards to climate change:

> Emissions from the transport sector represent the fastest growing source of global greenhouse gas emissions… The sheer number of private vehicles being added to roadways will likely overwhelm any technological advances. … The scenario analyses indicated that the cost of fuel-based solutions ranged from approximately US$148 to over US$3500/tonne of CO_2. By contrast, shifting mode share from high-emitting sources (private vehicles) to lower-emitting sources (public transport and nonmotorized options) produced emission reduction costs between US$14 and US$66/tonne of CO_2.

[103] BRT Inst.
[104] TransMilenio tour.

> This research has thus indicated that fuel-based solutions alone will not likely achieve cost-effective reductions in greenhouse gas emissions. **The most cost-effective means to emission reductions appears to be a diverse and integrated package of measures that promote shifts to lower-emitting modes.**[105] *(Emphasis mine.)*

Emissions are an unavoidable and very large consequence of diesel energy consumption (particularly as practiced by TM), and have serious implications for global climate change. In contrast, a trolleybus running on hydro power is not only a Zero Emissions vehicle locally, but its lifecycle GHG contributions are much smaller than those of diesel buses (see Table 2), and primarily embedded in the existing infrastructure which provides the hydro power, so no even fewer net new carbon emissions are added to the atmosphere. To adapt trolleybuses to TM fits with the idea of a "diverse and intergrated package of measures that promote shifts to lower-emitting modes." In TMs case, the shift is from Colectivos; with trolleybuses, the shift can also be from TM itself.

Pollution comparison diesel bus/trolleybus

Pollution	Local Emission		Global Emission		
	articulated-diesel bus g/km	articulated-trolleybus g/km	articulated-diesel bus g/km	articulated-trolleybus (*) g/km	articulated trolley. (**) g/km
SO^2	1.07	0	1.7	0.86	0.43
NO^2	23.6	0	24.2	1.31	0.66
Dust particles	0.47	0	0.5	0.25	0.13
CO	4.58	0	4.8	0.61	0.31
CO^2	1204	0	1314	912	456

(*) power generated by thermal electric stations
(**) power generated by hydroelectric stations
Source: P. G. Brandl, "Obus mit positiven Perspektiven", Nahverkehr, 9/2001

Table 2. Graph Summarizing Results of P.G. Brandl's "Obus mit positiven Perspektiven," Nahverkehr, 9/2001, showing major reduction of all emissions for articulated trolleys powered by hydroelectric stations.[106]

[105] Wright and Fulton, p. 715.
[106] Khorovich, p. 56.

Recent CO_2 emissions reductions estimates for various new-fangled fuel technology scenarios, when compared to Life Cycle Analysis (LCA) trolleybus findings by Brandl's (Table 2, above), shows the hydro-electric trolleybus contributes only 34.6% as much as a diesel bus over its lifetime (65% reduction) and a thermal-electric powered trolleybus contributes still only 69% (31% reduction). In contrast, the most optimistic operating costs for CNG (not an LCA) gave 75% reduction for fuel cells (pessimistic, 30%) and only 20%/5% for hybrid-electric, 0%/10% for CNG.[107] See summary graph, Figure 1, below.

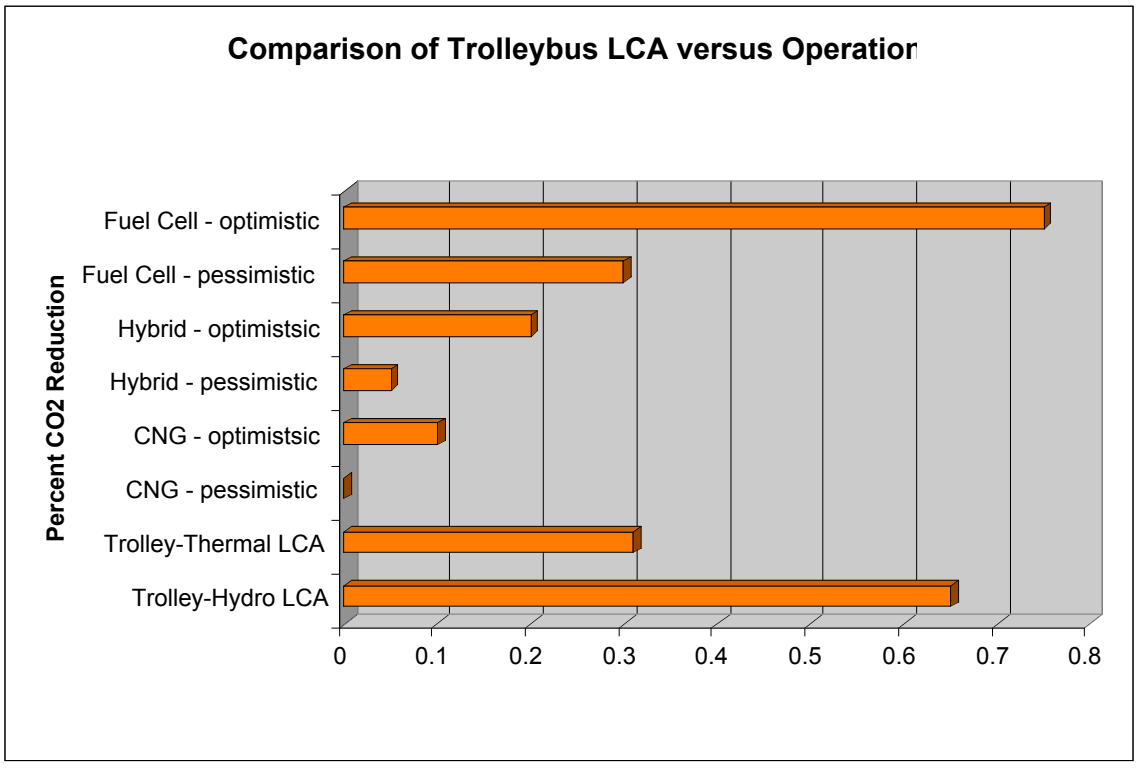


Figure 1. Summary of carbon emissions for a trolleybus powered by either hydro or thermal-electric, versus both optimistic and pessimistic predictions for hybrid buses, Compressed Natural Gas (CNG) buses, and fuel cell buses.

[107] Wright, p. 707, Table 3.

Moreover, due to altitude, CNG has significant problems such as accelerated engine wear and inefficient fuel use in Bogotá and emissions in general are worse than at sea level. Thus, there is only one such bus in use as an experiment.[108]

Fossil fuel based electric power plant substitutes for hydro power are under development in Colombia following an energy shortage, similar to California's response during the perceived energy crisis early this decade:

> a prolonged drought in 1992 forced severe electrical rationing throughout the country until mid-1993. The consequences of the drought on electricity-generating capacity has caused the government to commission the construction or upgrading of 10 thermoelectric power plants. Half will be coal-fired, half will be fired by natural gas. The government has also begun awarding bids for the construction of a natural gas pipeline system that will extend from the country's large gas fields to its major population centers. Plans call for the completion of this project, which will make natural gas available to millions of Colombian households, by the middle of the next decade.[109]

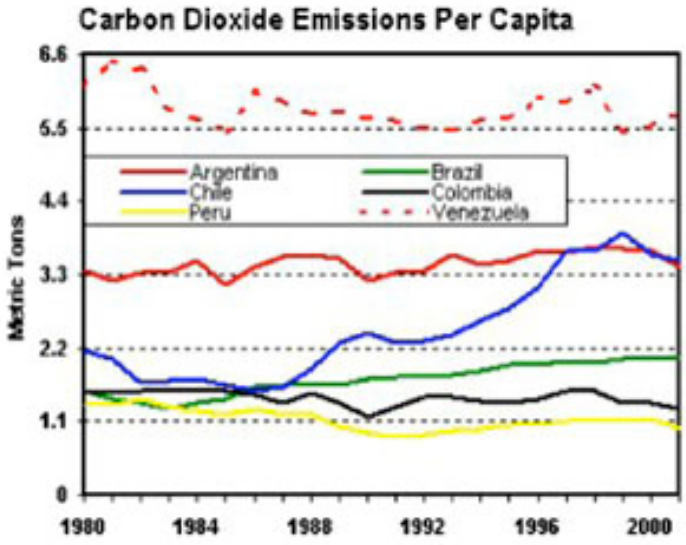


Figure 3. Carbon emissions per capita for various South American countries.[110]

The global warming implications of this are particularly dire, as the relatively low GHG impacts of Colombia and Brazil (see Figure 3, above) are due

[108] TransMilenio tour.
[109] http://www.javier.net/colombia/index.php?option=com_content&task=view&id=6&Itemid=30
[110] Latin American Growth Trends. http://www.eia.doe.gov/emeu/cabs/carbonemiss/chapter7.html

in large part to their use of hydro power; "Colombia is second to Brazil in its hydroelectric potential."[111]

Hydro no Panacea

Despite the potential for hydro power in Colombia, a deep irony looms: namely, the specter of global climate change caused by fossil fuel use, forcing an abandonment of hydro power and precipitating greatly increased use of fossil fuels for energy due to drought in the Amazon leaving hydro power stations dried out.

A year ago, a record drought hit the Amazon,[112] and dire future prospects have been predicted.[113] Furthermore, this paper absolutely ignores the negative effects of hydro power, but rather looks to existing hydro power as a resource that should be used more effectively and exclusively. Trolleybuses and line efficiencies, coupled with other efficiency campaigns, are a way to do that.

Cost Analysis and Decision Making

Could the TransMilenio decision have been made differently? Perhaps. Is it too late to adopt different practices? No. But approaching such a decision should be made carefully in light of the many considerations. How do we value human life, and the environment? The conventional discount rate, which is applied knee-jerk by conventional economists, immediately undermines the business sense of purchasing a bus for twice as much now, along with additional infrastructure and coordination responsibilities -- even if it lasts longer, costs less to operate, is more reliable, harms fewer people, carries more people more

[111] http://www.javier.net/colombia/index.php?option=com_content&task=view&id=6&Itemid=30
[112] Rohter, NY Times.
[113] "Richard Betts and other scientists at Hadley Centre for Climate Prediction and Research in Britain have developed a model which shows that if the current trend in warming continues, large tracts of the Amazon will die off by end of this century" in their report in New Scientist, "Forests Turn to Dust," May 6, 2000. http://www.ecobridge.org/content/g_tht.htm

quickly, is more comfortable, and will likely cost much less to power in the near future. This is a problem for policymaking and business which desperately needs to be addressed. Alternative methods of reaching important public policy decisions, including alternatives to the current discount rate system, are increasingly available and increasingly sophisticated.[114]

Conclusion

TransMilenio is a mass transit BRT system which is unique and remarkable in the world. Currently operating on diesel technology, the system has contributed to numerous measurable public benefits from crime and collision reduction to hundreds of hours of time saved traveling.

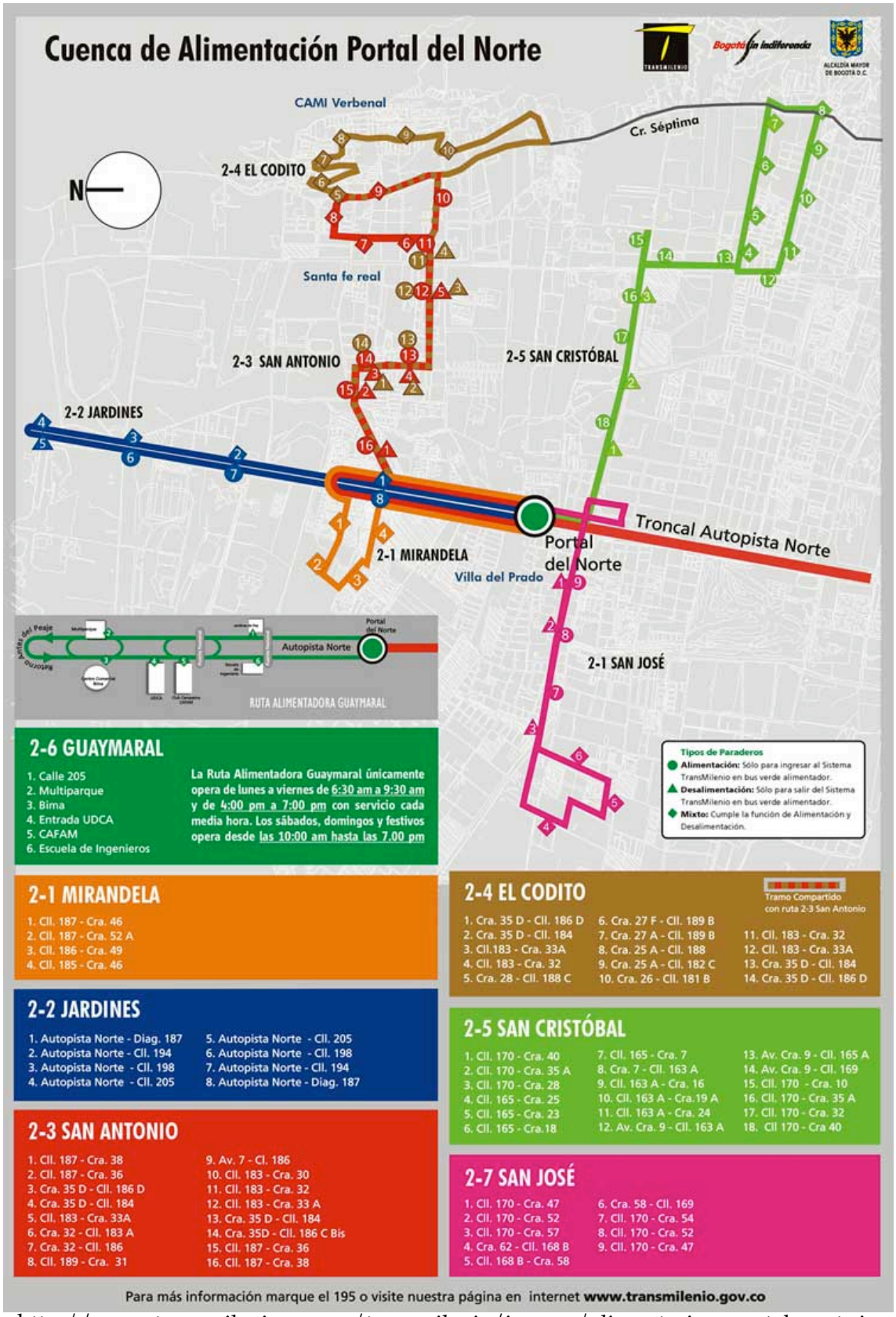
At the same time, TransMilenion contributes to the problems of air and noise pollution, and global climate change, more than it could; the potential to strategically incorporate electric trolleybus technology exists. Sustainability benefits of trolleybuses include greater social equity, good economic sense, and environmental protection (the three "E's" of sustainability).

A more careful investigation of the potential to phase in electrification of TransMilenio should be completed. The trade-offs in time and cost in the short term may indicate that expansion of TransMilenio, with its reported ability to retire 7.7 older, polluting vehicles per new articulated bus, is the best path for maximum public benefit in the short-term. However, long-term, phasing in electrification is expected to greatly add to the achievements of TransMilenio.

Given the deplorable pollution problem which Bogotá suffers, the fragile nature of energy availability and the environment for future generations, the argument for such a choice may be irrefutable. While policy agreements such as

[114] *Shah interview, paper and PowerPoint presentation.*

the Kyoto protocol may exempt developing nations from reducing GHG emissions, the benefits of storing petroleum for a rainy day, and setting a course to use less of it, should serve any nation well as we stand on the likely precipice of peak oil and progressive hardships from inexorable declines in cheap energy.



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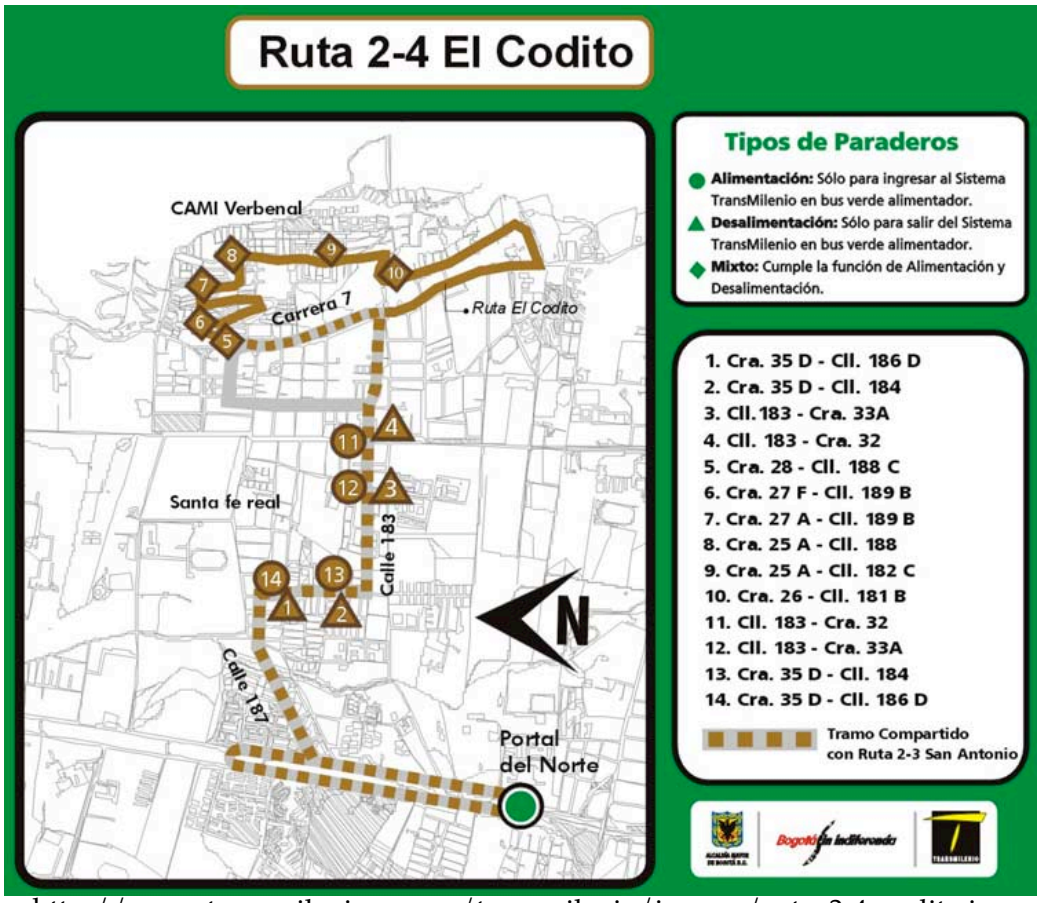

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http://www.transmilenio.gov.co/transmilenio/images/9-7_bosa_la_independencia.jpg

Portal Del Norte

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
2-1	Mirandela	04:44 a.m.	12:15 p.m.	04:44 a.m.	12:15 p.m.	05:44 a.m.	11:15 p.m.
2-2	Jardines	04:40 a.m.	12:15 p.m.	04:40 a.m.	12:15 p.m.	05:40 a.m.	11:15 p.m.
2-3	San Antonio	04:20 a.m.	12:15 p.m.	04:20 a.m.	12:15 p.m.	05:20 a.m.	11:15 p.m.
2-4	El Codito	04:14 a.m.	12:15 p.m.	04:14 a.m.	12:15 p.m.	05:14 a.m.	11:15 p.m.
2-3	San Antonio 2	05:40 a.m.	09:00 p.m.	No opera	No opera	No opera	No opera
2-5	San Cristóbal	04:25 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:25 a.m.	11:15 p.m.
2-6	Guaymaral	06:28 a.m.	07:00 p.m	09:00 a.m.	07:00 p.m.	09:00 a.m.	07:00 p.m.
2-7	San José	04:33 a.m.	12:15 p.m.	05:00 a.m.	12:15 p.m.	05:33 a.m.	11:15 p.m.

PORTAL 80

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
1-1	Álamos	04:36 a.m.	12:25 p.m.	04:36 a.m.	12:25 p.m.	05:36 a.m.	11:25 p.m.
1-2	Garcés Navas	04:42 a.m.	12:25 p.m.	04:42 a.m.	12:25 p.m.	05:42 a.m.	11:25 p.m.
1-3	Villas Granada	04:36 a.m.	12:25 p.m.	04:36 a.m.	12:25 p.m.	05:36 a.m.	11:25 p.m.
1-4	Cortijo	04:30 a.m.	12:25 p.m.	04:30 a.m.	12:25 p.m.	05:30 a.m.	11:25 p.m.
1-5	Colsubsidio	04:30 a.m.	12:25 p.m.	04:30 a.m.	12:25 p.m.	05:30 a.m.	11:25 p.m.
1-6	Bolivia Oriental	04:42 a.m.	12:25 p.m.	04:42 a.m.	12:25 p.m.	05:42 a.m.	11:25 p.m.
1-7	Quirigua	04:36 a.m.	12:25 p.m.	04:36 a.m.	12:25 p.m.	05:36 a.m.	11:25 p.m.
1-8	Calle 80	06:00 a.m.	08:00 p.m	No opera	No opera	No opera	No opera
1-9	Villas Dorado	04:36 a.m.	12:25 p.m.	04:36 a.m.	12:25 p.m.	05:36 a.m.	11:25 p.m.
1-10	Bolivia Bochica II	04:42 a.m.	12:25 p.m.	04:42 a.m.	12:25 p.m.	05:42 a.m.	11:25 p.m.

Intermedias Calle 80

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
5-1	Suba Rincón	04:30 a.m.	12:15 p.m.	04:30 a.m.	12:15 p.m.	05:30 a.m.	11:15 p.m.
5-2	Aures Villamaría	04:13 a.m.	12:17 p.m.	04:13 a.m.	12:17 p.m.	05:15 a.m.	11:17 p.m.
5-3	Serena Cerezos	04:46 a.m.	12:15 p.m.	04:46 a.m.	12:15 p.m.	05:46 a.m.	11:15 p.m.
5-4	Florida	04:42 a.m.	12:15 p.m.	04:42 a.m.	12:15 p.m.	05:42 a.m.	11:15 p.m.
5-8	Suba Compartir	04:13 a.m.	12:15 p.m.	04:13 a.m.	12:15 p.m.	05:15 a.m.	11:15 p.m.

Portal Américas

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
9-1	Casa Blanca	04:28 a.m.	12:20 p.m.	04:28 a.m.	12:20 p.m.	05:28 a.m.	11:20 p.m.
9-2	Metrovivienda	04:25 a.m.	12:20 p.m.	04:25 a.m.	12:20 p.m.	05:25 a.m.	11:20 p.m.
9-3	Bosa La Libertad	04:34 a.m.	08:30 p.m.	04:34 a.m.	08:30 p.m.	No opera	No opera
9-4	Patio Bonito	04:35 a.m.	12:20 p.m.	04:35 a.m.	12:20 p.m.	05:35 a.m.	11:20 p.m.
9-5	Av. Tintal	05:00 a.m.	07:52 p.m.	05:50 a.m.	08:56 p.m.	No opera	No opera
9-6	Av. Villavicencio	05:01 a.m.	08:00 p.m.	No opera	No opera	No opera	No opera
9-7(p)	Bosa Independencia	04:30 a.m.	08:30 p.m.	04:30 a.m.	08:24 p.m.	No opera	No opera
9-7(v)	Bosa Independencia	08:30 a.m.	12:20 p.m.	08:30 a.m.	12:20 p.m.	05:25 a.m.	11:20 p.m.

(p) Hora pico
(v) Hora valle

Intermedias Banderas

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
8-1	Kennedy Central	04:45 a.m.	12:08 p.m.	04:45 a.m.	12:08 p.m.	05:45 a.m.	11:08 p.m.
8-2	Kennedy Hospital	04:39 a.m.	12:08 p.m.	04:39 a.m.	12:08 p.m.	05:39 a.m.	11:08 p.m.
8-3	Castilla	04:45 a.m.	12:08 p.m.	04:45 a.m.	12:08 p.m.	05:45 a.m.	11:08 p.m.
8-4	Corabastos	04:42 a.m.	12:08 p.m.	04:42 a.m.	12:08 p.m.	05:42 a.m.	11:08 p.m.
8-5	Biblioteca El Tintal	04:43 a.m.	12:08 p.m.	04:43 a.m.	12:08 p.m.	05:43 a.m.	11:08 p.m.

Portal Tunal

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
6-1	Candelaria	04:10 a.m.	12:15 p.m.	04:40 a.m.	12:15 p.m.	05:40 a.m.	11:15 p.m.
6-2	San Francisco	04:10 a.m.	12:15 p.m.	04:40 a.m.	12:15 p.m.	05:40 a.m.	11:15 p.m.
6-3	Sierra Morena	03:53 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:25 a.m.	11:15 p.m.
6-4	Paraíso	03:42 a.m.	12:15 p.m.	04:10 a.m.	12:15 p.m.	05:10 a.m.	11:15 p.m.
6-5	Tesoro	03:51 a.m.	12:15 p.m.	04:21 a.m.	12:15 p.m.	05:21 a.m.	11:15 p.m.
6-6	JJRondón	04:00 a.m.	12:15 p.m.	04:30 a.m.	12:15 p.m.	05:30 a.m.	11:15 p.m.
6-7	San Joaquín	03:42 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:25 a.m.	11:15 p.m.
6-8	Vista Hermosa	05:05 a.m.	08:27 p.m.	No opera	No opera	No opera	No opera

Intermedias 40 sur

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
7-1	Uribe Uribe	04:16 a.m.	12:07 p.m.	04:46 a.m.	12:07 p.m.	05:46 a.m.	11:07 p.m.
7-2	Tunal	04:18 a.m.	12:07 p.m.	04:48 a.m.	12:07 p.m.	05:48 a.m.	11:07 p.m.
7-3	Inglés	04:20 a.m.	12:07 p.m.	04:50 a.m.	12:07 p.m.	05:50 a.m.	11:07 p.m.

Portal De Usme

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
3-1	Aurora	05:50 a.m.	08:00 p.m.	No opera	No opera	No opera	No opera
3-2	Santa Librada	03:58 a.m.	12:15 p.m.	04:32 a.m.	12:15 p.m.	05:32 a.m.	11:15 p.m.
3-3	Chunza	03:54 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:30 a.m.	11:15 p.m.
3-4	Alfonso López	03:52 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:25 a.m.	11:15 p.m.
3-5	Usminia	03:53 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	05:25 a.m.	11:15 p.m.
3-6	Danubio	04:12 a.m.	12:15 p.m.	04:44 a.m.	12:15 p.m.	05:44 a.m.	11:15 p.m.
3-7	Av. Caracas	04:40 a.m.	08:33 p.m.	04:44 a.m.	12:15 p.m.	05:44 a.m.	11:15 p.m.
3-8	Virrey	03:55 a.m.	12:15 p.m.	04:25 a.m.	12:15 p.m.	02:25 a.m.	11:15 p.m.
3-9	Marichuela	04:05 a.m.	12:15 p.m.	04:40 a.m.	12:15 p.m.	05:40 a.m.	11:15 p.m.

Intermedias Molinos

		Lunes a viernes		Sábado		Festivo	
		Primera Salida de estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación	Primera Salida de Estación	Última Salida de estación
4-1	Bochica	04:22 a.m.	12:10 p.m.	04:48 a.m.	12:10 p.m.	05:48 a.m.	11:10 p.m.
4-2	Diana Turbay	04:18 a.m.	12:10 p.m.	04:48 a.m.	12:10 p.m.	05:48 a.m.	11:10 p.m.
4-3	Molinos II	04:19 a.m.	12:10 p.m.	04:52 a.m.	12:10 p.m.	05:50 a.m.	11:10 p.m.

http://www.transmilenio.gov.co/transmilenio/index.asp?id=344

References:

Arana Novoa, Diana Margarita María; Medaglia, Andrés L.; Palacios, Fernando. *Herramienta para el diseño óptimo de la red de rutas en sistemas de transporte masivo con aplicación a Transmilenio S.A.* June 7, 2005. http://hdl.handle.net/1992/232

Booz, Allen & amilton, Inc. *Trolleybus Propulsion Evaluation: Final Report.* August 1987. SF Muni.

Castro, Angelica (Subgerente General (General Manager), Transmilenio SA). *The second phase of TransMilenio.* July 2004. Public Transport International, Vol. 53 (4/2004).

CIA World Factbook. *Colombia.* Updated November 30, 2006 (accessed December 11, 2006). https://www.cia.gov/cia/publications/factbook/geos/co.html

Class discussions, CP 219, Fall 2006. Class included one student from Bogotá who provided many first-hand insights into the history of TransMilenio.

Clean Air Initiative in Latin American Cities, accessed December 11, 2006. http://www.cleanairnet.org/infopool/1411/propertyvalue-17726.html

Custodio, Paólo, Consultant and Founder, Logit Consultoria, Sao Paulo, Brazil and a principle planner of Colombia's TransMilenio Bus Rapid Transit System. *Urban Transportation Trends in Asia, Africa, and Latin America and Bus Rapid Transit (BRT).* September 12, 2006. Global Metro Studies Lecture, UC Berkeley.

DAMA (Departamento Técnico Administrativo Medio Ambiente – Ministry of the Environment), Bogotá, Colombia. *Construcción de las políticas del distrito para el mejoramiento de la calidad de aire.* Presentation at Towards Carfree Cities Conference VI (TCFC VI), September 20, 2006.

Delucchi, Mark A. and Timothy E. Lipman. "An analysis of the retail and lifecycle cost of battery-powered electric vehicles." Nov. 2001. Transportation Research Part D. 6 (6), pp. 371-404.
http://pubs.its.ucdavis.edu/publication_detail.php?id=391

Ecobridge. *Threat of Climate Change.* Accessed December 11, 2006.
http://www.ecobridge.org/content/g_tht.htm

Echeverri, Germán Camilo Lleras. *Personal email communication.* Universidad de los Andes, Bogotá, Colombia. October 12, 2006.

EIA, International Energy Outlook 2006.
http://www.eia.doe.gov/oiaf/ieo/highlights.html

EIA, *Colombia Cano Limon Spot Price FOB (Dollars per Barrel), 1989 – 2006.* Accessed December 11, 2006.
http://tonto.eia.doe.gov/dnav/pet/hist/wepccoclw.htm

Galaverna, M; Genova, R. and Sciutto, G. *Present and future prospects for trolleybuses in Italy.* Urban Transport and the Environment for the 21st Century IV. Borrego, C. and Sucharov, L. (Editors), 1998. Computational Mechanics Publications, WIT Press. Southampton, UK, pp. 13-21.

Golub, Aaron. Personal interviews on XX and YY dates.

Gómez, Arturo Ardila. Personal email. 13 Oct 2006. Assistant Professor, Department of Civil and Environmental Engineering and Department of Industrial Engineering, at Universidad de Los Andes (Bogotá, Colombia).

Habib Mustafá, Yusif; Hidalgo, Darío. *Estudio de impacto de Transmilenio.* June 16, 2005. http://hdl.handle.net/1992/440

Hammerschlag, Roel and Patrick Mazza. "Questioning hydrogen." Energy Policy Volume 33, Issue 16 , November 2005, Pages 2039-2043.

Herrera, Gustavo Calderón. *Panel moderation and subsequent interview at the Towards Carfree Cities Conference VI.* September 20, 2006. Fundación Colombiana de Peatones (Colombian Pedestrian Foundation). http://www.geocities.com/peatones/

Hidalgo, Darió. *Personal interview.* September 20, 2006.

Hidalgo, Darió. *TransMilenio: A high capacity – low cost bus rapid transit system developed for Botoa', Colombia.* Urban Mobility for All – La Mobilite' Urbaine pour Tous, Godard & Fatonzoun (eds), 2002. Swets & Zeitlinger, Lisse, pp. 351 – 356.

Hidalgo, Darió. *The Backbone of the Mobility Strategy of Bogotá: TransMilenio.* Public Transport International - 5/2003, p. 28-31.

Hirsch, Robert L. *Peaking of World Oil Production: Impacts, Mitigation, & Risk Management.* February 2005. NETL, DOE. http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

Hirsch, Robert L. *Peakingof World Oil Production: the Mitigation Challenge.* October 2005. NAS conference.

ITDP. *Sustainable Transport: A Source-Book for Policymakers in Developing Cities. Module 3a: Mass Transit Options.* ITDP. Wright, Lloyd. *Module 3b: Bus Rapid Transit.* ITDP. http://itdp.org/read/brtplanningguidedec04.pdf

International Center for Technology Assessment. *In-Car Pollution: the Hidden Threat to Automobile Drivers.* July 2000. Washington, D.C. http://www.icta.org/doc/In-car%20pollution%20report.pdf

Kavanagh Transit Systems. *Seattle Trolley Buses.* Last updated Nov. 22, 2006; accessed December 11, 2006.
http://ktransit.com/transit/uspnw/seattle/sea_etb.htm

Khorovich, Boris. *The trolleybus in a modern city: state-of-the-art and future perspectives.* July 2004. Public Transport International, Vol. 53 (4/2004).

Klein, Jim and Olsen, Martha. 1997. *Taken for a Ride.* (Documentary Film.)

Kühn, Francis. *Bus Rapid or Light Rail Transit for Intermediate Cities?*. Urban Mobility for All – La Mobilité Urbaine pour Tous, Godard & Fatonzoun (editors), 2002. Swets & Zeitlinger, Lisse, pp. 357-365.

Meggs, Jason. *Wherever the Wheel: Into the Thickets of Bicycling's Dive, 1900 – 1920.* Fall 2006. Term Paper for CP 200, History of City Planning, DCRP, UC Berkeley.
http://bclu.org/wherever-the-wheel.pdf

Miranda, Maria Victoria. *Salida técnica a Transmilenio* (Interviews and presentations during 5+ hour TransMilenio tour). September 23, 2006.

Montezuma, Ricardo. *The Myths and Realities of Bogotá.* Presentation at TCFC VI Conference, September 19, 2006.
http://ciudadhumana.org/congresociudadessinautos/memorias/conferencias%20PDF/Transformaci%F3n%20Bogota%20VI%20Towars%20car%20free%20cities%20MONTEZUMA.pdf

National BRT Institute. *Applicability of Bogotá's TransMilenio BRT System to the United States: Final Report – May 2006.* May 2006. Federal Transit Administration. Project Number FL-26-7104-01.
http://www.nbrti.org/media/documents/Bogota%20Report_Final%20Report_May%202006.pdf

Natvig, Carl Ledru. *The Economics of the Trolley Coach.* 1975. Masters Thesis for MBA, SFSU.

Natvig, Carl. *5 Year Plan 1977-1982. Issue Paper 3: The Environmental and Economic Feasibility of Trolley Coach Expansion.* July 1978. Municipal Railway Planning Division, San Francisco Municipal Railway.

Natvig, Carl. San Francisco Municipal Transit Agency. Personal interview by telephone on November 28, 2006.

Muni Service Planning, MTA Planning Division. Personal interview by telephone on October X, 2006.

Onursal, B. and Gautam, S.P. V*ehicular air pollution: Experiences from seven Latin American Urban Centers*. 1997. World Bank Technical Paper No: 373, World Bank, Washington D.C.

Ordóñez, Thomas J. *Citizenship, Security and Inclusion: Perspectives from Colombia and Brazil*. Conference: Violence and the Americas
April 15-16, 2005. Center for Latin American Studies. UC Berkeley.
http://www.clas.berkeley.edu:7001/Events/spring2005/04-15-05-violenceintheamericas/index.html
Also: "the basic idea was that citizens can regulate other citizens" concept.

Peñalosa, Enrique. *Creating Livable Cities: Enrique Peñalosa and the Bogotá experience*. November 2006. ITDP.
http://itdp.org/read/Penalosa%20and%20Bogota.pdf

Peschkes, Robert. *World Gazetteer of Tram, Trolleybus, and Rapid Transit Systems, Part 1: Latin America*. 1980. The Quail Map Company, Exeter, England.

Peschkes, Robert. *World Gazetteer of Tram, Trolleybus, and Rapid Transit Systems, Part 2: Asia with USSR, Australasia, Africa*. 1987. Rapid Transit Publications, London, England.

Peschkes, Robert. *World Gazetteer of Tram, Trolleybus, and Rapid Transit Systems, Part 3: Europe*. 1993. Rapid Transit Publications, London, England.

Pillot, D. *Commercial vehicle emissions in urban areas.* Urban Transport and the Environment for the 21st Century IV. Borrego, C. and Sucharov, L. (Editors), 1998. Computational Mechanics Publications, WIT Press. Southampton, UK, pp. 359-368.

Rohter, Larry. *A Record Amazon Drought, and Fear of Wider Ills.* Dec. 11, 2005. New York Times. Final, section 1, Page 1.

San Francisco Municipal Railway. *Route Electrification Study.* December 16, 2002.

Sanín, José Alvear (Señal Editora). *El Negocio Del Metro (Expereiencias para Bogotá). Consideraciones sobre: Una decision apresurada, una obra no planificada, una contratacion leoninna, y una financiacion usararia*. 1990. Medellin.

Scorcia Tenjo, Harley Manuel; Lleras Echeverri, Germán Camilo. *Mejoramiento de la función tiempo de parada para transmilenio*. June 26, 2006. Universidad de Los Andes, Bogotá, Colombia. http://dspace.uniandes.edu.co:5050/dspace/browse-date

Shah, Nihar. *Climate Change and Discounting.* Shared December 9, 2006. Thesis Proposal.

Shah, Nihar. *Personal interview.* December 9, 2006.

Shah, Nihar. *Climate Change and Discounting.* November 30, 2006. Department of Mechanical Engineering, UC Berkeley. (Presentation.)

Shrestha, Ram M.; Anandarajah, Gabrail; Adhikari, Sushil; Jiang, Kejun; and Songli, Zhu. *Energy and environmental implications of Nox emission reduction from the transport sector of Beijing: a least-cost planning analysis.* January 2005. Transportation Research Volume 10D, issue 1, pp. 1-11.

Paine, Chris, director. *Who Killed the Electric Car?* 2006. Sony Pictures Classics. http://www.sonyclassics.com/whokilledtheelectriccar/

Rafter, David O. *The electric trolley bus: a neglected mode in U.S. transit planning.* Journal of the American Planning Association 61.n1 (Wntr 1995): 57(8).

Sousa, Luís de. *An assessment of world oil exports.* Nov. 10, 2006. Energy Bulletin. http://www.energybulletin.net/22213.html

Stiel, Waldemar Corrêa. *Historia Do Transporte Ubrano No Brasil: "Summa Tranviariae Brasiliensis": Historia Does Bondes E Trolebus E Das Cidades Onde Eles Trafegaram.* Edição Convênio. April 1984. Editora Pini Ltda. Empresa Brasileira Dos Transportess Urbanos. Brasília, DF.

Straus, Peter. Manager of Muni Service Planning, MTA Planning Division. Personal interview by telephone on October X, 2006.

TransMilenio web pages:
http://www.transmilenio.gov.co/transmilenio/nvaentrada.htm

TransMilenio. *Mapas de Ubicación* (location maps). Accessed December 10, 2006. http://www.transmilenio.gov.co/transmilenio/index.asp?id=187

Voris, Michael. *Email communication.* December 11, 2006. Supervisor, Transit Fleet Procurement, King County Metro Transit.

Wilkinson, B. 1997. "Nonmotorized transportation: The forgotten modes." *Annals of*
the American Academy of Political Science 553: 87 - 93.

Williams, P. *The Electric Trolleybus – its role in future transport systems.* Urban Transport and the Environment for the 21st Century IV. Borrego, C. and Sucharov, L. (Editors), 1998. Computational Mechanics Publications, WIT Press. Southampton, UK, pp. 471-480.

Wright, Lloyd and Fulton, Lewis. "*Climate Change and Transport in Developing Nations."* November 2005. Transport Reviews, Vol. 25, No. 6, 691-717.

Wright, Lloyd. *Sustainable Transport: A Source-Book for Policymakers in Developing Cities. Module 3b: Bus Rapid Transit.* ITDP.
http://itdp.org/read/brtplanningguidedec04.pdf

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To: jmeggs@berkeley.edu
Cc: "Voris, Michael" <Michael.Voris@METROKC.GOV>
Subject: Electric trolley buses

Jason, as you know, etbs are rare in North America. There are five cities in the US and two in Canada that operate them (Philadelphia is currently shut down until their order of New Flyer etbs arrive). San Francisco, Vancouver, Boston, and Philadelphia have recently bought or ordered new etbs. King County Metro in Seattle has not bought a new trolley bus since the 1990-91 Breda dual power buses. ETBs are not in series production like diesel or hybrid buses. Etbs are reinvented every time a transit property buys some. There is no typical mile of trolley overhead to cost out. Every mile built in a city is unique. You have the largest etb system in N.A. across the Bay from you. Have you talked to them?

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