The Potential for Bus Rapid Transit to Reduce Transportation-Related CO_2 Emissions

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Abstract

This article examines Bus Rapid Transit (BRT) as a near-term strategy for reducing CO_2 emissions in a typical medium-sized U.S. city. The paper compares the expected CO_2 emissions from three scenarios to meet the city's growth in work trips by 2011: a no-build option that relies upon private automobiles and a diesel bus fleet; building a light rail (LRT) system; and building a BRT system using 40-ft or 60-ft low emission buses. The paper calculates a CO_2 emissions inventory for each scenario and finds that BRT offers the greatest potential for greenhouse gas reductions, primarily because BRT vehicles generally offer lower CO_2 emissions per passenger mile than LRT. Lower capital costs for BRT infrastructure would enable cities to build more BRT than LRT for a given budget, increasing opportunities to shift commuters to public transit. Further study to enhance a methodology to estimate expected CO_2 reductions with BRT would be valuable.

Introduction

There is general consensus among the world's climatologists that human activity contributes significantly to global warming (Pew Center 2006). More than 140 nations have signed the Kyoto Protocol, making a commitment to reduce their greenhouse gas (GHG) emissions by 5.2 percent from 1990 levels by 2012. A notable exception is the United States, the world's leading greenhouse gas emitter (EIA 2005).

In the absence of federal action, many states and municipalities are committing to GHG reductions on their own. As of March 2006, 28 states had adopted climate action plans, with 9 setting state-wide GHG emissions targets (Pew 2006). Seattle Mayor Greg Nickles initiated the Mayors Climate Protection Agreement, which to date has been signed by more than 220 U.S. mayors. This agreement commits cities to strive to achieve or exceed Kyoto GHG reductions targets by 2012 (City of Seattle 2006).

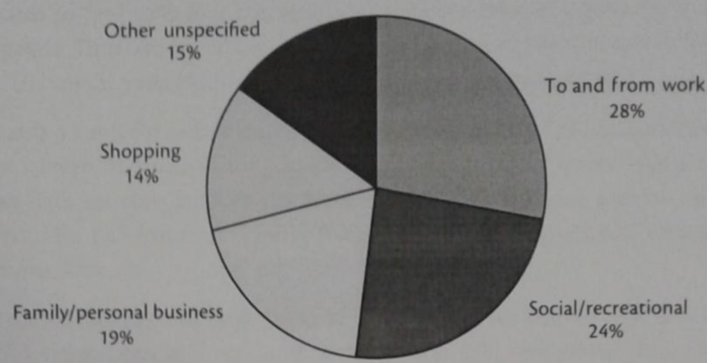
Public transportation often is seen as a GHG reduction strategy. In the U.S., the transportation sector accounted for 27 percent of total GHG emissions in 2003, second only to the electricity generation sector. Transportation emissions of CO_2, the leading greenhouse gas, are on a dramatic upward trend, increasing from 1,461.7 teragrams CO_2 equivalent in 1990 to 1,780.7 teragrams CO_2 equivalent in 2003 (US EPA 2005), a 22 percent increase. Passenger cars and light duty trucks are the most significant source of transportation CO_2 emissions.

This paper compares the GHG reduction potential of Bus Rapid Transit (BRT) with light rail (LRT) in a "typical," medium-sized U.S. city.[1] Although there has been some analysis of CO_2 emissions from transit, there has been little direct comparison among modes (see Shapiro 2002 and FTA 2005). Moreover, the most recent assessment of BRT CO_2 reduction strategies focuses on developing countries, not the U.S. (see Wright and Fulton 2005).

The paper postulates a current-year, base-case scenario where mobility is highly dependent upon automobiles, and public transportation services are provided by a fleet of diesel buses. The paper then looks at three scenarios for five years in the future, assuming population growth of 5 percent during that time. In the first scenario, mobility needs continue to be met principally by automobile and diesel bus. In the second scenario, the city builds a light rail system, which attracts work trips from both the existing bus system and automobiles. In the third scenario, the city builds a BRT system that also attracts work trips from the existing bus system and from automobiles.

Our analysis focuses on work trips because these trips offer the greatest potential to use transit as a CO_2 mitigation strategy. As shown in Figure 1, the 2001 National Household Travel Survey (NHTS) reported that work trips are the single largest component of total vehicle miles traveled in the United States.

Figure 1. Vehicle-Miles Traveled by Trip Purpose



Mean vehicle occupancy for work trips is 1.14, the lowest occupancy rate for any trip purpose. Moreover, work trips tend to follow fairly well-defined commuting patterns, making them relatively easy to serve with public transportation.

The paper calculates a CO_2 emissions inventory for work trips under each of the three scenarios and finds that BRT offers greater potential for GHG reductions than an electric rail system, based on national average electricity generation emissions. Because BRT can be implemented for lower capital costs and in much less time than LRT, BRT appears to be a good strategy for state and local officials looking to achieve near-term CO_2 emissions reductions.

As a scenario-based analysis, this paper relies upon assumptions about ridership, mode-shift and other parameters. These assumptions generally were derived from actual operating and performance data, and our approach is consistent with other scenario-based studies examining transit air quality.

It is important to note that localized factors, such as electricity generation mix, geography and culture, will affect the results in particular cities. Similarly, cities can implement complementary policies, like transit-oriented development and congestion pricing, to improve the performance of their transit system.

It also is important to note that our results are mostly due to the relatively high CO_2 emissions from electricity generation necessary for rail and to the relatively low CO_2 emissions for modern buses. Thus, our assumptions could be changed significantly without changing the underlying conclusion.

Additional research would be valuable in this area. For example, a BRT system typically operates at a higher average speed than an urban bus system. However, we were unable to find sufficient bus emissions data for vehicles operating at these higher speeds. Thus, we relied on data from the slower Central Business District (CBD) cycle, which most likely overestimates CO_2 emissions from BRT.

There is also a need for better data on average trip lengths, load factors for BRT operations, levels of mode-shifting to BRT and other relevant issues. Many transportation data sources, such as the National Transit Database, provide mode-specific data for LRT but not for BRT. This makes direct comparisons among the modes more difficult.

Despite the challenges and limitations of this analysis, we believe that it is likely that a BRT system can achieve significantly greater CO_2 reductions than LRT in most U.S. cities. Cities interested in new transit infrastructure as a way to reduce GHG emissions ought to look carefully at both BRT and LRT before reaching any conclusions.

Base-Case Scenario

For our base-case city, which we call "Transtown," we assumed a metropolitan area population of 2 million people. According to the 2001 National Household Travel Survey (NHTS), the average American makes 4.1 trips per day, or roughly 1,500 trips per year (U.S. DOT 2003). Multiplying by our population of 2 million, we assumed that Transtown residents make 3 billion annual trips.[2]

In 2001, work trips constituted 14.8 percent of all trips (US DOT 2003). Multiplying 3 billion annual trips by 14.8 percent results in 444 million annual work trips. Roughly 91.2 percent of commute trips are by personal vehicle and 4.9 percent are by transit (U.S. DOT 2003). Thus, we assumed that 404.928 million work trips are by personal vehicle and 21.756 million work trips are by transit.

The NHTS shows that average commuting trip length for both private vehicle and public transit travel hovered around 12 miles between 1990 and 2001, so we used 12 miles as our assumption for average bus and car trip lengths.

Using our assumption of 404.928 million work trips in personal vehicles, we derived 4.859 billion annual passenger miles in personal vehicles. Using our assumption of 21.756 million annual transit passenger trips, we derived 261.072 million annual passenger miles on transit.

Table 1. Base Case Annual Commuting Passenger Miles in Transtown

	Commuting Trips Via Mode	Percentage of All Commuting Trips	Average Trip Length (miles)	Total Passenger Miles
Personal Vehicle	404,928,000	91.2	12	4,859, 136,000
Transit	21,756,000	4.9	12	261,072,000
All Trips	444,000,000			5,120,208,000

CO2 Emissions per Passenger Mile—Existing Fleet in Base Year

Personal Cars

We assumed that the average CO_2 emissions for Transtown personal vehicles are 1 pound CO_2 per mile. The average U.S. passenger car emits 0.916 pounds CO_2 per mile, and the average light truck emits 1.15 pound of CO_2 per mile (U.S. EPA 2000). The U.S. vehicle fleet is roughly 60 percent automobiles and 40 percent light trucks (FHWA 2000). Our one pound per mile is the weighted average of the CO_2 emissions of the U.S. vehicle fleet and is consistent with other recent studies (Shapiro 2002).

The average vehicle occupancy for work trips is 1.14 (U.S. DOT 2003). We divided one pound CO_2 per mile by the average occupancy rate of 1.14, yielding average CO_2 emissions of 0.877 pounds, or 397.89 grams, per passenger mile. We multiplied 397.89 grams per passenger mile by 4.859 billion passenger miles and derived 1.933 million metric tons of CO_2 attributable to commute trips in personal vehicles.

Existing Bus Fleet

We assume that Transtown's current transit demand is met by a fleet of 1999 model year, 40-ft Orion V buses using Detroit Diesel Series 50 engines, diesel particulate filters and low sulfur diesel. In recent testing on the Central Business District Cycle (CBD), these buses were found to emit 2,942 grams CO_2 per vehicle mile (NYS DEC 2005).

Using bus data from the APTA 2005 Public Transportation Factbook, we divided total annual passenger miles by total annual vehicle revenue miles to derive an average occupancy rate on Transtown buses of 10 passengers per mile.[3] Dividing 2,942 grams CO_2 by the average occupancy rate of 10, we assumed 294.2 grams CO_2 emitted per passenger mile on Transtown's existing bus system. We then multiplied 294.2 grams per passenger mile by 261.072 bus passenger miles and derived 76,807.38 metric tons of annual CO_2 emissions attributable to commuting bus trips.

Table 2. Base Case CO_2 Emissions for Commuting in Transtown

	Passenger Miles	CO_2/Passenger Mile	Total Annual CO_2 Emissions (Metric Tons)
Personal Vehicles	4,859,136,000	397.89	1,933,401.62
Transit Buses	261,072,000	294.2	76,807.38
Total	5,120,208,000		2,010,209.00

CO_2 Emissions per Passenger Mile—Alternative Transit Fleet

Next, we calculated the CO_2 emissions associated with potential alternatives to Transtown's diesel bus system. The options we examined were light rail and low emission 40- and 60-ft buses operating in BRT service.

Light Rail

The national average of CO_2 emissions per kilowatt-hour (kWh) from electricity generation is 1.341 pounds (U.S. DOE and US EPA 2000).[4] U.S. light rail systems consume about 510 million kWh of electricity annually to deliver 1.476 billion passenger miles on 63.53 million vehicle revenue miles (APTA 2005).

Dividing passenger miles by vehicle revenue miles yields an average passenger load of 23.23 passengers per mile for light rail. Dividing 510 million kWh by 1.476 billion passenger miles yields an average of 0.345 kWh per passenger mile. Multiplying 0.345 by the average of 1.341 pound CO_2 emissions per kWh yields an average of 0.462 pounds, or 209.56 grams, of CO_2 per passenger mile.

Table 3. CO_2 Emissions From Light Rail Operation (National Average)

Average Electricity Consumption (kWh per passenger mile)	0.345
Average CO_2 Emissions (grams per passenger mile)	209.56

Low Emission Buses Operating in BRT Mode

Bus rapid transit is a system of bus-related improvements including dedicated rights-of-way, priority treatment for vehicles on shared rights-of-way, level boarding, off-vehicle fare collection, and reduced spacing between stops. The result is an integrated system that functions more like a rail system than a typical urban bus system, but at a fraction of the cost of a rail system.

There has been no systematic data reporting on average passenger loading of BRT systems. We assumed a passenger loading of 23.23, equivalent to the average LRT loading because BRT systems often are designed to perform like LRT. There is reason to believe that our assumptions may underestimate BRT passenger loads. For example, the Los Angeles Metropolitan Transportation Authority's Orange Line averages 70 to 80 passengers per 60-ft BRT bus on an average weekday (Drayton email).

Information for 40-ft buses was taken from a 2003 study that examined emission results for diesel, low sulfur diesel, hybrid, and CNG 40-ft buses tested on the CBD cycle.[5] The best performing bus in these CBD tests was a 1999 New Flyer hybrid-electric bus fueled by low sulfur diesel, which emitted 2,088 grams of CO_2 per mile. Using the assumed BRT load of 23.23 passengers per revenue mile, we assume 89.91 grams of CO_2 per passenger mile.[6]

We also looked at a 40-ft CNG bus with a 2000 DDC Series 50G engine tested on the Urban Dynamometer Driving Schedule (UDDS). This bus achieved average CO_2 emissions of 1,534.91 grams per mile. Dividing by 23.23, we calculated its emissions to be 66.07 grams CO_2 per passenger mile (Ayala 2002). The UDDS has a higher average speed (19 mph) than the CBD driving cycle and thus may be more representative of BRT service.

Finally, we looked at two 60-ft New Flyer buses: a diesel bus equipped with a 2004 Caterpillar C9 engine rated at 330 hp and a diesel particular filter (DPF) and a 60-ft hybrid-electric bus equipped with the identical engine and DPF device.[7] Both buses were recently subjected to fuel economy tests on the CBD cycle by the National Renewable Energy Laboratory.

We derived CO_2 per mile by dividing the emissions associated with burning one gallon of diesel by the vehicles' fuel economy. According to the Energy Information Administration, diesel fuel emits 22.4 lbs of CO_2 per gallon burned. The 60-ft diesel bus averaged 2.2 miles per gallon. Dividing 22.4 lbs per gallon by 2.2 gives us 10.18

lbs, or 4,617 grams, of CO_2 per mile. The hybrid-diesel bus averaged 3.3 mpg. Using the same calculation, we derived 6.79 lbs. (3,080 grams) per mile.

Finally, we divided the CO_2 emissions per mile by the average passenger load of 23.23. All four buses performed better than LRT. The results are presented in Table 4.

Table 4. CO_2 Emissions Per Passenger Mile for BRT 40-ft and 60-ft Bus Options

Bus Size	Fuel Type	Test Cycle	CO_2 g/mile	Passenger Load	CO_2 per Passenger Mile
40-ft	Hybrid-Diesel	CBD	2,088	23.23	89.91
	CNG	UDDS	1,535	23.23	66.07
60-ft	Diesel	CBD	4,617	23.23	198.75
	Hybrid-Diesel	CBD	3,080	23.23	132.59

Future Transportation Options for Transtown

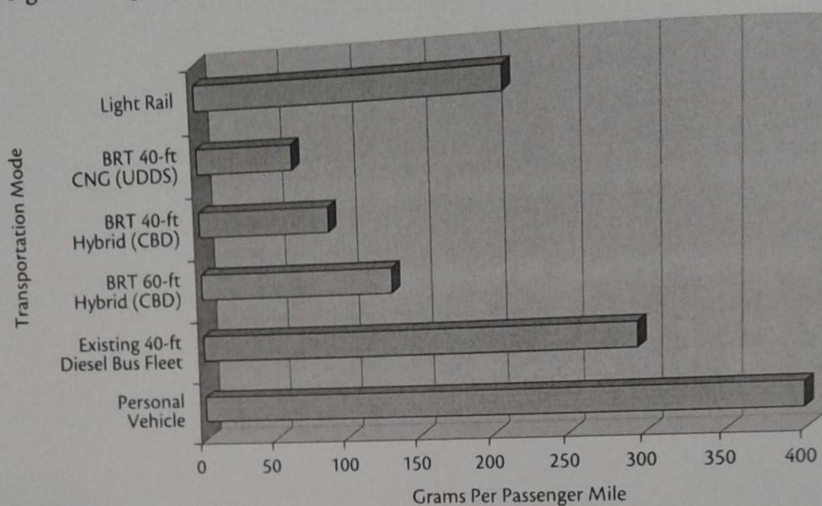
The mayor of Transtown recently signed the Mayors Climate Protection Agreement and is committed to meeting the Kyoto CO_2 emissions reduction targets in Transtown within five years. To reduce CO_2 emissions from the transportation sector, the mayor is considering implementing a new public transit service to encourage commuters to use transit as part of the city's overall transportation GHG emissions reduction strategy.

We assumed that Transtown will add 100,000 residents over the next five years, for a total population of 2,100,000 in 2011. We then analyzed the CO_2 emissions that would result from the following scenarios for meeting increased transportation demand:

- Accommodating increased demand with the existing transportation system
- Building an LRT system
- Building a BRT system using low emission buses

Figure 2 compares the CO_2 emissions we derived in the previous section for the existing transportation and these new transit options.

Figure 2. CO_2 Emissions Per Passenger Mile For All Transportation Modes



Meet Demand with Existing Travel Options—"No Build" Option

Using our estimate of 1,500 trips per year, Transtown will have a total annual demand of 3.150 billion personal trips in 2011, an increase of 150 million. Multiplying 3.150 billion trips by 14.8 percent, we calculated 466.2 million annual commute trips in 2011. Multiplying by 91.2 percent, our assumed mode share for personal vehicles, results in 425.174 million annual personal vehicle trips. Multiplying by 4.9 percent, our assumed mode share for transit, results in 22.843 million annual transit trips.

To calculate passenger miles, we multiplied the number of trips by an average of 12 passenger miles per trip. This results in 5.102 billion annual passenger miles in personal vehicles and 274.125 million annual passenger miles in transit. As shown in Table 5, multiplying by grams per passenger mile results in 2.03 million metric tons of CO_2 annually due to commuting by cars, and 80.6 thousand metric tons of CO_2 from buses. Adding these together, we derived 2.110 million metric tons of CO_2 emissions in 2011 from commuting.