Energy and Environmental Impacts of BRT in APEC Economies

On the Cover

Photo 1: México City Metrobús. Credit: Breakthrough Technologies Institute.

Photo 2: Passenger with bicycle boarding the EmX Green Line in Eugene, Oregon. Credit: Breakthrough Technologies Institute.

Authors

This report was written primarily by Bill Vincent of the Breakthrough Technologies Institute (BTI) in Washington, DC, with significant assistance from Elizabeth Delmont of BTI and Colin Hughes of the Institute for Transportation and Development Policy (ITDP).

Acknowledgments

The authors relied upon the hard work and valuable contributions of many men and women in government and in the transportation industry. The authors especially wish to thank ITDP for providing data on Guangzhou and other systems, and for providing comments on the draft document. The authors also wish to thank Paulo Custodio, Peter Midgley, Michael Replogle, and Sandra Curtin, Research Director at BTI, for their insightful review and comments.

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Abbreviations

ADB	Asian Development Bank
APEC	Asia-Pacific Economic Cooperation
ASIF	Activity-Structure-Intensity-Fuel
AVL	Automatic Vehicle Location
BRT	Bus rapid transit
CDM	Clean Development Mechanism
CERs	Certified Emissions Reductions
CISA	Corridor Insurgentes SA de CV
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2eq}	Carbon dioxide equivalent
GPS	Global positioning system
GZ-BRT	Guangzhou BRT
IPCC	Intergovernmental Panel on Climate Change
ITDP	Institute for Transportation and Development Policy
ITS	Intelligent transportation systems
KTOE	Kilotonnes of oil equivalent
LPG	Liquefied petroleum gas
NH_3	Ammonia
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
p/m	Passengers per month
PM	Particulate matter
ppd	Passengers per day
pphpd	Passengers per hour peak direction
ppmv	Parts per million by volume
ppw	Passengesr per week
SO_2	Sulfur dioxide
TOD	Transit-oriented development
ULSD	Ultra-low sulfur diesel
VKT	Vehicle kilometers traveled
VOC	Volatile organic compounds

Executive Summary

Bus Rapid Transit (BRT) can help Asia-Pacific Economic Cooperation (APEC) economies reduce oil consumption and associated emissions of air pollution and greenhouse gases. BRT also can help mitigate growing traffic congestion and encourage more sustainable urban development.

BRT systems typically include dedicated bus corridors, fare collection prior to boarding, high quality stations, intelligent transportation technologies, and other features designed to maximize convenience and reduce travel times. BRT systems also may be associated with other improvements to the urban environment, such as transit-oriented development and improved facilities for bicyclists and pedestrians.

The first modern BRT was implemented in Brazil in the 1970s. By 2010, at least 120 cities operated either BRT systems or dedicated bus corridors, serving nearly 27 million passengers per weekday. Many APEC economies now have experience with BRT, including the United States, Canada, Mexico, Peru, Chile, New Zealand, Australia, Indonesia, and China.

This paper reviews the environmental benefits of three of the world's leading BRT systems: México City, México; Guangzhou, China; and Bogotá, Colombia. The criteria for reviewing projects included the availability of data and whether the project is located in an APEC member economy. Bogotá is not located in an APEC member economy, but is included because it is one of the world's leading BRT systems, the CO_2 reductions associated with the project have been well documented, and it provides a good model for APEC economies.

This paper also briefly discusses the experience with three other major BRT projects in the APEC region: the Brisbane, Australia busways; the Jakarta, Indonesia TransJakarta BRT; and the Chongqing, China BRT, Lines 1-4. Although data on these projects is not as robust as data available for México City, Bogotá, and Guangzhou, each has unique attributes and lessons-learned that may be important for future APEC BRT systems.

The project relied primarily on data from existing sources, such as the Clean Development Mechanism (CDM) of the Kyoto Protocol, and studies sponsored by the U.S. Environmental Protection Agency's Integrated Environmental Strategies program. The parameters reviewed include reductions in CO_2 and local pollution emissions, reductions in fuel consumption, and other benefits, such as travel time savings and land use impacts. The analysis showed significant reductions compared with project baselines, including:

- CO_2 reductions as high as 61.8 percent;
- diesel consumption reductions of 50 percent or more; and
- criteria pollution reductions as high as 92 percent.

Table ES1 summarizes the environmental and other benefits of these projects.

Table ES1: Summary of Environmental Benefits of Major BRT Projects Assessed.

Project	CO_2 Reductions (tCO_{2eq})	Air Pollution Reductions	Fuel Savings	Other

TransMilenio, Bogotá, Colombia (Phases II-IV)	Anticipated over 7 years:
	• 1,725,940
	• 61.8% reduction from the baseline
	
	Actual (2009):
	• 79,326
	• 1.7% reduction from the baseline
		Anticipated over 7 years (tons):
		PM: -6,700 (-92% from baseline)
		NOx: -53,00 (-85% from baseline)
		SO_2: -800 (-51% from baseline)
			Anticipated over seven years:
			• 407.4 million liters of diesel
			  • 50.7% reduction from the baseline
			• Estimated 264.8 million liters of gasoline
			
			Actual (2009):
			• 21.6 million liters of diesel
			  • 52% reduction over the baseline
				• Travel time savings of 136,750 hours per day (Phase I).
				• Positive impact on property value.
				• 79% reduction in traffic collisions in Transmilenio corridors.

MetroBús Line 1, México City, México	Anticipated over seven years: • 301,798 • 40 percent reduction from the baseline	Anticipated over 7 years (tons): THC: -842 NO_x: -4314 $PM_{2.5}$: -13.3 SO_2: -4.2 CH_3: -34.6 N_2O: -49.8	Anticipated over 7 years: • equivalent of 115.5 million liters of diesel • 37 percent reduction compared with the baseline	• Prevent 6,100 lost work days, 660 restricted activity days, 12 new cases of bronchitis, and three deaths each year. • Significantly reduced benzene, CO, and $PM_{2.5}$ for passengers. • Up to 50% travel time reduction. • 15 percent mode shift.
Guangzhou, China	Anticipated over 10 years: • 866,879	Anticipated over 10 years (tons): PM: 113 CO: 16,464 NOx: 4,401 SO_2: 222	Anticipated over 10 years: • 400-500 million liters of gasoline	• Average bus speed increase: 29 percent. • Average passenger wait-time decrease: 19 percent. • Mixed traffic speed increase: 20 percent

The Brisbane busways, Transjakarta BRT, and the Chongqing BRT Lines 1-4 also are showing substantial benefits, or the potential for such benefits. For example, the Brisbane Southeast busway has reduced travel times by up to 70 percent; a busway trip is estimated to emit roughly 25 percent of the CO_2 of a comparable trip by private car; and the system has many examples of transit-oriented development around busway stations. Passenger volumes can reach 18,000 passengers per hour per direction, the equivalent of roughly 7.5 lanes of freeway. The Transjakarta BRT was estimated to reduce CO_2

emissions by 37,000 tons in 2009. Similarly, the Chongqing BRT has the potential to reduce 1.77 million tons of CO_{2eq}.

Finally, all of the BRT projects that are registered, or are seeking registration in the CDM program as of July 2011, were examined. As shown in Table ES2, these projects have the potential to reduce more than 12.2 million tons CO_{2eq}, a 40 percent reduction over their cumulative baselines.

Table ES2: BRT Projects in the CDM Program

City	CDM Status	Methodology Used	Estimated Project Baseline CO_2 Emissions (tCO_{2eq})	Estimated CO_2 Emissions Reductions (tCO_{2eq})	Percent Reduction From Baseline
APEC Countries					
Chongqing, China	Registered	AM0031	3,225,401 (2009-2016)	1,526,469 (2009-2016)*	47 %
Zhengzhou, China	Validation	AM0031	2,824,200 (2010-2017)	1,238,578 (2010-2017)	44 %
Seoul, South Korea	Validation	AM0031	6,511,745 (2009-2015)	1,017,391 (2009-2015)	16 %
Guadalajara, México	Validation	AM0031	872,710 (2011-2018)	354,590 (2011-2018)	41 %
México City, México	Validation	ACM0016	762,452 (2011-2018)	301,798 (2011-2018)	40 %
Zona Metroplitana del Valle de México, Zona Metropolitanan del Valle de Toluca, México	Review Requested	ACM0016	2,757,022 (2010-2017)	1,036,817 (2010-2017)	38 %
* This estimate is deemed unreliable. See Chongqing BRT section of this report.					
Non-APEC Countries					
Barranquilla, Colombia	Validation	AM0031	664,311 (2010-2017)	430,577 (2010-2017)	65 %
Bogotá, Colombia	Registered	AM0031	2,791,689 (2006-2012)	1,725, 940 (2006-2012)	63 %
Cartagena de Indias, Colombia	Validation	AM0031	778,873 (2011-2021)	380,279 (2011-2021)	49 %
Medellin, Colombia	Validation	AM0031	1,044,795 (2012-2018)	864,354 (2012-2018)	83 %
Quito, Ecuador	Validation	AM0031	2,363,346 (2010-2017)	1,026,056 (2010-2017)	43 %
Guatemala City, Guatemala	Validation	AM0031	5,773,501 (2012-2018)	3,739,317 (2012-2018)	65 %
Indore, India	Validation	AM0031	393,484 (2009-2016)	255,508 (2009-2016)	65 %
TOTAL			**30,763,509**	**12,231,410**	**40 %**

"[W]e express our resolve to provide the APEC region with seamless and environmentally friendly transportation systems through innovation and the use of advanced technology, congestion reduction, enhanced transportation safety, security, and effective sustainability."

- Joint Transportation Ministerial Statement, 6th APEC Transportation Ministerial Meeting (April 2009)

Introduction and Purpose

The Asia-Pacific Economic Cooperation (APEC) is actively addressing the twin challenges of energy security and the environment. At the sixth Transportation Ministerial in the Philippines, Ministers expressed their resolve to promote innovative and environmentally friendly transportation systems. Ministers also noted that the transportation sector must contribute to greenhouse gas emissions reductions.

Similarly, the Fukui Declaration[1], issued at the ninth meeting of APEC Energy Ministers in Fukui, Japan, sets forth an ambitious agenda to strengthen the ability of member economies to respond to oil supply shocks, improve energy efficiency, and promote lower carbon energy sources. The Declaration includes a number of initiatives related to the transport sector, including a series of workshops on fuel and carbon savings and the establishment of a task force to implement a low carbon model town project.

Table 1: BRT Systems Reviewed

System	Date	Length (km)	Number of stations	Cost
MetroBús, México City, México	2005	67	113	Línea 1 – 30 million USD
TransMilenio, Bogotá, Colombia	2000	82	116	Phase I – 240 million USD
Guangzhou, China	2010	22.5	26	675 million Yuan (103 million USD)
South East Busway Brisbane, Australia	2000	16.5	10	$520 million AD
TransJakarta Jakarta, Indonesia	2004	172	181	$2 million USD/km
Chongqing, China*	2008	91.3	54	$0.7 million USD/km

* As of the date of this report, only an initial pilot line has been implemented in Chongqing.

The purpose of this report is to review one public transportation option to address transport-related emissions and oil consumption – bus rapid transit (BRT). Specifically, this paper assesses the experience with BRT in terms of reducing local air pollutants, emissions of CO_2 and other greenhouse gases, and fuel consumption. Table 1 provides a list

[1] http://www.apec.org/Meeting-Papers/Ministerial-Statements/Energy/2010_energy.aspx

of the primary systems reviewed. Although the focus is upon BRT systems in APEC economies, we also examined the TransMilenio BRT in Colombia. TransMilenio is one of the world's leading BRT systems and provides a model for cities in APEC economies. Moreover, it is the first mass transit project to be registered in the Clean Development Mechanism (CDM) program and, as a result, extensive environmental data is available for the system.

This paper is divided into three general parts. First, a brief overview discusses the transportation, energy, and emissions challenges facing the APEC region and the key characteristics of successful BRT systems. Second, the methodology for collecting environmental performance data on BRT systems is reviewed. Finally, the paper discusses the environmental performance of several of the world's most prominent BRT systems.

“More efficient use of energy and a cleaner energy supply will simultaneously boost our energy security, grow our economies and lower our emissions.”

- Fukui Declaration On Low Carbon Paths To Energy Security (June 2010)

Overview

Transport, Energy, and the Environment

Transport is responsible for 26.9 percent of all energy consumed in the APEC region (See Table 2 on the following page). In nearly half of APEC member economies, transport accounts for more than one-third of all energy consumed. Brunei Darussalam has the highest proportion of energy consumption by the transport sector, followed by México and the United States. Despite its rapid economic growth and increasing motorization, China has the lowest proportion of energy consumed by the transport sector, at roughly 11.9 percent.

Transport energy is consumed primarily through the combustion of petroleum products, such as gasoline and diesel fuel. As a result, more than 59 percent of the energy consumed from oil in the APEC region is consumed by the transport sector (Table 2). In New Zealand, Australia, the United States, and Brunei Darussalam, transport accounts for more than 70 percent of total energy consumed from oil and petroleum products.

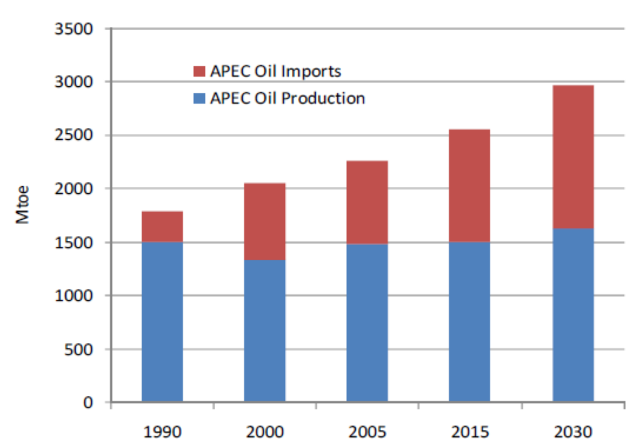

Figure 1: APEC Oil Imports and Production. Source: Asia Pacific Energy Research Centre

Demand for oil continues to rise significantly in APEC economies, but APEC oil production is projected to remain flat. The APEC region is therefore projected to import nearly half of its oil by 2030 (Figure 1), raising concerns about both energy security and threats to the economy from rising oil prices. The APEC Energy Ministers have made enhancing regional energy security a high priority.

Growing oil use also will have a significant environmental impact. Roughly 13 percent of global greenhouse gas emissions and 25 percent of global carbon

Table 2: Total and Transport Sector Energy Consumption, APEC Member Economies (2008)[2] (KTOE*)				
APEC Economy	Total Energy Consumption	Transport Sector Energy Consumption	Energy Consumed from Oil and Petroleum Products	Transport Sector Energy Consumed from Oil and Petroleum Products
All APEC Economies	4,551,620	1,223,799 (26.9%)	1,921,820	1,140,418 (59.3%)
Australia	76,431	27,610 (36.1%)	37,517	26,873 (71.6%)
Brunei Darussalam	759	363 (47.8%)	460	363 (78.9%)
Canada	202,222	57,344 (28.4%)	90,753	53,784 (59.3%)
Chile	25,568	8,988 (35.2%)	13,901	8,937 (64.3%)
China	1,218,756	145,300 (11.9%)	334,189	130,122 (38.9%)
Hong Kong	6,879	2,144 (31.2%)	2,764	2,084 (75.4%)
Indonesia	145,112	26,025 (17.9%)	54,276	26,001 (47.9%)
Japan	335,724	81,232 (24.2%)	176,063	79,389 (45.1%)
Republic of Korea	146,762	29,263 (19.9%)	77,686	28,357 (36.5%)
Malaysia	44,354	16,378 (36.9%)	24,433	16,175 (66.2%)
Mexico	116,079	52,563 (45.3%)	76,253	51,714 (67.8%)
New Zealand	12,421	4,745 (38.2%)	5,943	4695 (79%)
Papua New Guinea	1,222	348 (28.5%)	970	348 (35.9%)
Peru	12,590	4,382 (34.8%)	7,123	4,252 (59.7%)
Philippines	22,425	7,452 (33.2%)	10,733	7,442 (69.3%)
Russia	442,405	101,527 (22.9%)	98,599	58,971 (59.8%)
Singapore	16,129	5,494 (34.1%)	12,787	5,494 (43.0%)
Chinese Taipei	64,332	11,521 (17.9%)	37,889	11,427 (30.2%)
Thailand	67,959	19,680 (29.0%)	32,909	19,011 (57.8%)
USA	1,550,305	612,774 (39.5%)	812,767	596,360 (73.4%)
Vietnam	43,187	8,666 (20.1%)	13,806	8,622 (62.5%)
* Kilotonnes of Oil Equivalent				

[2] Source: APEC Energy Database, available at: http://www.ieej.or.jp/egeda/database/database-top.html

dioxide (CO_2) emissions from fossil fuel combustion are attributable to the transport sector, according to the Intergovernmental Panel on Climate Change (IPCC). In the APEC region, CO_2 emissions from fuel combustion are expected to increase roughly 40 percent between 2005 and 2030, with the transport sector accounting for the second greatest portion of CO_2 emissions from fuel combustion (Figure 2).

Among APEC member economies, the United States is by far the leading emitter, in absolute terms, of CO_2 from petroleum consumption, followed by China, Russia and Canada (Table 3). Despite the global recession, most APEC economies experienced increases in CO_2 emissions from oil consumption between 2007 and 2009, with China experiencing the greatest percentage increase (10.49 percent). Most of the developed economies, however, experienced significant percentage decreases over the same period.

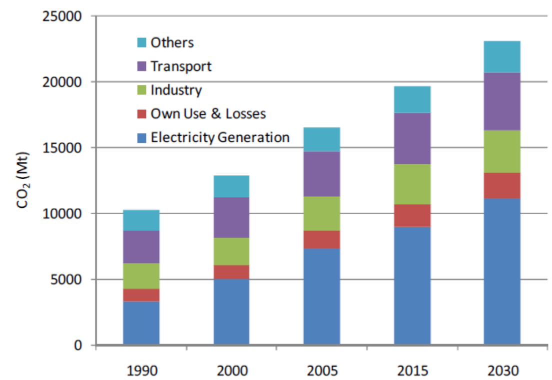

Figure 2: APEC CO_2 Emissions from Fossil Fuel Consumption, by Sector. Source: Asia Pacific Energy Research Centre

The transport sector also is a leading cause of local air pollution, causing two million air pollution-related deaths annually, according to the World Health Organization. The transport-related pollutants that impact human health include lead, particulate matter (PM), ozone (O_3), volatile organic compounds (VOC), nitrogen dioxide (NO_2), carbon monoxide (CO), ammonia (NH_3) and sulphur dioxide (SO_2). Air pollution also damages waterways, agriculture, and man-made structures, such as buildings.

The economic impact of air pollution can be substantial. A study by the Asian Development Bank (ADB) found that in Jakarta the cost of health problems associated with PM_{10}, NO_2 and SO_2 pollution was $181 million in 1998, which was roughly equivalent to the city's total revenue for that year.[3] In France, Austria, and Switzerland, the combined economic cost of health impacts from transport-related air pollution was estimated at 26,700,000,000 Euros in 1996.[4]

The amount of air pollution and greenhouse gas emissions caused by transport activities depends upon factors that are specific to individual cities, including: the number of vehicles and the extent to which these vehicles are used; characteristics of the transportation fleet (e.g., vehicle type, engine and emission control technology, average vehicle age, and quality of maintenance); types of fuel used; and local conditions, such as topography and climate. Except for topography and climate, governments have the ability to enact policies and programs that can significantly address each of these factors. These include standards for fuel economy and quality, inspection and maintenance programs, and transport

[3] Syahril, Shanty, et al., Study on Air Quality: Future Trends, Health Impacts, Economic Value and Policy Options Jakarta, Indonesia. Asian Development Bank. September 2002. P. 37

[4] Sommer, H., *et al.*, Economic Evaluation Of Health Impacts Due To Road Traffic-Related Air Pollution; An Impact Assessment Project Of Austria, France And Switzerland. World Health Organization. 2000. P. 23

demand management programs, such as improved public transport, parking management, congestion pricing, and vehicle occupancy requirements.

APEC economies clearly have a strong incentive to reduce oil consumption and transport-related emissions. Accomplishing this will require a broad-based strategy that addresses each of the factors that contribute to transport-related emissions.

Table 3: APEC CO_2 Emissions from the Consumption of Petroleum (2007-2009) (Million Metric Tons)[1]

APEC Economy	2007	2009	Percent Change
Australia	129.44	130.11	0.51%
Brunei Darussalam	2.11	2.3	0.19%
Canada	291.55	271.74	-6.79%
Chile	37.22	39.28	5.55%
China	959.18	1,059.74	10.49%
Hong Kong	50.05	51.65	3.20%
Indonesia	172.75	178.53	3.35%
Japan	598.61	511.38	-14.57%
Republic of Korea	215.87	210.50	-2.49%
Malaysia	74.93	76.18	1.66%
Mexico	287.61	275.10	-4.35%
New Zealand	22.48	22.23	1.08%
Papua New Guinea	4.05	4.60	13.47%
Peru	23.03	25.16	9.22%
Philippines	45.16	45.00	-0.41%
Russia	328.37	333.56	1.58%
Singapore	131.84	137.39	4.21%
Chinese Taipei	104.85	106.89	1.94%
Thailand	127.23	127.05	-0.14%
United States	2603.15	2318.88	-10.92%
Vietnam	39.59	41.84	5.69%

Defining Bus Rapid Transit

BRT is a public transportation system that uses rubber-tired vehicles to provide performance and service quality typically associated with rail transit, but at a fraction of the cost. The first BRT system was developed in Curitiba, Brazil in the 1970's. In 2010, at least 120 cities operated either BRT systems or dedicated bus corridors, serving nearly 27 million passengers per weekday.[5]

Figure 3: Eugene, Oregon EmX BRT system. Source: Breakthrough Technologies Institute.

Many APEC economies now have experience with BRT, including the United States, Canada, México, Peru, Chile, New Zealand, Australia, Indonesia, and China. Table 4 shows the major BRT lines or systems with dedicated lanes operating in APEC economies.

Some APEC economies have government programs that actively research and promote the benefits of BRT systems. For example, the United States Federal Transit Administration (FTA) supports BRT demonstrations, publishes research, planning guides, and other key BRT documents, evaluates BRT systems in the United States, sponsors the National Bus Rapid Transit Institute to promote education and knowledge sharing about BRT, and funds new BRT projects. The FTA BRT program has been a critical driver in BRT development in the United States, supporting either directly or indirectly the deployment of dozens of BRT systems or enhanced bus corridors over the last decade.

[5] Hidalgo, Dario, Status of the BRT Industry, Power Point presentation, 2010.

Table 4: Major BRT Systems With Dedicated Right-of-Way Operating in APEC Countries

Country	BRT Project	Year	Single Line or Network	Length	Capital Cost	Ridership	Vehicle Type	Fuel Type
Australia	Adelaide O-Bahn	1986	Single Line	12 km	AD 98 million	30,000 ppd	EURO V	Diesel
	Northern Busway Brisbane	2009	Network	1.2 km	AD 198 million		EURO IV, V	ULSD and CNG
	Inner Northern Busway, Brisbane	2008	Network	2.8 km	AD 493 million	1 million p/m	EURO IV, V	ULSD and CNG
	Eastern Busway, Brisbane	2009	Network	2.1 km	AD 366 million		EURO IV, V	ULSD and CNG
	South East Busway, Brisbane	2000	Network	16.5 km	AD 520 million	93,000 ppd	EURO IV, V	ULSD and CNG
	Liverpool-Parramatta T-Way, Sydney	2003	Network	31 km	AD 350 million	41,500 ppw	EURO III	Diesel
	North-West T-Way, Sydney	2007	Network	21 km	AD 330 million	60,000 ppw	EURO III	Diesel
Canada	Transitway Ottawa	1983	Network	54 km	CD $14 million/km	240,000 ppd		Diesel
	VIVA York Region	2005	Network	50 miles	CD $172 million	1.6 million p/m		Diesel
Chile	TransSantiago	2005	Network	92 km			EURO III	Diesel
China	BRT Beijing	2005	Network	34.5 km	$4.8 million	1350,000 ppd	EURO III	Diesel
	Changzhou BRT	2008	Network	44.9 km	30 million Yuan/km	120,000 ppd	EURO III	Diesel
	BRT Chongqing	2004	Single Line	17.5 km	$0.7 million/km	12,000 ppd	EURO III	CNG
	Dalian BRT	2008	Network	13.7km	19.5 million Yuan/km	5,800 pphpd	EURO III	Diesel
	Guangzhou BRT	2010	Single Line	22 km	950 million Yuan	805,000 ppd	EURO III	LPG
	Hangzhou BRT	2006	Network	55.4 km		40,000 ppd	EURO III	Diesel
	Hefei BRT	2010	Network	15 km		65,250 ppd		
	Jinan BRT	2008	Network	34.4 km		3,300 pphpd	EURO III	Diesel
	Bus Lanes Kunming	1999	Network	46.7 km	6 million Yuan/km	156,000 ppd		Diesel
	Xiamen BRT	2008	Network	51 km		180,000 ppd		Diesel
	Yancheng BRT	2010	Single Line	15 km		20,000 ppd		Diesel
	Zhengzhou BRT	2009	Network	30.5		5,600 pphpd		Diesel
	Zaozhuang BRT	2010	Network	33 km		20,000 ppd		Diesel
Indonesia	TransJakarta	2004	Network	172 km		83,000 ppd (Corridor I)	EURO III	CNG (Corridor 1 – Diesel)
Republic of Korea	BRT Seoul	2004	Network	44.4 km	$52.8 million	220,000 ppd	EURO III	Diesel, CNG
Mexico	MacroBús, Guadalajara	2008	Network	16 km	$100 million	120,000 ppd	EURO IV	ULSD

	Optibus León	2003	Network	31 km	$22 million	580,000 ppd	EURO III	Diesel
	Metrobús Mexico City	2005	Network	48 km	$30 million (Phase I)	260,000 ppd	EURO III, IV	ULSD
New Zealand	Central Connector, Auckland	2009	Network	5 km	NZD $43 million	9,280 ppd		
	Northern Busways, Auckland	2006	Single Line	9 km	NZD $300 million	2,860 ppd	EURO IV	
Perú	Lima	2010	Single Line	28 km	$4.7 million/km	340,000 ppd	EURO V	CNG
Thailand	Bangkok	2010	Single Line	15.3	$62.2 million	10,000 ppd	EURO III	CNG
USA	Busways, Pittsburgh, PA	1977	Network	18.5 miles	$25.8 million/mile	48,000 ppd		Diesel, Hybrid, CNG
	Healthline, Cleveland, OH	2010	Single Line	6.8 miles	Approx. $200 million	14,000 ppd		Diesel Hybrid
	Lynx Lymmo, Orlando. FL	2003	Network	2,500 sq. miles	$21 million	5,000 ppd		ULSD Diesel
	Orange Line, Los Angeles, CA	2005	Single Line	14 miles	$349.6 million	22400 ppd		CNG
	Silver Line Boston, MA	2004	Network	4.7 miles	$654 million	15,509 ppd		CNG, ULSD
	EmX, Eugene, OR	2007	Single Line	4 miles	$24 million	2,700 ppd		Diesel Hybrid
	MAX, Las Vegas, NV	2004	Single Line	7 miles	$20.3 million	6,000 ppd		Diesel Hybrid
	South Miami-Dade Busway, FL	1997	Network	19.7 miles	$42.9 million	293,000 ppd		Diesel, CNG Hybrids

Key Characteristics of Successful BRT Systems

Typical BRT systems include dedicated rights-of-way, high-capacity vehicles with level-boarding through multiple doors, off-vehicle fare payment, high quality stations, frequent service, intelligent transportation system (ITS) technologies, and significant marketing and branding of the service.[6] Many also integrate land use in station areas and provide access and parking for bicycles. Some BRT systems also use passing lanes so that vehicles can overtake each other, thus enabling express and limited stop services to be provided on a single right-of-way. Understanding these elements is important, because each contributes to the performance of the BRT system, and thus to the environmental benefits it may achieve.

Some systems use a “closed architecture,” also known as “trunk and feeder,” whereby BRT vehicles operate in a dedicated right-of-way reserved exclusively for those vehicles. Passengers arrive at BRT stations by other modes, such as feeder buses or walking, and use the dedicated trunk service to travel to other BRT stations, where they again transfer to other modes or another trunk line. Thus, operations

[6] See Characteristics of Bus Rapid Transit for Decision Making. Federal Transit Administration. February 2009, Project Number FTA-FL-26-7109.2009.1 p. E-1

on a closed architecture system are comparable to operations on a heavy rail metro and typically are limited to an all-stops service along the right-of-way.

Figure 4: TransJakarta BRT trunk service. Photo: Breakthrough Technologies Institute.

Closed architecture systems generally are best suited to corridors with very high passenger demand. High demand requires high frequency service, resulting in large numbers of vehicles that must use each station. This creates the potential for significant delays, as the number of vehicles exceeds station capacity. A closed architecture system therefore limits the number and type vehicles using the right-of-way, creating the so-called trunk service. Closed architecture systems are common in Latin America and exist in other parts of the APEC region, such as the United States and Indonesia.

Other systems use an "open architecture" or "direct service" design, whereby the dedicated lane is used by vehicles that operate both on and off the right-of-way. In other words, vehicles can pick up passengers in neighborhoods and activity centers, then provide direct service to BRT stations without requiring passengers to transfer. Open architecture systems therefore promote greater network connectivity with the public transport system, because any bus can use the right-of-way to receive priority. One of the most prominent examples of an open architecture system in the APEC region is the busway network in Brisbane, Australia.

Figure 5: Cultural Centre Busway Station, South Bank, Brisbane, Australia. Photo: Breakthrough Technologies Institute.

Dedicated Right-of-Way

Ensuring that BRT vehicles are not stuck in traffic is one of the most important attributes of a BRT system. Accomplishing this generally requires providing a right-of-way for the exclusive use of public transport vehicles. This can take many forms, including bus lanes on arterial streets and grade-separated corridors, often built on converted rail lines.

Where the BRT system is operating in close proximity to other traffic, enforcement is required to ensure that exclusive use for public transit vehicles is maintained. In many cases, enforcement is accomplished through the use of physical barriers that separate the BRT guideway from general traffic.

Figure 6: Physical separation in Eugene, Oregon and Pereira, Colombia. Photos: Breakthrough Technologies Institute

If the right-of-way is located on an arterial street, it is usually located in the center median, rather than in the curb lane. Placing the right-of-way in the center can help improve performance, because it minimizes conflicts than can reduce BRT speeds, such as illegally parked vehicles in the curb lane and vehicles entering and exiting the roadway. It also enables the provision of a central island station that can serve passengers travelling in both directions, thus helping to reduce capital and operating costs as well as saving space in the roadway. However, such a configuration requires ensuring safe pedestrian access to the stations and also may require special vehicles, such as vehicles with doors on both sides.

Stations, Vehicles, and Fare Collection

Stations, vehicles, and fare collection must work together to maximize BRT performance. For example, stations should be designed to allow level-boarding between the vehicle and the station platform. This is accomplished by making the station platform the same height as the vehicle floor, ensuring that the vehicle floor is flat, and minimizing or eliminating the gap between vehicles and the platform.

Passengers should be able to board vehicles through multiple doors, without stopping to pay a fare. Generally, this requires that a fare collection system be located either in the station or at the station entrance. This system should be integrated with other public transport services in the city.

Figure 7: Level boarding. Photos: Breakthrough Technologies Institute

Vehicles should use the most recent engine and emission control technologies, and the cleanest fuels. Many current BRTs use Euro III buses with either ultra-low sulfur diesel (ULSD) or compressed natural gas (CNG). In the United States, hybrid-electric diesel propulsion is common on BRT systems, including the Cleveland Healthline, the Eugene EmX, and the Las Vegas MAX. A notable exception is the Los Angeles Orange Line, which uses CNG.

Where demand is high or where multiple routes use the station (i.e., an open-architecture system), stations often have multiple stopping zones. This allows more than one vehicle to serve the station at any given time and enables passengers using different routes to wait in different sections of the station. Many stations also are designed with passing lanes, allowing express services to bypass certain stations and thus substantially reducing travel time, especially for passengers traversing the length of the corridor.

Finally, stations tend to be located on the far-side of intersections (i.e., after the signal) or in the middle of the block. A station placed on the near-side of an intersection (i.e., before the intersection) can result in delays, because a vehicle that is ready to depart can be blocked by a red light, causing all other vehicles behind it to be delayed as well. It should be noted, however, that far-side stations placed too close to an intersection also can cause delays, if vehicles back up in the station and into the intersection. Thus, some space should be allocated for vehicle queuing into stations.

Figure 8: Examples of off-vehicle fare collection (barrier turnstile, Guayaquil, Ecuador and automatic ticket machine, Mexico City). Photos: Breakthrough Technologies Institute.

Figure 9: Real-time arrival information, Brisbane, Australia. Photo: Breakthrough Technologies Institute.

Intelligent Transportation Systems

ITS technology generally refers to the use of information technology in the transportation context. An operational control center can maintain operational performance, ensure rapid incident response, and support performance-based contracting. Real-time vehicle information can be used to control vehicle operations, thereby reducing delays caused by vehicles operating too closely together ("bunching"). Real-time vehicle information also can be used to alert passengers of the time remaining before the next vehicle arrives, which is especially important where service frequencies are low. Sensors at intersections can detect approaching vehicles and ensure that the traffic light remains green. Many BRT systems use ITS technologies to improve speed and reliability and thus overall system performance.

Frequent Service

In many cities, a key component of the environmental performance of BRT is the ability to attract passengers who might otherwise make their trip using a personal vehicle. Frequent service, especially during peak hours, minimizes passenger wait time, thus making the trip more competitive with a personal vehicle trip. As a rule of thumb, a vehicle at least every five minutes during peak hours is considered frequent, but actual frequencies must be determined based upon demand and vehicle capacity. The Southeast Busway in Brisbane has experienced peak frequencies of 24 seconds between vehicles.[7]

Marketing and Branding

Just like any other service, BRT needs to attract and retain customers. Passengers must be informed about the service and to identify the service with key attributes, such as speed, comfort, and reliability. Many BRT systems use marketing campaigns, logos, unique and attractive station designs and vehicle liveries, and other techniques to achieve this.

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[7] Currie, Graham, Bus Rapid Transit in Australasia: Performance, Lessons Learned, and Futures, Journal of Public Transportation. 2006. P. 6

Land Use and Access

Figure 10: Bicycle parking at Transmilenio BRT station. Photo: Breakthrough Technologies Institute.

Many cities seek to focus development around BRT stations and to improve pedestrian and bicycle access to stations. These are frequently accomplished through the development of station area plans and transit-supportive zoning policies. In Cleveland, Ohio, a new zoning ordinance was created for the Midtown area to encourage development around the city's new Healthline BRT system. Among other things, the ordinance provides for higher density, mixed-use development near stations, building locations that are closer to the front property line and to each other as compared with other parts of the city, improved pedestrian access to BRT stations, and the location of retail shopping on the ground level of buildings. As of 2008, roughly $187 million in new development had occurred near Midtown BRT stations, and property values had doubled.[8] In total, the Healthline has been credited with encouraging roughly $4.3 billion in economic development.[9]

In some cases, BRT systems have captured direct economic value from these developments. In Brisbane, for example, the system operator sold the air rights above the Mater Hill BRT station to enable construction of a hospital facility.

BRT systems also have provided bicycle parking and shared bicycle systems as part of their BRT systems. In Guangzhou, for example, roughly 5,000 bicycles have been installed at shared bicycle stations, and the system is integrated with the BRT. In Brisbane, the new King George Square busway station includes a secure, underground bicycle parking facility with its own dedicated access from the street. Operated by *cycle2city*, the facility provides customers with a range of services, including 420 bike parking spaces, secure electronic entry for members, showers and fresh towels, and a full-service bicycle shop with mechanic.

Methodology

Due to budget constraints, the methodology relied primarily upon assembling and analyzing data from existing sources. For Bogotá and México City, the primary resources were design, monitoring, and other

[8] Interview with Midtown Cleveland, Inc.

[9] "Euclid Corridor Project Driving Over $4.3 Billion in Cleveland Development," Cleveland Plain Dealer, February 10, 2008.

documents related to the CDM, which is discussed in more detail below. This information was supplemented by emissions inventories as well as studies of air pollution and exposure in both cities. For Guangzhou, China, this report used an ad-hoc methodology developed by the Institute for Transportation and Development (ITDP). The methodology uses traffic counts, speed surveys, passenger questionnaires, ridership statistics, and bus operations statistics both before and after the Guangzhou BRT was implemented.

BRT projects in the CDM pipeline as of June 2011 have the potential to reduce a total of more than 12.2 million tons of CO_2 equivalent during their crediting periods, a 40 percent reduction over baseline conditions.

CDM

The CDM was designed to promote sustainable development and reduce greenhouse gas emissions by enabling developing countries to sell Certified Emissions Reductions (CERs) earned through projects that reduce CO_2 emissions. All projects, regardless of sector, must complete the same CDM project development process, although a simplified process is available for small-scale projects.[10] In general, the CDM process includes:

- Developing a project design document, which includes identifying baseline and monitoring methodologies as well as emission reductions;
- validation of the project design by an independent third party;
- registration of the project by the CDM Executive Board;
- monitoring of project emissions based upon the approved methodology;
- verification that any emissions reductions in fact occurred; and
- issuance of the CERs.

CER's are issued during the "crediting period" of the project, which is the timeframe set forth in the methodology during which reductions are measured and validated. The crediting period is selected by the project participants and may either be seven years, renewable twice, or a single 10-year period.

Currently, there are two approved CDM methodologies that may be used by BRT projects. The first is AM0031, "Monitoring Methodology for Bus Rapid Transit Projects."[11] The methodology was developed

[10] To date, no small-scale methodology applicable to BRT exists.

[11] Monitoring Methodology For Bus Rapid Transit Projects AM0031. Available on the web at: http://cdm.unfccc.int/filestorage/C/D/M/CDMWF_AM_IK6BL2878HZ4NHV86V65CBJ2Y1ZBDI/AM0031_ver01.pdf?t=ZWF8MTMwNTIyMzY1OS4yNA==|ZZb10Ao3i56JtZa8tGvUvN2w9Sk=

for the Bogota Transmilenio BRT and applies generally to BRT systems with integrated trunk lines and feeder lines.

The methodology has a number of conditions that apply to its use, including:

- The project has a clear plan to reduce existing public transport capacities either through scrapping, permit restrictions, economic instruments or other means and replacing them by a BRT system;
- local regulations do not constrain the establishment or expansion of a BRT system;
- the BRT system partially or fully replaces a traditional public transport system in a given city, except that an urban rail-based mass transit system cannot be replaced; and
- various conditions related to the type of fuel used by the BRT.

The second approved methodology applicable to BRT is ACM0016, "Baseline Methodology for Mass Rapid Transit Projects."[12] This methodology applies to rail-based systems as well as to bus-based systems that use bus lanes. The methodology was developed for the México City Metrobús project, and thus is intended primarily for BRT projects that do not use feeder bus systems. The methodology has conditions that are similar to the conditions set forth for AM0031.

The CDM provides useful data for assessing the environmental performance of BRT systems, including project design documents and ongoing monitoring reports. However, the CDM does not account for benefits beyond CO_2 reductions, such as air quality improvements, and thus the amount of information available through CDM is somewhat limited.

Moreover, there are very few transport projects in the CDM program. As of June 2011, there were roughly 3,000 registered projects in the CDM program, but only six were in the transport sector. Two of these six were BRT projects – Bogota's TransMilenio and Chongqing, China Lines 1-4. In addition, there are a number of BRT projects in the validation phase of the CDM process, but it is not clear when and if they will be registered.

There are a number of reasons why transport projects are not well represented in the CDM. First, CDM requires extensive data collection and analysis, and many developing countries do not have access to the required data. Developing such data is expensive, creating a significant barrier to entry. These costs are estimated at $300,000 - $500,000 to achieve registration and $200,000 annually thereafter.

Second, it can be difficult for transport projects to meet certain eligibility requirements, such as the "additionality" rule. Additionality requires that anthropogenic greenhouse gases emissions be reduced below those that would have occurred in the absence of the registered CDM project. In other words, if a project would have been built in the absence of CDM, it is part of the baseline scenario, and thus is not creating "additional" emission reductions.

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[12] Approved Consolidated Baseline and Monitoring Methodology ACM0016. Version 01. "Baseline Methodology for Mass Rapid Transit Projects."
Available at: http://cdm.unfccc.int/methodologies/DB/9N83FPTC1SDQ7GHUSPM9EZT7K2W3TM

Third, the total revenue likely to be realized through CDM is a small proportion of overall project costs. For example, the projected CER revenue for Transmilenio between 2006 and 2027 constituted just one to two percent of total annual project costs, assuming a CER price of 13 Euros per ton.[13] The actual CER revenue is much lower, primarily due to overly-optimistic ridership projections and lower than expected CER prices. The low revenue potential of CDM creates little incentive for many projects to participate in the CDM and also creates challenges in meeting the additionality test.

Table 5 shows all BRT projects in the CDM pipeline as of June 2011. If each of these projects is constructed and meets emissions estimates, they will reduce a total of roughly 12.2 million tons of CO_2 equivalent during the crediting period for those projects. This constitutes, on average, about a 40 percent reduction in CO_2 emissions as compared with the baselines for the projects. The BRT project in Medellin, Colombia currently is projected to achieve an 83 percent reduction as compared with its baseline, and four other projects are expected to achieve reductions greater than 60 percent.

It is important to note, however, that most of these projects are in the validation phase and have been so for a number of years. Others, such as the Chongqing system, have not been completed in accordance with the originally anticipated timeframe. Finally, the experience with Transmilenio suggests that actual reductions may be lower than predicted reductions, although the percentage reductions may be comparable to original projections. Thus, it is unclear whether and when the reductions anticipated by the projects in the CDM pipeline will be realized.

[13] Clapp C., *et al* (2010), "Cities and carbon Market Finance, Taking Stock of Cities' Experience with Clean Development Mechanism (CDM) and Joint Implementation (JI), OECD Environment Working Papers No. 29. P. 31

Table 5: BRT Projects in the CDM Pipeline

City	CDM Status	Methodology Used	Estimated Project Baseline CO_2 Emissions (tCO_{2eq})	Estimated CO_2 Emissions Reductions (tCO_{2eq})	Percent Reduction From Baseline
APEC Countries					
Chongqing, China	Registered	AM0031	3,225,401 (2009-2016)	1,526,469 (2009-2016)*	47 %
Zhengzhou, China	Validation	AM0031	2,824,200 (2010-2017)	1,238,578 (2010-2017)	44 %
Seoul, South Korea	Validation	AM0031	6,511,745 (2009-2015)	1,017,391 (2009-2015)	16 %
Guadalajara, México	Validation	AM0031	872,710 (2011-2018)	354,590 (2011-2018)	41 %
México City, México	Validation	ACM0016	762,452 (2011-2018)	301,798 (2011-2018)	40 %
Zona Metroplitana del Valle de México, Zona Metropolitanan del Valle de Toluca, México	Review Requested	ACM0016	2,757,022 (2010-2017)	1,036,817 (2010-2017)	38 %
* This estimate is deemed unreliable. See Chongqing BRT section of this report.					
Non-APEC Countries					
Barranquilla, Colombia	Validation	AM0031	664,311 (2010-2017)	430,577 (2010-2017)	65 %
Bogotá, Colombia	Registered	AM0031	2,791,689 (2006-2012)	1,725, 940 (2006-2012)	63 %
Cartagena de Indias, Colombia	Validation	AM0031	778,873 (2011-2021)	380,279 (2011-2021)	49 %
Medellin, Colombia	Validation	AM0031	1,044,795 (2012-2018)	864,354 (2012-2018)	83 %
Quito, Ecuador	Validation	AM0031	2,363,346 (2010-2017)	1,026,056 (2010-2017)	43 %
Guatemala City, Guatemala	Validation	AM0031	5,773,501 (2012-2018)	3,739,317 (2012-2018)	65 %
Indore, India	Validation	AM0031	393,484 (2009-2016)	255,508 (2009-2016)	65 %
TOTAL			**30,763,509**	**12,231,410**	**40 %**

Methodology for Guangzhou

The Guangzhou BRT (GZ-BRT) currently is not part of the CDM. As a result, an "ad hoc" methodology was developed to analyze the impacts.

In general, BRT systems can reduce emissions in the following ways:

- Modal shift;
- improved fuel efficiency due to increased transit and mixed traffic speeds, as well as improved vehicle technology;
- reduced transit vehicle kilometers traveled (VKT) due to rationalized routes; and
- decreased demand for private vehicle trips resulting from transit-supportive land uses.

The Guangzhou methodology accounts for all of these impacts, except improved vehicle technology and land use. This is because the Guangzhou BRT primarily uses vehicles that are similar to the vehicles that were in service prior to the BRT, and because land-use impacts are long-term and not subject to measurement for recently-implemented projects.

The methodology is based on the general "activity – structure – intensity – fuel" (ASIF)[14] approach and comparable to the CDM AM0031 methodology for calculating the greenhouse gas impacts of BRT systems. However, the AM0031 methodology calculates a per-passenger emission factor for all modes, including the BRT, and then multiplies these by the per-passenger travel activity of that mode in baseline and project scenarios. By contrast, the Guangzhou methodology calculates emissions based primarily upon VKT. This is because the bus ridership and occupancy data needed for the per-passenger approach is not reliable. However, reliable data is available regarding BRT ridership, bus VKT from both before and after the BRT implementation, and mode shift. Thus, the actual bus VKT was used to create pre-BRT and post-BRT emissions.

The Guangzhou methodology calculates the impacts of modal shift, improved efficiency, and reduced transit VKT then sums them together to find the total emissions impact of the GZ-BRT[15]:

$$E_{\text{modal shift}} + E_{\text{reduced transit VKT}} + E_{\text{improved transit speed}} + E_{\text{mixed traffic speed}} = I_{BRT}$$

I_{BRT} = Cumulative Yearly Emissions Impact of Implementation of Guangzhou BRT

E_x = Emissions Avoided Annually, by source

Emissions factors for each of the variables were based upon regionally specific studies or averages from the International Vehicle Emissions model. Appendix I provides additional detail on the Guangzhou methodology.

[14] Schipper, Lee and Celine Marie-Lilliu and Roger Garham. "Flexing the Link between Transport and Greenhouse Gas Emissions." International Energy Agency, Paris 2000. P. 3

[15] Note: The impacts of bus speed on fuel efficiency and changes in bus VKT are necessarily combined, as both an emissions factor and travel activity are needed to calculate CO_2 emissions

Discussion

Public transport systems can reduce emissions in a number of ways.

- A fully-loaded public transport vehicle generally is more efficient than a personal vehicle, resulting in lower emissions per passenger kilometer. Public transport can attract car drivers (i.e., "mode shift") by offering a high quality, reliable service.
- New public transport systems can improve the efficiency of existing systems by replacing older vehicles with cleaner, higher capacity vehicles, and by improving service efficiency, such as by optimizing the number of public transport vehicles in operation.
- Improvements related to public transport, such as enhanced traffic signals and better traffic management, can reduce congestion delays for all traffic, thus further reducing emissions and fuel consumption.
- Public transport systems can support higher density, walkable communities around transit stations, creating an environment that encourages public transport use and walking rather than the use of personal vehicles.

BRT has some unique attributes that impact environmental performance. BRT systems can be designed to enable vehicles to skip stations stops, reducing travel times for passengers choosing express services. Open architecture BRT systems allow local buses to use the BRT guideway, eliminating many transfers and thus reducing travel time, improving efficiency, and making the service more attractive to potential customers. The capital costs for BRT are much lower than the capital costs for comparable rail systems, enabling more BRT to be built for a given amount of funding.

Conversely, BRT vehicles contribute to local air pollution, especially if the vehicles operate with poor quality diesel fuel. However, this impact can be mitigated with low sulfur diesel and emission control systems, hybrid electric vehicles, or by using other fuels, such as compressed natural gas. The result can be lower overall emissions as well as reduced exposure to pollutants as compared with previous conditions in the corridor.

The following is a discussion of the environmental benefits of several of the world's most prominent BRT systems. These systems were selected because they are using the CDM to quantify emissions and generate CERs, or because the systems are located within an APEC member economy and are otherwise noteworthy.

México City, México Metrobús

The Metropolitan Zone of the Valley of México has a population of 19 million inhabitants who take more than 22 million journeys per day.[16] The city's vehicle fleet is very old[17], often pre-dating catalytic converters, and poor maintenance contributes to excess tail-pipe emissions. Model years before 1990 can emit four to seven times more CO and VOCs, and three to five times more nitrogen oxides (NO_x) than model year 2000 vehicles and newer.[18] Fuel quality historically has been poor[19] and the demand for privately owned vehicles has been high.[20]

México City's unique geography contributes to its air quality problems. The city is located in a high altitude valley (7,350 feet), which decreases engine efficiency. It has been estimated that diesel engines in México City have emission factors over 47 percent higher than at lower-altitudes.[21] Weather patterns hold emitted particles over the city, and a lack of rain keeps pollution suspended in the air. About 4,000 deaths per year in México City are caused by respiratory illness that can be attributed to poor air quality.[22] Roughly 18 percent of CO_2 emissions are attributed to the transportation sector.[23]

México City, México

Demographic Information

- City Population: 19,000,000 (metro area)
- Land Area: 573.4 sq. miles
- Number of Private Autos: 8,000,000
- Percent Use Mass Transit: 70%

System Characteristics

- System Name: Metrobús
- Date Implemented: 2005
- Number of Lines: 3
- System Length: 67 km
- Number of Stations:
  - Línea 1 – 45
  - Línea 2 – 36
  - Línea 3 – 32
- Cost: Phase I – 30 million USD

Key Benefits

- Travel Time Savings: Reduced travel time 40%
- Estimated CO_2 emission reductions: 301,798 tCO_{2eq}

In 2001, daily PM standards were exceeded on 100 days and the O_3 standard was exceeded on 273 days.[24] Concentrations of CO exceeded the World Health Organization guidelines of 25 parts per million by volume (ppmv) for one hour[25] before Metrobús.

[16] "Metrobús: Una Fórmula Gandora, Metrobus: A Winning Formula." Centro de Transporte Sustentable de México. 2009., P.13
[17] Molina, Luisa T. "Sustainable Transportation in Latin America and the Caribbean." Massachusetts Institute of Technolog/MCE2, September 15, 2010. 15th IUAPPA World Clean Air Congress Session 6E: Greener Transport, Vancouver, Canada. Adobe Acrobat File. , P.3.
[18]Zavala, M. et al. "Evaluation of mobile emissions contributions to Mexico City's emissions inventory using on-road and cross-road emission measurements and ambient data." Atmospheric Chemistry and Physics. September 2, 2009. P. 6313
[19] Molina, P.3
[20] Molina, P.4
[21] Stevens, Gretchen and Mirium Zuk, Leonora Rojas, and Rodolfo Iniestra. "The Benefits and Costs of a Bus Rapid Transit System in Mexico City: Final Report." Instiuto Nacional de Ecología. May 2008 P. 36
[22] Metrobus: A Winning Formula. P.32
[23] Metrobus: A Winning Formula, P. 32

System Background

Metrobús Línea 1 opened on June 19th, 2005 with an initial 20 km of exclusive bus lanes in the median of Insurgentes Avenue, a major arterial road running on a north-south alignment through the city.[26] Traffic is heavy during both the morning and evening peak, in both directions, and is generally congested throughout the day. Small barriers separate the bus lanes from general traffic. The system's average bus speed is 19 km/h.[27]

Figure 11: México City, Metrobús, Línea 1. Photo: Breakthrough Technologies Institute

In 2008, Línea 1 was extended 10 km, bringing it to a total of 30 km. Línea 2 began operating in January 2009 and consists of an additional 20 km of route. Construction began on the 17 kilometer Línea 3 in March 2010 and the line opened in early 2011. A total of ten corridors are planned.

Table 6: Metrobús System Overview

Línea	Length (km)	Number of Stations	Annual Ridership
Línea 1	30	45	93,371,431[28]
Línea 2	20	36	33,754,004[29]
Línea 3	17	32	Not yet available

Metrobús is a closed architecture BRT system, with the dedicated guideway reserved for exclusive use of BRT vehicles. Unlike many other closed architecture systems, Metrobús does not include feeder lines. However, the system has many important BRT elements, including stations with controlled access, pre-paid, reloadable fare-cards, and elevated platforms for quick boarding and alighting.[30] Metrobús vehicles are equipped with a global positioning system (GPS) and automatic vehicle location (AVL), which updates

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[24] "Cleaner Buses for Mexico: An Opportunity to Save Lives." EMBARQ. Available online at: http://www.embarq.org/sites/default/files/RetrofitPolicyBriefVersionFinal.pdf P.2

[25] Wöhrnschimmel, Henry et al. "The Impact of Bus Rapid Transit System on Commuters' Exposure to Benzene, Co, PM2.5 and PM10 in Mexico City." Atmospheric Environment. Pages 8194-8203. Vol. 42, 2008. P. 8197

[26] Stevens, P.5

[27] Pai, Madhav. "GHG estimation & measuring co-benefits MetroBus, Mexico City." Center for Sustainable Transport-India. P.11

[28] Director of Metrobús. "Informe Annual de Actividades 2009 Y Primer Bimestre 2010". Metrobús and Ciudad México. March 2010. Adobe Acrobat File. Translated into English by Elizabeth Delmont, P.4 Total number of riders, 2009

[29] Director of Metobús, P. 4 Total number of riders, 2009

[30] "La Línea 3 – Bienvenido a Metrobús." Metrobús, 2010. Adobe Acrobat File. Translated into English by Elizabeth Delmont. Pgs. 3-7

real-time information displays for passengers.[31] The system is 100 percent accessible by the disabled, with ramps, level boarding, and Braille placards.[32]

The Metrobús system uses 268 articulated buses and 12 biarticulated buses.[33] Each new bus meets Euro III standards, a significant improvement over the vehicles they replaced, which were were Euro 0 or older.[34] In all, 647 microbuses and 31 autobuses were scrapped for Línea 1 and 2.[35] Metrobús also began using ULSD fuel in 2008.

Metrobús is managed by a public-private partnership. The government entity, RTP, manages the infrastructure and purchased 25 percent of the rolling stock[36] for Línea 1. The private entity, Corridor Insurgentes SA de CV (CISA), is responsible for ticket selling, validation systems, operations and 75 percent of the rolling stock.[37] CISA purchased 60 articulated Volvo buses, and later purchased four additional vehicles.[38] To ensure buy-in, all former microbus and autobus drivers were hired as Metrobús employees.[39]

Environmental Benefits

In 2008, a detailed analysis of the Insurgentes corridor was conducted by the Instituto Nacional de Ecologia, with support by the U.S. Environmental Protection Agency. The study assessed greenhouse gas and air pollution reductions, health benefits, and travel time savings as compared to a baseline scenario consisting of conditions in the corridor in 2004, before Metrobús was implemented.

The study projected the potential emissions reductions for the first ten years of the project lifespan (i.e., 2005-2015). Due to data limitations, the study focused upon the emissions associated with Metrobús operations, such as changes in vehicle technology and mode shift. The study did not assess the impact of improved conditions for general traffic, and thus likely underestimated the environmental benefits of the project.

Table 7 shows the types and activities of vehicles that were replaced by Metrobús in the Insurgentes corridor. Much of this data was derived from a CDM application prepared in 2005. The project was not registered and subsequent CDM applications were prepared, which is discussed below.

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[31] Pai, P. 12
[32] La Línea 3, P.19
[33] La Línea 3, Pgs. 8 - 10
[34] Clean Development Mechanism Project Design Document. BRT Metrobus Insurgentes, Mexico. Version 2.0 February 22, 2011 P. 9
[35] La Línea 3, P. 13
[36] CDM PDD BRT Metrobus Insurgente, Mexico, P. 3
[37] CDM PDD BRT Metrobus Insurgente, Mexico, P. 3
[38] Stevens, P.12
[39] Stevens, P.31

Emission factors were derived in a number of ways, including the MOBILE6-Mexico model and the IPCC. To calculate mode shift, a rider survey was conducted in June 2005, shortly after the initial Insurgentes corridor opened. The survey found that 4.6 percent of Metrobús users had previously used a car and that 1.8 percent had previously used a taxi, for a total 6.4 percent mode shift. Based upon an assumed average trip length of seven km, the study estimated that Metrobús reduced 32 million vehicle-km per year from private cars and taxis.[41]

Table 7: Vehicle Type and Characteristics Replaced by Metrobus Insurgentes Corridor[40]

	Buses	Microbuses		
Fuel Type	Diesel	Gasoline	Liquefied Petroleum Gas	CNG
Number of Vehicles	277	29	54	7
Activity (km/day)	140	130	130	130
Average Speed (km/hr)	17.4	17.4	17.4	17.4
Fuel Economy (km/l)	1.53	1.95	1.141	2.2*

*** CNG reported in km/m^3**

The study concluded that mode shift and improved transit vehicle technology would result in 26.7 tons CO_{2eq} reduced in 2011, with comparable amounts for each of the other years during the 10-year projection. [42]

The study also calculated emissions reductions for total hydrocarbons, NO_x, fine particles ($PM_{2.5}$), SO_2, CH_3, and N_2O. Table 8 provides the estimated reductions in air pollution for 2011. The study concluded that reduced air pollution would prevent an average of 6,100 lost work days, 660 restricted activity days, 12 new cases of bronchitis, and three deaths each year, and that the economic value of these benefits is $3 million per year.[44] Finally, the study estimated that 5,323,000 liters of gasoline, 3,083,000 liters of diesel, 2,246,000 liters of liquefied petroleum gas (LPG), and 151,000 m^3 of CNG would not be consumed during the 10-year study period as a result of the project.[45] The economic value of these projected fuel savings was estimated at nearly US $3.7 million.

Table 8: Metrobús Insurgentes Corridor Estimated Air Pollution Reductions (metric tons) (2011)[43]

THC	NOx	$PM_{2.5}$	SO_2	CH_3	N_2O
-115	-421	-2.7	-2.0	-2.6	-3.1

[40] Stevens, P. 10.
[41] Stevens, P.11.
[42] Stevens, P.27
[43] Stevens, P. 21.
[44] Stevens, P 26.
[45] Stevens, P. 34

In 2011, a new CDM application was submitted for the initial portion of the Insurgentes corridor. The application contains substantially more detailed information than the 2008 study, including updated projections for Metrobús operations, mode shift, passenger trips, vehicle speeds, and other parameters. Based upon this updated information, the CDM application predicts that Metrobús on Insurgentes will reduce 301,798 tons CO_{2eq} over a seven-year crediting period (2011-2018), or an average of 43,114 tons per year, which is significantly higher than the estimated reductions contained in the 2008 study (Table 9). This constitutes a roughly 40 percent reduction in CO_2 emissions as compared with the CDM baseline. Estimated fuel savings based upon these reductions are the equivalent of 115.4 million liters of diesel over the crediting period, or 37 percent compared with the baseline.[46]

On a city-wide basis, the percentage CO_2 reductions for the Insurgentes corridor are significantly lower. A recent emissions inventory found that total transport-related CO_2 emissions in México City are 22,290,505 tCO_2,[47] resulting in reductions of 0.2 percent. This result is to be expected however, because of the sheer size of México City as compared with the Insurgentes corridor. Moreover, if all 10 corridors are built as planned, the city-wide percentage reduction should be much more significant.

Table 9: Estimated Metrobús Emissions Reductions (2011-2018) (tCO2eq)[48]

2011*	2012	2013	2014	2015	2016	2017	2018*	Total
22,410	44,344	43,868	43,373	42,877	42,382	41,885	20,659	301,798
* Values for 2011 and 2018 are for 6 months only, not the full year.								

The PDD did not calculate criteria pollutants. However, previous studies found that Metrobús reduces exposure for bus passengers. Before Metrobús, a baseline study was conducted along Insurgentes to determine personal exposure to a number of criteria pollutants for users of autobúses and microbúses. The study used personal air quality monitors on board vehicles to measure exposure, as well as monitors to determine the ambient concentrations of PM.

A follow-up study was conducted after Metrobús was implemented. The study found that commuters inside a Metrobús vehicle are exposed to significantly less benzene, fine particles, and carbon monoxide as compared with passengers using traditional buses and microbuses.[49] (Table 10). Moreover, because travel time on Metrobús is about 40 percent faster than previous bus modes, commuters are exposed to pollutants for a shorter period of time.

[46] Calculated using project CO2 emissions savings, the diesel CO_2 emission factor of 72.6 gCO_2/MJ set forth in the project design document, and a conversion factor of 36MJ/liter of diesel.

[47] Martínez, Oscar Vázquez and Gabriela Malvido Álvarez, Berta Gutiérrez Guzmán and Francisco Javier López Saldivar. "Programa de Acción Climática de la Ciudad de México 2008-2012 Informe de Avances 2011." June 2011.

[48] CDM PDD BRT Metrobus Insurgente, Mexico, P. 12

[49] Wöhrnschimmel et al., P. 8201

Table 10: Baseline Concentrations of Criteria Pollutants in México City[50]			
Exposure	Autobus	Microbus	Metrobus
CO (Ppmv)	11.4	20	7.8
Benzene (Ppbv)	8.5	13.9	4.0
PM2.5 (μ/m^3)	152	167	112

Finally, the large majority of Metrobús riders believe the service to be safe, rapid, and superior to former transit modes.[51] Metrobús has reduced travel time significantly in all corridors, by roughly 40 percent.[52] For riders traveling Línea 1 between Indio Verdes and Doctor Gálves, travel time has been cut in half. It is estimated that Línea 2 also cuts travel time in half, down to an hour.[53] The savings from both lines return about 60 million man-hours to people's lives.[54]

Metrobús has decreased travel time variability. Previously, travelers on Insurgentes had a 25 percent chance of being seven minutes late and a five percent chance of being a half hour late. In comparison, Metrobús users traveling the full length of Línea 1 are five minutes late less than five percent of the time.[55] Traffic accidents in the corridor are down 20 percent, and on Insurgentes alone there has been a reduction in accidents of up to 40 percent.[56]

Metrobús also has attracted choice riders, with roughly 15 percent of users previously making the same trip by car, the equivalent of 65,000 fewer daily trips that otherwise would have been made by car.[57] This is significantly higher than the 6.4 percent estimated in June 2005, immediately after the project opened. Properties located on, or close to, the Metrobús system have appreciated nearly 20 percent since construction of Metrobús.

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[50] Wöhrnschimmel, Henry. "Evaluación de la Exposición Personal a Contaminantes Atmosféricos en Pasajeros de Vehículos de Transporte Púlico." Centro de Transport Sustentable. September 30, 2004. Translated into English by Elizabeth Delmont. P. 7; Wöhrnschimmel et al., P. 8198

[51] La Línea 3, survey of MetroBús users by Investigaciones Social Asociades S.C. in Sept. 2009 Pgs. 29-33

[52] Molina, P. 13

[53] La Línea 3, P. 27

[54] La Línea 3, P. 27

[55] Stevens, P. 30

[56] Metrobus: A Winning Formula, P. 30

[57] Metrobus: A Winning Formula, P.15

Bogotá, Colombia TransMilenio

Bogotá is a densely populated city of nearly eight million people, situated in the Andes Mountains at 8,500 feet above sea-level.[58] Air pollution has become an increasing problem, due in large part to population growth and an expanding private vehicle fleet, especially motorcycles. Over the past decade PM levels have increased through the city, exceeding limits in half of the city.[59] Nearly 70 percent of all PM emissions are from transportation.[60] In 2004, half the districts in Bogotá exceeded the PM_{10} and O_3 pollution limits.[61]

Before the implementation of the TransMilenio system, one million private vehicles used 95 percent of the road, making 1,394,301 trips per day,[62] while transporting only 16 percent of the population.[63] The traditional public transportation system had 21,000 registered urban public transit vehicles and an additional 9,000 illegal vehicles[64], making nearly 4,112,214 trips per day.[65] More than 60 private companies leased 509 routes to bus operators and their drivers, with an average length of 49.2 km.[66]

Bogotá, Colombia

Demographic Information

- City Population: 7,400,000
- Land Area: 612.7 sq. miles
- Number of Private Autos: 832,000
- Percent Use Mass Transit: 75-80%

System Characteristics

- System Name: TransMilenio
- Date Implemented: 2000
- Number of Lines: 9
- System Length: 84 km
- Number of Stations: 116
- Cost to Build:
- Phase I – 240 million USD
- Phase II – 545 million USD

Key Benefits

- Travel Time Savings: Approximately 16 minutes
- CO_2 emission reductions: Phase II – 79,326 tCO_{2eq} in 2009

The traditional system enabled extensive coverage across the city and frequent service, with passenger volumes as high as 25,000 passengers per direction per hour.[67] However, there was a significant

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[58] Cain, Alasdair and Georges Darido, Michael Baltes, Pilar Rodrigues, and Johan Barrios. "Applicability of Bogotá's TransMilenio BRT system to the United States." Federal Transit Administration. Report number FL-26-7104-01. May 2006 P. 3

[59] Pachon, Jorge E. and Eduardo Behrentz and Néstor Y. Rojas. "Challenges in Bogotá Air Quality: Policies and Technology." P.1 http://www.ing.unal.edu.co/grupos/calidad_aire/doc/eventos/0058airqualityinbogota.pdf

[60] Ministry of Environment, Housing, and Territorial Planning, Republic of Colombia. "National Experiences in Expanding Urban Public Transportation Services: BRTs in Bogotá, Cali, and Pereira." United Nations Forum on Climate Change Mitigation, Fuel Efficiency, and Sustainable Urban Transport. Seoul, South Korea. March 16, 2010. P. 3

[61] Echeverry, Juan Carlos and Ana María Ibáñez and Luis Carlos Hillón. "The Economics of TransMilenio, A Mass Transit System for Bogotá." Universidad de los Andes. 2004. P. 26

[62] Ministry of Environment, Housing, and Territorial Planning, Republic of Colombia, P. 5

[63] Ministry of Environment, Housing, and Territorial Planning Republic of Colombia, P. 3

[64] Cain et al., P. 4

[65] Ministry of Environment, Housing, and Territorial Planning Republic of Colombia, P. 5

[66] Ministry of Environment, Housing, and Territorial Planning Republic of Colombia , P. 5

oversupply of buses, resulting in inefficient operations. Bus occupancy levels typically were between 60 and 75 percent at peak times, and between 25 and 40 percent off peak.[68] In 1998 an average public transportation trip took one hour and 10 minutes at an average speed of 12-18 km/h.[69]

In the traditional system, bus operators generated revenue exclusively from fares. The oversupply of buses therefore resulted in intense competition for riders resulting in the "penny wars", where bus drivers aggressively sought more passengers through lower fares, aggressive driving, deviating from the designated route, and frequent stops.[70]

System Background

Figure12: Bogota Colombia, TransMilenio. Photo: Breakthrough Technologies Institute.

In the 1990's, Bogotá planned for 18 miles of heavy rail. The proposed system would have cost more than three billion dollars but would have served just 16 percent of the city's transit trips.[71] A new plan was developed that included the TransMilenio BRT, increased fuel taxes, on-street parking limitations, "pico y placa" rules limiting car use during peak periods[72], non-motorized transport improvements[73], and policies to stimulate urban renewal.[74]

TransMilenio is a trunk and feeder system with stations located in the median and passing lanes to enable express services. Private contractors are responsible for operations, including vehicle costs, and fare collection[75] and are reimbursed per service kilometer provided, rather than per passenger.[76] The public sector provides infrastructure.

There are a total of eight phases planned for TransMilenio, ultimately resulting in 388 km (241 miles) of dedicated trunk corridors.[77] However, the current expectation is that the entire system as set forth in the master plan will not be constructed. Phase I and II are complete, and Phase III currently is under construction. Currently, TransMilenio has 1179 articulated, nine biarticulated, and 514 feeder buses,

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67 Cain et al., P. 4
68 Cain et al., P. 4
69 Ministry of Environment, Housing, and Territorial Planning Republic of Colombia, P. 3
70 Cain et al., P.4
71 Cain et al., P. Xii
72 Cain et al., P. 5
73 Cain et al., P. iv
74 Cain et al., P. Xiii
75 Cain et al., P. Vii
76 Cain et al., P. Xiv
77 Cain et al., P. iv

serving 116 stations along 84km of trunk corridors. Completion of Phase III will bring the total length to 116 km.

Construction of TransMilenio Phase I began in 1998, with the initial section opening in 2000. Phase I covers 41 km (25.6 miles) and was fully completed by early 2002.[79] Phase I has 32 km (19.9 miles) of dual carriage way lanes, with the rest of the corridor operating single lanes, with an extra passing lane at stations.[80] On trunk routes, Phase I uses 19-meter articulated buses with 160 passenger capacity. Feeder routes use 40-foot buses with 80 passenger capacity.[81] All Phase I buses have high floors and are Euro II compliant.[82]

The diesel fuel initially used during Phase I had high sulfur content, resulting in excessive PM pollution. This problem was exacerbated by heavy use, with vehicles operating 350 km per day, mostly at full loads, and at high altitude.[83]

Each bus is equipped with a logic unit including a GPS, odometer, and door opening system. The logic unit keeps the bus in contact with central control every six seconds, and reports the bus location with two meter (6.6 ft.) accuracy.[84]

Table 11: Characteristics of TransMilenio[78]

Phase	Trunk Corridor	Lenth in km (miles)
III	Stage 1 – Calle 26/Av. Eldorado Stage 1 – Carreras 10 y 7 Stage 2 – Carrera 7 extention Stage 2 – Av. Boyaca TOTAL	8.8 (5.5) 12.2 (7.6) 6.6 (4.1) 19.5 (12.1) 47.1 (29.3)
IV	Av. 68 Av. 1 de Mayo Av. Ciudad de Cali Calle 13 TOTAL	10.6 (6.6) 12.3 (7.6) 16.8 (10.4) 7.1 (4.4) 46.8 (29.1)
V	NQS 2 (CL.92-CL.170) Av. V/cencio Calle 170 Calle 6 TOTAL	16.5 (10.3) 10.3 (6.4) 13.9 (8.6) 4.9 (3.0) 45.6 (28.3)
VI	CFS Av. de los Cerros Caracas 2 TOTAL	12.0 (7.5) 7.9 (4.9) 21.0 (13.0) 40.9 (25.4)
VII	Calle 63 Calle 200 Av. Ciudad de Cali Autopista Norte 2 Total	8.7 (5.4) 6.8 (4.2) 14.1 (8.8) 10.0 (6.2) 39.6 (24.6)
VIII	ALO Remaining Connectors TOTAL	48.0 (29.8) 38.3 (23.8) 86.3 (53.6)

The buses run with high average occupancy, carrying an average of 1,600 passengers per day.[85] This is nearly five times more than the traditional bus system.[86]

Phase I has four terminal stations, four intermediate stations, and 53 standard stations,[87] located approximately 500 meters (1,640 ft.) apart. Stations have between one to five platforms that are 25-

[78] Phases III – VIII Cain et al., P. 26
[79] Cain et al., P. 7
[80] Cain et al., P. Vii
[81] Cain et al., P. 8
[82] Cain et al., P. Viii
[83] Cain et al., P.11
[84] Cain et al., P. Viii
[85] Cain et al., P. Xi
[86] Cain et al., P. 18
[87] Cain et al., P. 10

119 meters long (82-623 ft) and typically five meters wide. All stations use off-board fare collection, pre-paid contact-less smart cards, and level boarding with automatic doors.[88] The system's smart cards can only be purchased in stations, which have caused queuing issues.[89] As part of the larger city-wide mobility plan, all stations are pedestrian accessible, with walkways, bridges, and paths as necessary.

Phase I ridership grew steadily through 2002 and reached 770,000 passengers, exceeding projected demand by over 100,000 riders.[90] By 2005 weekday ridership along Phase I was estimated at 790,000 passengers, and with the opening of parts of Phase II, ridership further increased to 900,000 passengers. The TransMilenio system currently serves about 1.6 million trips per day, roughly twice the number of the Washington, D.C. metro system.

Construction of Phase II began in 2000, and consists of an additional 41 km (25.6 miles) of trunk corridors, with three new terminal stations, two intermediate, and 50 standard stations.[91] Phase II's 13 km Americas Corridor was partially opened in 2003, and completed November 2004.[92] The remainder of Phase II, NQS (19.3 km) and Suba (10 km) was completed in 2006.[93] Phase II added over 335 articulated buses and 200 feeder buses to the system.[94] Buses are Euro II and III[95] using ULSD fuel.

As a result of TransMilenio and related measures, transit mode share increased from 64 percent in 1999 to 70 percent in 2005, and roughly nine percent of TransMilenio riders previously made their trip by car.[96] Non-motorized trips also increased over the same time frame.[97]

Phase I cost nearly $240 million U.S. dollars.[98] Phase II cost roughly $545 million U.S. dollars, and was financed primarily through the national government (66 percent), with the rest of the funding coming from local fuel surcharges.[99]

TransMilenio appears to have a positive impact on land use and properly values. TransMilenio stations are close to banks, clinics, and police stations, and large shopping centers have been built near existing stations.[100] Rents have been found to decrease between 6.8 and 9.3 percent for every additional five

[88] Cain et al., P. Vii
[89] Cain et al., P. 12
[90] Cain et al., P. 19
[91] Cain et al., P. 10
[92] Cain et al., P. 7
[93] Grütter, Jürg and Susana Ricaurte Farfán, and Deysi Rodriguez. "Monitoring Report. CDM Project 0672: BRT Bogotá, Colombia: TRANSMILENIO Phase II to IV Monitoring Period 1.1.2009-31.12.2009." Grütter Consulting. Report Version 1.0, February 28, 2010. P. 6
[94] Cain et al., P. 11
[95] Grütter, Monitoring Report 2009 Bogotá, Colombia , P. 5
[96] Cain et al., P. X
[97] Cain et al., P. 19
[98] Cain et al., P. 8
[99] Cain et al., P. Vii
[100] Perdomo-Calvo, Jorge et al. "Study of the Effect of the TransMilenio Mass Transit Project on the Value of Properties in Bogotá, Columbia." Lincoln Institute of Land Policy Working Paper. 2007., P. 20

minutes of walking time to a station, suggesting that people are willing to pay more to live within close proximity of the system.[101]

TransMilenio has increased travel speeds approximately 15-26.7 km/h (9.3-16.6 mph). System-wide travel time savings of 136,750 hours per day, 32 percent in average transit travel times, which equates to nearly 16 minutes per trip for transit users, and 13 minutes for trips city wide. The travel-time savings have been a boon for the lowest income groups, who tend to live at the edges of the city.[102]

Finally, TransMilenio has improved safety. Collisions in corridors have fallen 79 percent, dramatically reducing the number of traffic accident related injuries and fatalities.[103] There also is significant police presence both in and around the stations, resulting in a significant decrease in crime.[104]

Environmental Benefits

Phase I is not registered in the CDM. TransMilenio Phases II through IV were registered in 2006 and the total expected greenhouse gas emission reductions are 1,725,940 tCO_{2eq} over the project's seven-year crediting period. This constitutes a 61.8 percent decrease in emissions compared with the projected baseline of 2,791,689 $tCO_{2eq.}$ These reductions are achieved primarily through:

- Replacement and scrapping of older buses;
- larger capacity buses;
- improved operating conditions, such as dedicated lanes;
- mode shift from cars and taxis;
- centralized fleet control, which enables bus supply and frequency to be optimized based upon demand; and
- the introduction of pre-paid fares, which speeds passenger boarding and reduces dwell time.[105]

TransMilenio also may reduce emissions by improving conditions for mixed traffic in the TransMilenio corridors. However, these reductions are not included in the CDM registration.

As shown in Table 12, actual emissions reductions have been lower than expected, making it unlikely that the total anticipated reductions will be achieved. There are a number of reasons for this, including construction delays and ridership and mode shift projections that were overly optimistic.[106] However, as shown in the table, the baseline for each year also decreased, resulting in actual percentage decreases that are similar to the original projected decrease of 61.8 percent.

[101] Perdomo-Calvo, P. 8
[102] Cain et al., P 14
[103] Cain et al., P. 17
[104] García, Álvaro José Moreno. "Impacto De TransMilenio en el Crimen de la Avenida Caracas Y sus Vecindades" Universidad de los Andes. September 2005. Translated into English by Elizabeth Delmont., P. 35
[105] Grütter Consulting. Clean Development Mechanism Project Design Document. "BRT Bogotá, Colombia: TransMilenio Phase II-IV." Version 02. P. 7
[106] Grütter, Monitoring Report 2009 Bogotá, Colombia, P. 15

In terms of criteria pollutants, TransMilenio Phases II through IV are expected to reduce emissions by 7,000 tPM, 50,000 tNO_x, and 800 tSO_2 over the crediting period.[107] Compared with the baseline, this represents reductions of 27 percent, 25 percent, and 9 percent respectively. TransMilenio Phase I had a measurable impact on air quality in the vicinity of Caracas Avenue, with a 43 percent decrease in SO_2, an 18 percent decrease in NO_2, and a 12 percent decrease in PM between 1998 and 2002.[108]

Table 12: Estimated and Actual TransMilenio CO_2 Emission Reductions(tCO_{2eq}), and Percent Reduced

Year	Estimated and (Actual) Reductions	Estimated and (Actual) Baseline Emissions	Percent Reduced, Estimated and (Actual)
2006	94,567 (59,020)	154,569 (131,835)	61.2% (44.8%)
2007	134,011 (70,109)	216,246 (114,539)	62% (61.2%)
2008	230,201 (68,813)	365,885 (118,582)	62.9% (58%)
2009	304,432 (79,326)	486,767 (131,835)	62.5% (60.2%)
2010	298,719 (76,466)	481,900 (134,986)	62% (56.6%)
2011	336,735 (n/a)	545,890 (n/a)	61.7% (n/a)
2012	327,276 (n/a)	540,431 (n/a)	60.6% (n/a)

Sources: CDM Project Design Document Bogotá, Colombia; Grütter Consulting, Monitoring Reports: CDM Project 0672, Bogotá, Colombia (2006, 2007, 2008, 2009, 2010).

TransMilenio also is showing significant benefits beyond the boundaries of the CDM registration. In 2010, an emissions inventory was completed for the citywide transport sector in Bogota. The inventory found that total annual CO_2 emissions from the transportation sector are 4,700,000 $tCO_{2eq,}$ and that total annual criteria pollutant emissions from the transport are 107,973 tPM, 57,658t NO_x and 13,009 tSO_2. In 2009, TransMilenio reduced 79,326 tCO_{2eq}, 349 tPM, 2,686 tNO_x, and 25 $tSO_{2.}$[109] Thus, against a city-wide, transport-sector baseline, TransMilenio is achieving reductions of approximately 1.7 percent CO_{2eq}, 0.3 percent PM, 4.7 percent NO_x, and 0.2 percent SO_2. Because only two of TransMilenio's eight planned phases have been completed, TransMilenio has the potential to achieve significantly greater city-wide reductions.

Between 2006 and 2008, the average fuel efficiency of articulated buses was 6.3 km/gal, and 10.2 km/gal for feeder buses,[110] a marked improvement over traditional bus service. Over the seven-year CDM crediting period, TransMilenio Phases II-IV are estimated to save 411.2 million liters of diesel and 246.8 million liters of gasoline.[111] For diesel, this is a reduction of approximately 51.2 percent over the baseline of 803 million liters of diesel for the project. For gasoline, the reduction is 100 percent over the baseline, because all passengers using gasoline vehicles in the baseline scenario switch to diesel vehicles in the project scenario. Therefore, no gasoline is being used in the project scenario. In 2009,

[107] Project Design Document Bogotá, Colombia, P. 63
[108] Cain et al, P. 25
[109] Hernandez-Gonzalez, Alvaro and Rodrigo Jiménez. "Desarrollo de Uninventario geoeferenciado de emissionese de dioxide de carbon por fuentes móviles en el area urbana de Bogotá." Grupo de Investigación en Calidad del Aire, Departmento de Ingenieria Química y Ambiental, Universidad Nacional de Colombia, Bogotá.
[110] Ministry of Environment, Housing, and Territorial Planning Republic of Colombia, P. 10
[111] Calculated using the difference between baseline and project CO2 emissions for buses, cars, and taxis, and multiplying by the CO_2 emission factor as reported in the project design document.

TransMilenio Phases II-IV reduced 21.6 million liters of diesel, a 52 percent reduction compared with the baseline, and 8.4 million liters of gasoline. Again, the reduction in gasoline is 100 percent compared with the baseline, because no gasoline is used in the project scenario.

Guangzhou, China, BRT

Guangzhou is China's third largest city, and is a main manufacturing hub of the Pearl River Delta. In 1997 the city opened the first line of a subway, with eight lines now operational. Both air pollution and traffic in the city have been getting worse each year, due to an increase in the use of private vehicles. Guangzhou has been listed at number eight in the top ten worst cities for air pollution, with PM levels exceeding Beijing (tied for first) and SO_2 levels second only to Beijing.[112]

Prior to the implementation of the GZ-BRT, traffic speeds along Zhongshan Avenue were plummeting, and buses from 40 different routes blocked traffic while struggling to load passengers, often in traffic lanes. The 12-meter buses required on-board payment, which further reduced loading time. The city has been replacing its aging fleet of diesel buses with new LPG buses, and in 2009 36 percent of buses operating in the corridor ran on diesel. Now all buses in the corridor use LPG.

Guangzhou, China

Demographic Information

- City Population: 12,700,800
- Land Area: 2,870 sq. miles
- Number of Private Autos: 2,150,000
- Percent Use Mass Transit: 59.6%

System Characteristics

- System Name: Guangzhou BRT
- Date Implemented: 2010
- Number of Lines: 1 busway, utilized by 30 routes
- System Length: 22 km
- Number of Stations: 26
- Cost to Build: 950 million Yuan

Key Benefits

- Average Travel Time Savings: 7.2 minutes
- CO_2 emission reductions: Appx. 45,000 tons in 2010

System Background

Planning for a BRT system began in 2003. In 2005, city determined that the BRT would be located on Zhongshan Avenue, one of its busiest and most congested corridors, and by 2008 the station planning, basic operational plans, and multi-modal integration planning was completed. All infrastructure construction for the BRT was done in 2009, while fare collection systems, ITS, and vehicle procurement were completed in 2010.

The Guangzhou BRT opened in February of 2010. It runs through the northeast sector of central Guangzhou, and links some of the city's most developed areas to places where future growth is anticipated. On the west end of the corridor there is intense development with the Tianhe Sports Complex, the Guangzhou East Rail Station, high-rise residential complexes, the TEEM mall shopping complex, and office towers, including the fourth tallest skyscraper in China. The eastern end of the corridor serves the Huangpu district, which includes urban villages, high-rise residential complexes, public parks, universities, and large industrial and agricultural sites.

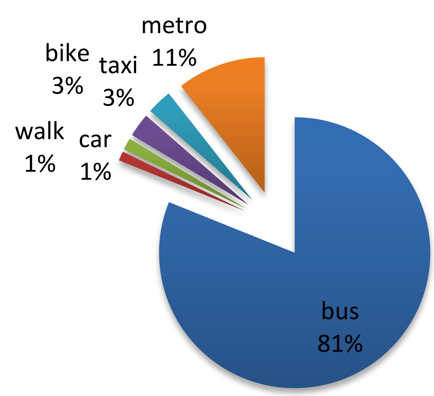
[112] http://www.dailyfinance.com/story/10-cities-with-worlds-worst-air/19729753/

Figure 13: Zhongshan Avenue before and after BRT. Photos ITDP.

The grade-separated runningway covers 22.5 km and uses an open architecture operating system, with more than 30 different routes using various portions of the guideway, eliminating the need for many transfers. The corridor has 26 stations, each with passing lanes, allowing for express services. The GZ-BRT has real time passenger information, off-board fare collection, and level boarding through multiple doors. Three corporate groups consisting of seven different bus companies operate routes along the BRT corridor, and are paid based upon operational performance and upon their percentage of total bus-kilometers delivered.

Most of the stations have pedestrian access via bridges or walkways, improving pedestrian safety and reducing the impact on mixed traffic due to red lights. However, the system is currently wheelchair inaccessible. Fares are collected upon entrance to the station at turnstiles. There are glass boarding gates that open on the platform once the bus has arrived. The size of stations varies across the whole system, with Ganding Station being the largest, at 250 meters. Ganding Station is also thought to be the busiest bus station in the world, with 55,000 daily boardings.

Figure 14: Mode Shift to Guangzhou BRT



The GZ-BRT serves up to 27,000 pphpd at peak hours and, in the first year of operation, averaged 805,000 daily boardings, which exceeds the ridership of the city's metro system. The majority of riders on the GZ-BRT used the previous bus system. Only 1.4 percent of riders switched from private vehicles, three percent previously used taxis, and 11 percent previously used the metro. Overall bus ridership is up 18 percent in the corridor over the year before.

Originally, the GZ-BRT used 12-meter buses. Due to crowding and other issues, 18-meter articulated buses are being introduced. Currently the system has between 26 and 38 twelve-meter buses and 47 eighteen-meter buses. All of the BRT buses use LPG fuel, but this is not factored into the emission saving calculation, because the city had previously changed to LPG from diesel before the Asian Games in 2009. Moreover, the city has no scrapping program in place, and it is likely that the older diesel buses are still in use elsewhere in the city.

The vehicles have front and rear boarding doors, with 28-36 seats. Occupancies during peak hours are typically 2.5 times the seated capacity, and crowding continues to be an issue. The new 18-meter buses are expected to help alleviate crowding and increase overall capacity.

Four BRT stations have access to three different metro lines, and one station has direct tunnel access with the metro. A bikeway was built on both sides of the GZ-BRT busway, and pedestrians have benefited from improved sidewalks.

Before BRT implementation, most bus fares were two Yuan (USD 0.30), but some longer routes had fares as high as five Yuan. Now all route fares are set at two Yuan, and within the BRT system riders are allowed free bus transfers. Riders who use smart cards receive a discount. Fares are established by the city government and the system currently requires a subsidy. The city government reports that on the BRT corridor routes the operational subsidy has decreased 66 percent since the opening of the GZ-BRT, from 0.9 Yuan per bus VKT to 0.3 Yuan per bus VKT.

Daily average bus speed has increased 29 percent, from 17 kph to 22 kph, with peak speeds increasing from 15 to 20 kph, and off-peak from 18 kph to 23 kph. These speeds translate to an average timesaving of 4.7 minutes per trip within the BRT corridor, or a combined savings of nearly 35 million hours, just from improved bus speeds. Additionally, average passenger-reported waiting times have decreased 19 percent, from 17 minutes to 14.5 minutes, saving another 2.5 minutes. Total average passenger time savings are around 7.2 minutes. Finally, mixed traffic speeds in the corridor have increased 20 percent. This has improved fuel economy by six percent.

Environmental Benefits

To calculate the emissions impact of the Guangzhou BRT, empirical data from 2009 (pre- BRT) was compared with data from 2010 (post-BRT) to find the observed CO_2 impact in 2010. In order to estimate the long-term impact of the BRT over its first ten years of operation, the City of Guangzhou's projections on vehicle speed and modal share were applied to the observed impacts in 2010.

The GZ-BRT reduced CO_2 emissions by approximately 45,000 tonnes in 2010. Over the next 10 years of operations, the GZ-BRT is expected to reduce 866,879 $tCO_{2,}$ with annual totals exceeding 100,000 tons. A shown in Figure 15, nearly half the reductions in many years is projected to be the result of improvements in mixed traffic speeds. Mode shift and improved bus operations also significantly contribute to CO_2 reductions.

Table 13: Estimated CO_2 Emissions Impact of GZ-BRT, 2010-2019

	BRT Mode Shift	BRT VKT Reduction	BRT Speed Increase	Mixed Traffic Speed Increase	Total Emission Reductions
tCO2 Emission Reductions	186,969	190,078	85,759	404,073	866,879

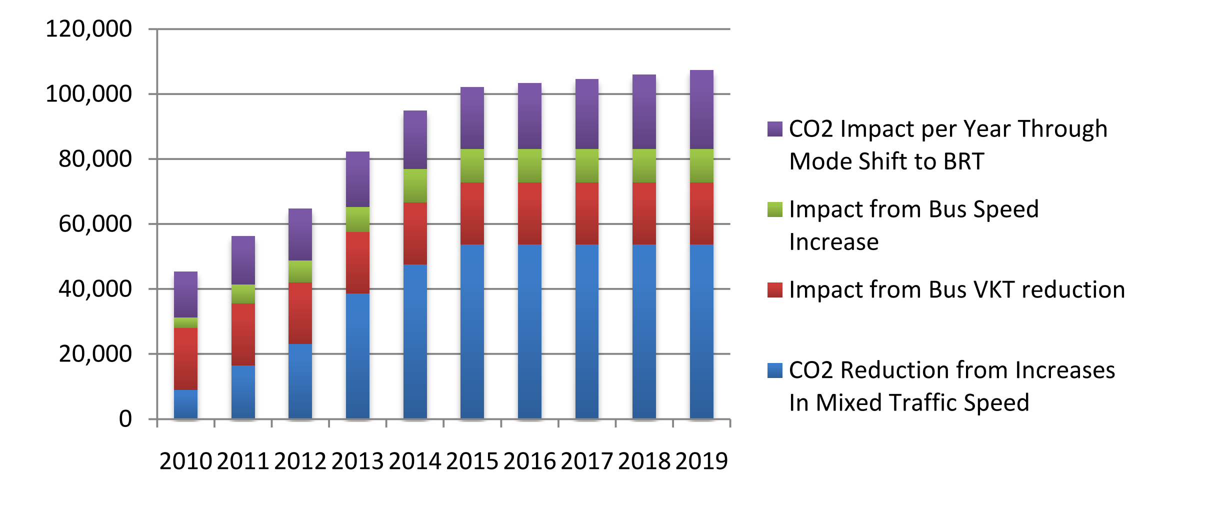


Figure 15: Guangzhou CO2 Emission Reductions, by Source

The impact of the GZ-BRT on criteria pollutants is low, because buses and taxis in Guangzhou were converted to LPG prior to the construction of the GZ-BRT. LPG vehicles tend to release fewer PM and SO_2 emissions than gasoline vehicles and diesel trucks. Over the 10-year period from 2010 through 2019, it is estimated that CO emissions will be reduced 16,464 tons, NO_x emissions will be reduced 4,401 tons, SO_2 emissions will be reduced 222 tons, and PM will be reduced 113 tons (Table 14). As with CO_2 emissions, most of the reductions derive from improvements to mixed traffic operations.

Table 14: Estimated Criteria Pollutant Emissions Impact of GZ-BRT, 2010-2019 (t)

	BRT Mode Shift	BRT VKT Reduction	BRT Speed Increase	Mixed Traffic Speed Increase	Total Direct Emissions Reductions
tPM	14	0	0	99	113
tCO	3,765	1,904	859	9,936	16,464
tNO_x	668	502	321	2,910	4,401
tSO_2	22	0	0	200	222

Figures 16 through 19 break down pollution reductions by the source of those reductions and by year.

Figure 16: GZ BRT Yearly PM Reductions by Source 2010-2019

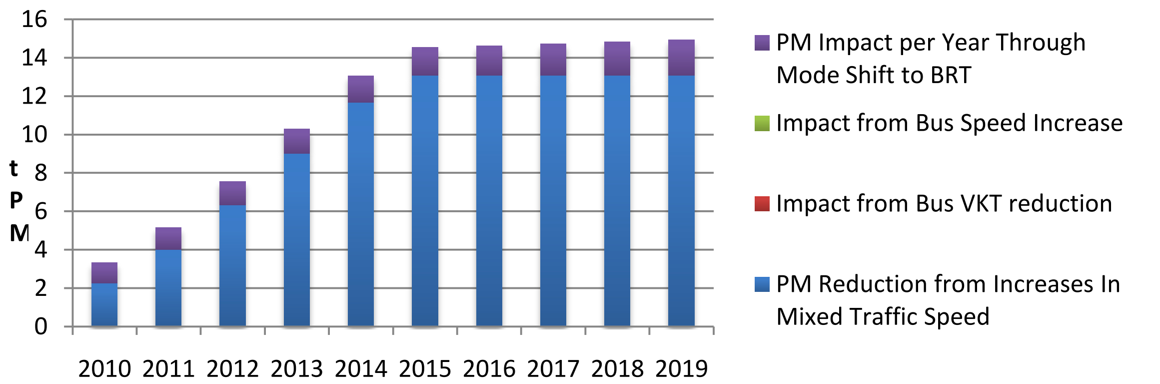


Figure 17: GZ BRT Yearly CO Reductions by Source 2010-2019

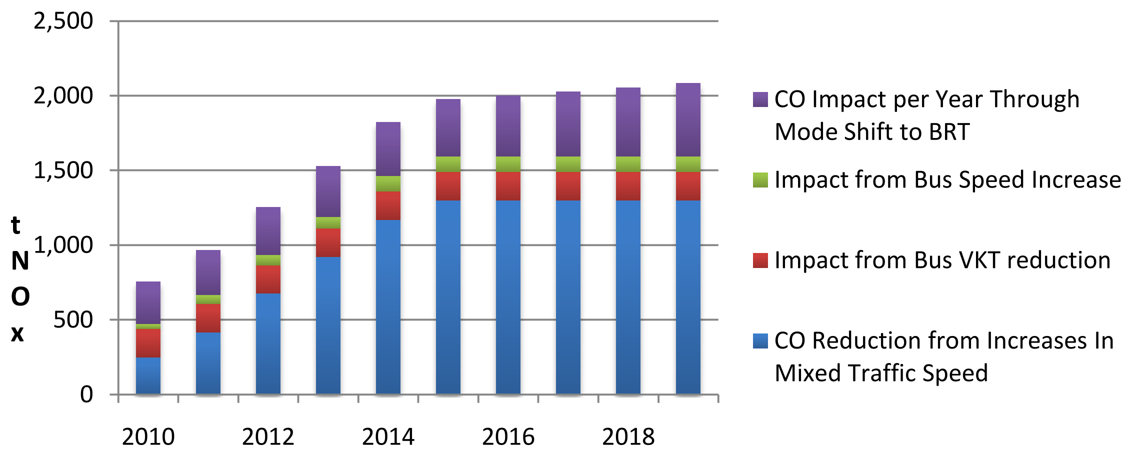


Figure 18: GZ BRT Yearly NOx Reductions by Source 2010-2019

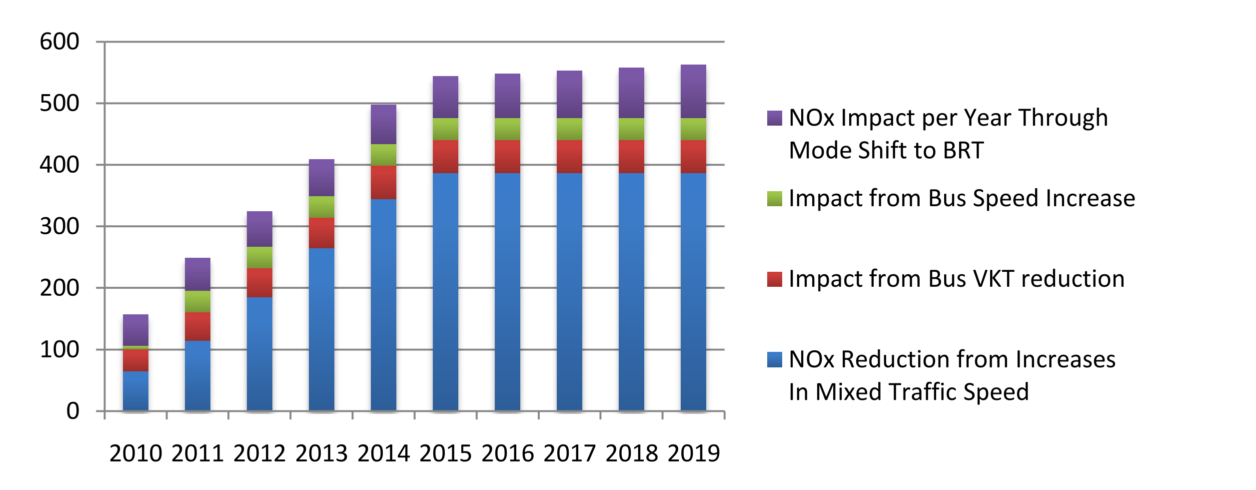
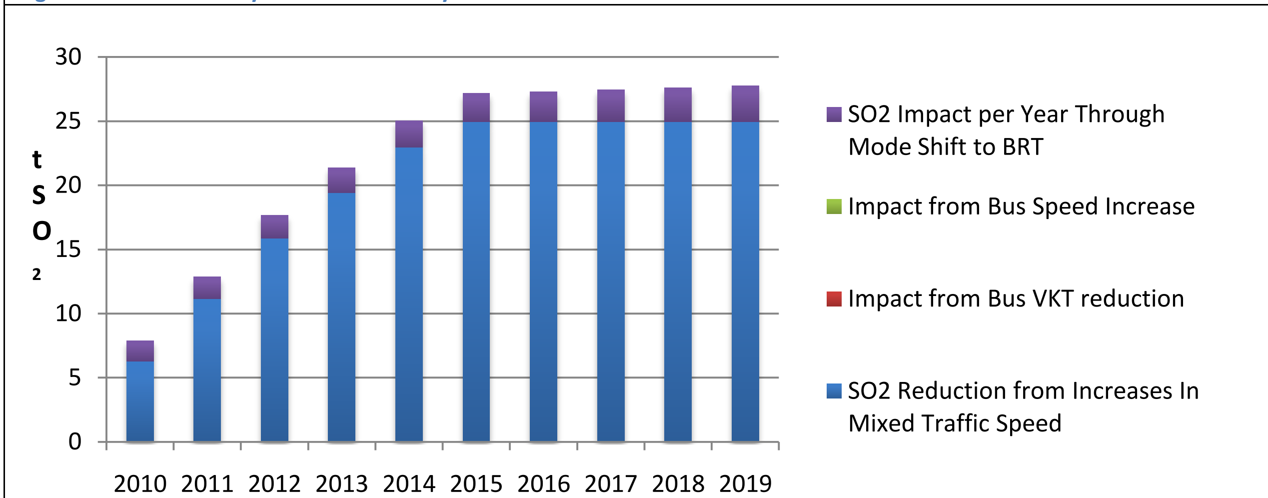


Figure 19: GZ BRT Yearly SO2 Reductions by Source 2010-2019

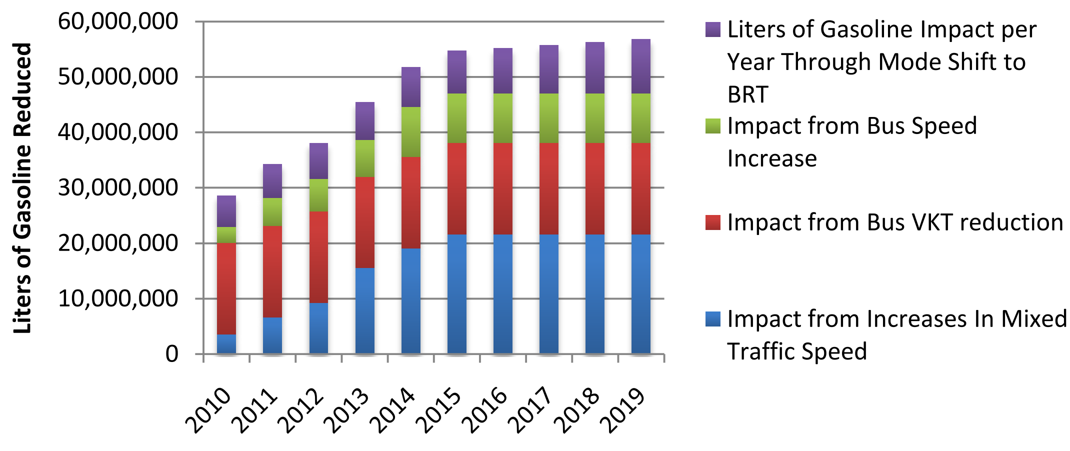


The amount of gasoline saved by the GZ BRT project was roughly estimated by back-calculating the emissions impact of the system to fuel volume by dividing the tonnes of CO_2 reduced by the CO_2 emission rate of the combustion of one liter of fuel. LPG fuel volume saved from bus operations was converted to gasoline using their ratio of BTU content.

The project is estimated to save an average of 40-50 million liters (10-13 million gallons) of gasoline per year, from 2010-2019[113] (Figure 20). The reductions are primarily the result of improvements to mixed traffic and operational improvements to buses, reflected as reductions in bus VKT.

[113] China imports roughly 30-33 billion gallons of gasoline equivalent each year.

Figure 20: Gasoline Consumption Reduction from GZ BRT, 2010-2019



Other APEC Systems

Brisbane, Australia

Brisbane is the capital city of the state of Queensland, located on the east coast of Australia. It is the largest city in Queensland, and the third largest in the country. Since the 1990's, Brisbane has been growing faster than any other state capital in Australia.

Australia enjoys relatively good air quality, although 70 percent of urban dwellers rank air pollution as a major concern, and the country has some of the strictest air quality standards in the world.[114] Brisbane also enjoys relatively good air quality. Between 1991-2001 concentrations of lead, CO, SO_2, and NO_2 all declined due to banning leaded fuels and improvements in motor vehicle emission controls.[115] Air quality has continued to improve through 2008[116] and motor vehicles continue to be a major source of air pollution.[117] It is estimated that personal vehicles are responsible for 70 of the smog experienced in Brisbane.[118]

In 1993, the TransLink Transit Authority[119] was created to manage planning and operations of public transport in Brisbane and South East Queensland. In 1997, South East Queensland issued a transportation plan to address regional growth.[120] The goal of the plan was to balance

Brisbane, Australia

Demographic Information

- City Population: 2 million
- Land Area: 2,280 sq. miles
- Number of Private Autos: approx. 1.8 million
- Percent Use Mass Transit: 35%

System Characteristics

- System Name: South East Busway
- Date Implemented: 2000
- Number of Lines: 1 of 4 busways
    - South East Busway utilized by 130 routes
- System Length: 16.5 km
- Number of Stations: 10
- Cost to Build: 520 million Australian Dollars

Key Benefits

- Travel Time Savings: 42 minutes
- CO_2 Emissions: South East Busway emits a quarter of the CO_2 emissions per passenger than a trip on the adjacent highway

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114 State of the Air: Community Summary 1991-2001. Department of the Environment and Heritage. http://www.environment.gov.au/atmosphere/airquality/publications/status/index.html P.2
115 State of the Air 1991-2001, P. 5
116 State of the Air in Australia: 1999-2008. Department of Sustainability, Environment, Water, Population, and Community. http://www.environment.gov.au/atmosphere/publications/state-of-the-air/pubs/state-of-the-air.pdf P. 42
117 Dluett, Jeff and Kaitie Dey and Gavin Fischer. "Assessing Vehicle Air Pollution Emissions." Department of the Environment, Water, Heritage, and the Arts. July 2008.
118 http://www.brisbane.qld.gov.au/environment-waste/air-quality/pollution-sources/index.htm
119 http://translink.com.au/
120 Integrated Regional Transport Plan for South East Queensland, Part 1. http://www.tmr.qld.gov.au/~/media/1008ff20-4b7-4a18-89df-10c19d3348d6/pdf_irtp_part01.pdf

non-motorized transport, private vehicles, and public transport. For public transport, the goal was to increase mode share by 50 percent, from roughly seven percent to 14 percent, by 2011. [121]

Busway Network

As part of the integrated transport plan, the city of Brisbane envisioned a series of busways that would separate bus routes from mixed traffic. The South East Busway was the first section of the network and opened in 2000.[122] Other sections of busway are beginning to open, including the Inner Northern and Eastern sections.

The network is an open architecture design, enabling both trunk services and local buses to use the dedicated guideway. The South East Busway is the most heavily used route, serving 130 different bus routes, including a dedicated trunk service. It has eight stations and two terminal stations, which include raised walkways and bicycle parking.

Currently the South East Busway is operating close to capacity and many destinations have a high mode share for public transport.[123] For example, sporting events at the Woolongabba stadium have seen 60 percent of spectators use the Busway, up from 10 percent before the Busway was built.[124]

Figure 21: Brisbane Busway Map. Source: Translink

There has been little comprehensive study on the environmental impacts of the South East Busway in Brisbane. However, a study conducted in 2007 and 2008 determined that buses at half capacity emitted a quarter of the CO_2 emissions per passenger than a similar trip along the adjacent freeway. Since many buses operate near capacity during peak hours, this is likely a conservative estimate of the emissions reductions related to the Busway.[125] A survey of riders found that almost 40 percent of riders are "choice riders" who previously made the same trip by car.[126]

[121] Integrated Transport Plan, P. x
[122] "TransLink Transit Authority Annual Report 2009-10." TransLink. Queensland Government. September 13th, 2010. P. 46
[123] Bitzios, Damian and Nicole Dennis and Stein Grodum. "Measuring Benefits of the South East Busway: Towards a New Approach for Valuing Public Transportation Projects." ATRF 2009 National Conference. P.1
[124] Rathwell, Sean and Stephen Schijns. "Ottawa and Brisbane: Comparing a Mature Busway System with Its State-of-the-Art Progeny." Journal of Public Transportation, Vol. 5, No.2, 2002. Pgs. 163-182. P. 178
[125] Bitzios, P. 9
[126] Bitzios, P. 9

In fiscal year 2009-2010, the busiest section of the South East Busway carried 18,000 passengers per direction at peak hours, which is roughly equivalent to 7.5 lanes of highway traffic.[127] This is an increase from 2004 when the Busway only carried 15,000 passengers per direction at peak hours.[128] The Busway has also achieved significant travel time savings. In 2003, it was estimated that a trip from Eight Miles Plains, the southern terminus, to downtown took an hour by car but only 18 minutes via the South East Busway.[129]

A major success of the busway network has been integration of public transport and land use, with examples of existing and planned transit-oriented development (TOD) at several busway stations. This includes green field developments and urban in-fill.[130]

Figure 22: Mater Hill Hospital and Busway Station. Photo: Breakthrough Technologies Institute.

At the Mater Hill Station, the TransLink sold the air rights over the station to the Mater Hill Hospital, which then built a multi-story structure linking existing buildings on either side of the Busway. The link includes surgical wings, and the operating theaters are directly above the Busway.[131]

The northern terminus of the South East Busway is located at the Myer Center, a shopping center in downtown Brisbane on a pedestrian-only street, the Queen Street Mall. The Myer Center has become the favorite shopping center for Busway users.[132]

At Eight Mile Plains, the southern terminus of the South East Busway, a master-planned community was under construction in 2008 directly across from the station. Brochures for the community advertise, "what could be smarter than a lifestyle where fast, efficient public transport is so close…?" [133]

The South East Busway is also seeing in-fill development around urban stations. Woolloongabba was once a thriving neighborhood, with a cricket stadium. In the 1970s, a new highway routed activity away from the neighborhood.[134] In 2000, the cricket stadium was renovated for the Olympics, and the Woolloongabba station was constructed, in part to serve the Olympic venue. The area is experience a renaissance, including construction of "Gabba Central," a

[127] TransLink Annual Report, P. 58
[128] Currie, P. 7
[129] Currie, P. 12
[130] Vincent, William and Lisa Callaghan Jerram. "Bus Rapid Transit and Transit Oriented Development: Case Studies on Transit Oriented Development Around Bus Rapid Transit Systems in North America and Australia." April 2008. P.14
[131] Vincent, P.18
[132] Vincent, P. 18
[133] Vincent, P. 21
[134] Vincent, P. 19

mixed use community across the street from the bus station. Similarly, at the Buranda station, a developer has purchased several square blocks of older homes and is planning a redevelopment of residential, commercial and retail spaces. The proposal includes buildings as high as 30 stories, significantly increasing density in the station area.[135]

Finally, the Busway has had positive effects on property values. Suburbs with busway service experienced increases in value 15 percent greater than suburbs without Busway service.[136] Additionally, properties within six miles of stations along the South East Busway saw their property values grow two to three times faster than properties farther away from Busway stations.[137]

[135] Vincent, P. 22

[136] The Mission Group. UC Davis Extension Course on Improving Public Transportation. Part 6: Putting It All Together - - Case Studies. Sacramento, California. March 8, 2006. http://www.missiongrouponline.com/sitebuildercontent/sitebuilderfiles/improvingpt6.pdf

[137] Currie, P. 12

Transjakarta

Jakarta is the capital of Indonesia, located on the northwest coast of the island of Java. The population of the city center is nearly 10 million and has one of the highest population densities in the world. The greater Jakarta metropolitan area has a population of roughly 28 million.

Prior to the creation of TransJakarta, the city was experiencing growing congestion on roadways that affected both mixed traffic and public transport vehicles. Between 1990 and 2000 bus ridership doubled, yet modal split was declining due to the growth in use of private vehicles.[138] Over the same period the number of buses increased approximately 20 percent, while private vehicles increased 300 percent and motorcycles increased 400 percent.[139]

Jakarta has around nine million private vehicles, roughly 70 percent of which are motorcycles. Traffic congestion costs the city nearly $1.5 billion per year, not including the cost of health impacts from air pollution.

Jakarta, Indonesia

Demographic Information

- City Population: 9,580,000
- Land Area: 285.8 sq. miles
- Number of Private Auto: 11,362,396
- Percent Use Mass Transit: 12.5%

System Characteristics

- System Name: TransJakarta
- Date Implemented: 2004
- Number of Lines: 10
- System Length: 172 km
- Number of Stations: 181
- Cost: Phase I – 2 million USD/km

Key Benefits

- Travel Time Savings: 1 hour during peak
- Estimated CO_2 emission reductions: Corridors 11-13 could reduce 20,000 tCO_{2eq}

System Background

The TransJakarta BRT master plan calls for 15 corridors to be built in six phases. Preliminary planning began in 2001, followed by site visits to Bogotá in 2003. The first corridor opened in January 2004 and is 12.9 km long and runs through the city center. It is a closed trunk system, without feeder buses.

By 2005 the first corridor carried 65,000 passengers per day.[140] During peak, the corridor carried about 2,300-2,500 passengers per direction.[141] Roughly 14 percent of riders previously used a private car, five percent used taxis, and six percent used motorcycles,[142] accounting for roughly 16,250 daily trips.

Ridership on Corridor 1 is significantly lower than comparable BRT systems, especially considering the population of the city. One of the main reasons for this is the design of the vehicle. TransJakarta uses 12-meter, high floor buses that have just one door for boarding and alighting (Figure 23). This design

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[138]Making TransJakarta a World Class BRT System." Final Recommendations of The Institute for Transportation and Development Policy for the Livable Communities Initiative. Institute for Transportation and Development Policy and USAID. June 30, 2005 P. 23

[139] ITDP, P. 23

[140] ITDP, P.4

[141] ITDP, P. 4

[142] Hook, W. and J. Ernst. "Bus Rapid Transit in Jakarta, Indonesia: Successes and 'Lessons Learned'". Institute for Transportation and Development Policy. 2005. P. 8

has contributed substantially to delays and overcrowding on the system, because all passengers are funneled through the single door. TransJakarta has been working to address this problem, but single door buses still persist on the system, especially in the earliest corridors. The system is beginning to purchase higher capacity, articulated buses and as of 2010 operated 385 standard buses and 23 articulated buses.[143]

Figure 23: TransJakarta 12-meter bus with single door. Photo: Breakthrough Technologies Institute

Another reason for the relatively poor performance of Corridor 1 was the lack of a passing lane at stations. A delay suffered by any one vehicle causes all other vehicles to back up behind it. Moreover, it is not possible to provide express or skip stop operations in the corridor.

Corridors 2 and 3 were opened in April 2006, with four more corridors opening by April 2007. A 2007 survey found that more than 18 percent of TransJakarta passengers previously made the same trip by private vehicle.

Corridor 3 was the first to include passing lanes, and buses operating in Corridor 4 and beyond have multiple door boarding. By 2008, TransJakarta was the longest BRT system in the world and was carrying just over 200,000 ppd. This is far fewer than other major BRT systems, such as TransMilenio, which carries roughly 1.4 million trips per day. As of 2011, TransJakarta operated in 10 corridors. Corridors 1 and 9 are the most heavily used, carrying roughly 83,000 and 43,000 passengers per day, respectively.

TransJakarta continues to face relatively low ridership, primarily due to the ongoing use of single floor buses and a number of operational issues. These issues include long wait times for passengers at stations, insufficient vehicle frequencies, no passenger information systems, and the poor physical condition of many stations. For example, contractual disputes have limited the number of vehicles operating in certain corridors. At the same time, Pertamina, the state-owned oil and gas company, operates only three refueling stations for TransJakarta vehicles, and operators can wait up to three hours to be refueled. Except for Corridor 1, most vehicles are CNG and have a relatively limited range of around 100 km, resulting in frequent refueling trips.

TransJakarta also lacks an operational control center and intersections are not well-designed to accommodate the service. Vehicles are prone to bunching and can spend up to 30 percent of their service time in some corridors stopped at intersections. Vehicle over-crowding is a major problem on the system.

[143] Antell, David and Owen Podger. "Final Mid-term Evaluation Report on UNEP/GEF project GF/4010-07-01 (4960) Bus Rapid Transity and Pedestrian Improvements in Jakarta." United Nations Environmental Program. August 2010. P.6

In 2010, there were three different fare collection systems across the system.[144] This is due to complications with the initial fare collection system, and subsequent efforts to fix it. Efforts are under way to move to a smart card system that can support distance based fares, and different fare structures for time of day and type of rider.

TransJakarta normally operates 17 hours per day, from 5 a.m. to 10 p.m. In 2011, service hours were being extended to 11 p.m. in a number of corridors.

Environmental Benefits

There have been relatively few studies of the environmental benefits of TransJakarta. It has been estimated that TransJakarta reduced CO_2 emissions by 37,000 tons in 2009, or the equivalent of removing 6,800 cars from the road.[145] It has been estimated that Phase V, which includes corridors 11 – 13, could reduce carbon emissions by 20,000 tCO_{2eq}.[146]

In Corridor 1, mode shift reduced NO_x emissions nearly 212 kg/day and PM_{10} emissions nearly 31 kg/day.[147] Corridors 2 and 3 used CNG buses instead of diesel, which has been estimated to reduce particulate matter by 8 kg per day, or 2.5 tons per year, and to reduce carbon monoxide by 14 kg per day, or 4 tons per year.[148]

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[144] Antell, P.22

[145] http://www.itdp.org/index.php/our_work/detail/jakarta/

[146] Bordoloi, Amrita and Stefan Bakker. "CDM Viability of CURB-AIR Cases: Four Asian Projects Evaluated." January 2008. P.19

[147] Ernst, J.P.. "Initiating Bus Rapid Transit in Jakarta, Indonesia. Transportation Research Record. 1903; 20-26. 2005. As cited in Nugroho, S.B. and A. Fujiwara and Junyi Zhang. "The Influence of BRT on the Ambient PM10 Concentration at Roadside Sites of TransJakarta Corridors." Procedia Environmnetal Sciences 2. Pgs. 914-924. 2010. P. 915.

[148] Hook, Walter, Indonesia and India Livable Cities Project and Prioritizing Low and Zero Emission Vehicles for Africa, Power Point presentation. 2006.

Chongqing, China

Chongqing is a major city located in southwest China, with a population of more than 5 million. The city lies within the larger Chongqing "municipality," a province roughly the size of the Czech Republic. The urban area is located at the confluence of two rivers and is surrounded by low mountains.

Chongqing, China

Demographic Information

- City Population: 5,400,000
- Land Area: 280 sq. miles
- Number of Private Autos: 1 million
- Percent Use Mass Transit: Unavailable

System Characteristics

- System Name: Chongqing BRT
- Date Implemented: 2008
- Number of Lines: 1 (four are planned in total)
- System Length: 91.3 km
- Number of Stations: Line 1 – 7, Line 2 – 10, Line 3 – 12, Line 4 – 25
- Cost to Build: 0.7 million USD/km (infrastructure) 1.1 million USD/km (including buses and operation investment)

Key Benefits

- Travel Time Savings: none
- Estimated Future CO_2 Emission Reductions: data deemed not reliable

System Background

The Chongqing BRT is managed by the Chongqing Bus Rapid Transit Development Corporation Ltd., which is part of the municipal government of Chongqing. A pilot corridor opened in 2008 and continues to be the only operating corridor. A total of four corridors are planned, with 81 km of dedicated bus lanes. The pilot corridor is 11.5 kilometers long, but only six km is in a dedicated lane. The remaining 5.5 km operates in mixed traffic.

Currently, the Chongqing BRT uses a fleet of 10, 12-meter, Euro III CNG buses, which are configured like intercity motor coaches, rather than urban transit buses. In the future, the system plans to use 18-meter articulated buses. The service currently is trunk-only, and fares are collected at the entrance of the station through magnetic ticketing and turnstiles.

Figure 24: Chongqing BRT. Photo: ITDP.

The performance of the Chongqing BRT has been quite poor, especially in light of the relatively large population in the urban area. Total daily ridership has been estimated at just 12,000 trips, and the passengers per hour, per direction peak capacity has been estimated at just 600. In March 2009, an informal survey was conducted, and only four buses per hour, per direction were observed during peak.[149] The system is reported to provide no travel time savings for bus passengers in the corridor.

[149] Conversation with Karl Fjellstrom, ITDP.

Environmental Benefits

The environmental benefits of the Chongqing BRT are likely very low, because of the low reported ridership of the pilot line. However, the first four lines of the system have been registered as a CDM project. According to the CDM project design document, all four lines should have been operational in 2010, and the estimated CO_2 reductions associated with the project were built upon this assumption.

Table 15 provides the estimated CO_2 reductions for the completed system. However, because only one line has been built, and this line is experiencing relatively low ridership, these estimates do not appear to be realistic and thus should be deemed unreliable.

Table 15: Estimated Emission Reductions from the Chongqing BRT[150]

Years	Estimated Emission Reductions (tCO_{2eq})
2009 (6 months)	69,054
2010	211,656
2011	239,439
2012	252,185
2013	265,538
2014	279,452
2015	294,133
2016 (6 months)	154,685
Total	1,766,142

[150] Grütter, Jürg. Clean Development Mechanism Project Design Document. "BRT Chongqing Lines 1-4, China." Version 3.3. February 10, 2010. P. 8

Appendix I. Guangzhou Methodology

Over the last several years ITDP has been collecting data on the transport activity on Zhongshan Avenue – traffic counts, speed surveys, passenger questionnaires, ridership statistics, bus operations statistics, etc. – during the period both before and after the BRT was implemented. An “Ad Hoc” methodology was developed that is comparable to the UNFCCC’s CDM AM0031 methodology for calculating the GHG impacts of BRT systems. This methodology calculates the impacts separately and then sums them together to find the total GHG impact, in accordance with the following formula:[151]

$$E_{\text{modal shift}} + E_{\text{reduced transit VKT}} + E_{\text{improved transit speed}} + E_{\text{mixed traffic speed}} = I_{BRT}$$

I_{BRT} = Cumulative Yearly Emissions Impact of Implementation of Guangzhou BRT

E_x = Emissions Avoided Annually, by Source X

One critical data point in these calculations has been the selection and calibration of vehicle emission factors from the available body research, since large-scale fleet surveying, modeling, and in-field fuel economy testing was beyond the scope of this study. All emissions factors used in the study were selected from the regionally specific studies or from the International Vehicle Emissions model.

To calculate the emissions impact of the Guangzhou BRT, empirical data from 2009 (pre-BRT) was compared with data from 2010 (post-BRT) to find the observed CO_2 impact in 2010. In order to estimate the long-term impact of the BRT over its first ten years of operation, the City of Guangzhou’s projections on vehicle speed and modal share were applied to the observed impacts in 2010.

Calculating Emissions Impact of Motor Trips Avoided by BRT

The emissions avoided when a traveler takes the BRT instead of taking a car, taxi, or the metro are calculated by finding the amount of vehicle kilometers traveled (VKT) avoided for each mode and multiplying that by the appropriate emissions factor. To find the amount of VKT of various motorized modes, ITDP conducted a large-sample survey[152] that asked BRT riders “What transport mode would you have used to make this trip a year ago, before the BRT was in place?”

The “previous mode” data showed that 81 percent of BRT riders rode the bus previously and 19 percent switched from another mode. This figure corresponds relatively well to rough BRT operator estimates that bus ridership increased in the corridor by 18 percent. The mode share from pre-BRT trip mode was applied to ridership totals and used in conjunction with average trip length, occupancy, and emission factors for cars, taxis, and the metro.

It should be noted that the BRT trips that were shifted from other modes still have emissions associated with their BRT trip. However, all BRT emissions are accounted for in the “BRT Operations” emission calculation – this step only focuses on calculating the emissions avoided from other motorized trips, so

[151] Note: The impacts of bus speed on fuel efficiency and changes in bus VKT are necessarily combined, as both an emissions factor and travel activity are needed to calculate CO_2 emissions

[152] Randomly administered BRT passenger surveys were carried out in September, 2010 and January, 2011. Cumulative sample size: 707.

BRT trips and non-motorized trips are not included in the below equation.

$$[\sum M_{car,\ taxi,\ metro}\ (R_{2010})\ (S_M)(D_M)\ (E_M)] = I_{mode\ shift}$$

I = Cumulative Yearly Emissions Avoided from Other Modes in tonnes of emissions

M = Mode used before BRT implementation: car, taxi, metro

R = Yearly cumulative ridership for bus routes included in BRT corridor

S = Modal Shift for mode (M)

D = Average Travel Distance for mode (M)

E = Emissions Factor for mode (M)

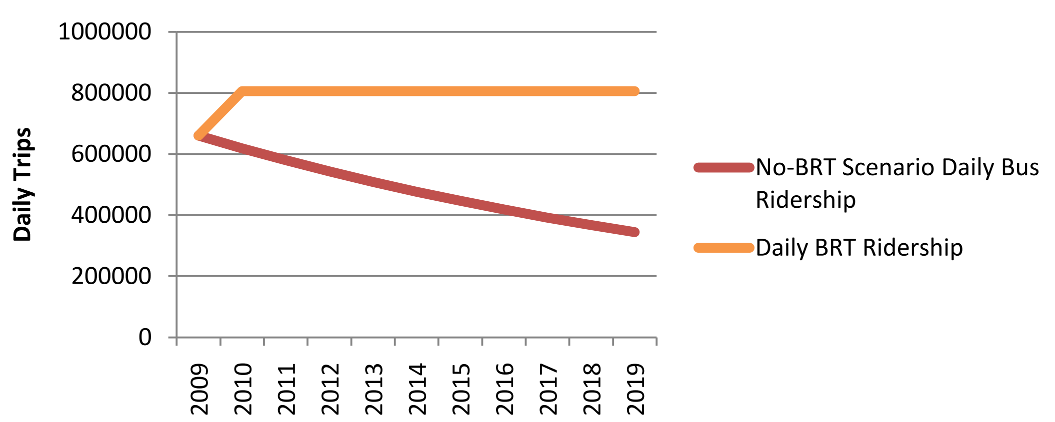
Emissions factors for cars were obtained from a study of Chinese passenger cars average emission factors.[153] Emissions factors for LPG taxis were taken from a study prepared for a CDM application in Pune, India.[154] The data points are given in the table below.

Figure A1: Data for Modal Shift Emissions Impact Calculation			
Daily Boardings	**805,000**		
Average BRT Trip Distance	**8.3**		
	Avg. Private Auto	**LPG Toyota Taxi**	**Metro (per-pax-km)**
Average Load Factor	1.6	1.5	1.0
Days of Operation	365	365	365
Co2 Emfac (g co2/km)	192.00	140.00	11.80
PM Emfac (g PM/km)	0.05	0.00	0.00
CO Emfac (g CO/km)	1.99	4.90	0.00
NOx Emfac (g NOx/km)	1.38	0.42	0.00
SO2 Emfac (g SO2/km)	0.03	0.02	0.00
% of BRT Trips avoided from Mode	1.40%	3.00%	10.60%
Avoided Trips in Base Year	2,570,969	5,876,500	31,145,450
Yearly VKT Avoided	21,339,041	48,774,950	258,507,235

[153] Oliver et al., Harvard University, 2010.
[154] ARAI, 2007.

Survey results showed that a relatively small portion of BRT riders had shifted from other motorized modes: only 1.4 percent of BRT riders switched from private auto, three percent from taxi, and 11 percent from metro. Despite small shares of overall BRT ridership coming from motorized modes, this still equates to 30,000 auto trips are avoided daily for a total of 90 million VKT avoided in 2010 due to the BRT.

Figure A2: Projected BRT Ridership Baseline & BRT Scenario 2009-2019



In order to project the emissions impact of modal shift over the period of 2010-2019, data on expected bus mode share in 2015 from the City of Guangzhou, which projected a yearly decrease of 6.3 percent in bus ridership for the "no-project" baseline scenario.[155] Though development along the corridor is increasing rapidly, there was no strong data on the rate of growth in demand for the new BRT service, so this calculation conservatively assumed that bus ridership in the BRT scenario would hold steady at 2010 levels, instead of declining sharply as in the "no-project" baseline scenario.

Calculating the CO_2 Impact of Changes in Bus Speed & VKT from BRT Operations

While the previous formula calculates the emissions avoided when passengers switch to the BRT, the following formula finds the emissions emitted by the BRT, inclusive of any changes in ridership from modal switch, speed/fuel economy, and VKT. The emissions impact of changes in average bus operating speed and yearly VKT due route rationalizations are calculated together because in order to find the operating emissions of the BRT system, the VKT of the BRT and the speed-adjusted emissions factor of the BRT must be applied to each other in order to produce an emissions estimate. The formula below finds emissions impact of BRT operations, including changes in VKT due to route rationalization and changes in fuel efficiency due to operating characteristics. The formula subtracts total yearly BRT emissions from yearly emissions without the BRT in place, in order to find the total emissions impact from BRT operations. Yearly bus emissions are found by multiplying a speed-adjusted emissions factor by the total VKT for the year.

[155] Based on 2010-2015 Modal Shift Projections of *City of Guangzhou's 12th 5-Year Plan*.

$$[(E_{BRT} * T_{BRT}) - (E_{No\ BRT} * T_{No\ BRT})] = I_{operations}$$

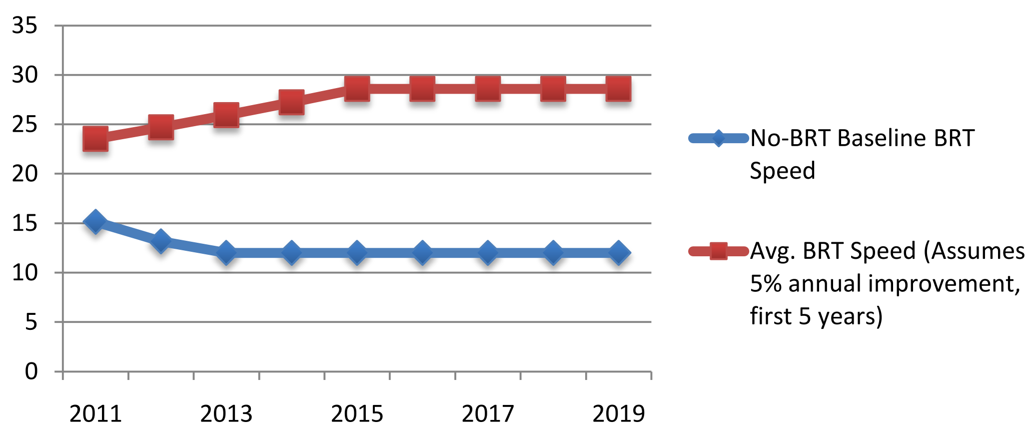
$I_{operations}$ = *Cumulative Yearly Emissions Impact from changes in Bus Operations*

E = Emissions Factor for Buses given year, including changes from average speed

T = Cumulative Vehicle Kilometers Traveled for all buses in BRT corridor in a given year.

There is limited research and reporting on the fuel economy and emission factors of LPG buses. Several sources on the fuel economy of an LPG bus were evaluated in-depth, including fleet-wide figures given to ITDP by the GZ BRT authority, which were considered to be unreliable. In the end, the running emission factors for the range of LPG buses within the IVE database were averaged. The average running emission factor of a loaded LPG bus (532 g/km of CO_2) was then calibrated for pre-BRT (830 g/km) and post-BRT (770 g/km) in 2010 average operating speeds using a speed-to-fuel-economy curve from the COPERT emissions model. As discussed earlier, the average operating speed of Zhongshan buses has gone up 29 percent, creating a fuel efficiency gain of about six percent.

Figure A3: Assumed Speed Changes for BRT & No-BRT Baseline



To calculate the emissions impact from changes in BRT operations for 2010-2019, two assumptions were made. First, the BRT improves its speed five percent per year for the first five years (reaching 28.5 km/h). Second, the comparative no-BRT scenario sees BRT speeds dropping from its pre-BRT speed of 17.5 km/h by 13 percent per year (as reported by the Guangzhou Institute of Transportation Planning) until it reaches 12.5 km/h in 2013, and bottoming out at that level through 2019. Note that there is no significant reduction in particulate matter or sulfur dioxide from BRT operations as the buses in Guangzhou are powered by LPG, which emits almost no particulate matter when combusted.

Calculating the CO_2 Impact of Changes in Mixed Traffic Speed in the Corridor

The completion of the GZ-BRT corridor removed hundreds of buses from Zhongshan Avenue's mixed traffic lanes and concentrated them in just two center lanes, leaving three lanes clear of buses for mixed traffic. The last formula of this methodology calculates emissions impact of increases in speed for the mixed traffic speeds on Zhongshan Avenue, which operate with higher fuel efficiency.

In order to calculate this impact, the number of trips made on the corridor by each basic vehicle class is estimated from ITDP traffic counts and multiplied by the average trip distance in the corridor to get the VKT of each vehicle class. Next, average running emission factors from the IVE database are calibrated for observed pre-BRT and post-BRT operating speeds on Zhongshan Avenue and applied to the VKT estimates to create pre-BRT and post-BRT mixed traffic emissions estimations. Pre-BRT mixed traffic emissions are subtracted from post-BRT mixed traffic emissions to find the annual emissions impact from speed increases in mixed traffic.

$$\sum V_{\text{vehicle class}} [(T)\,(D)\,(F_{\text{pre-BRT}} - E_{\text{post-BRT}})] = I_{\text{mixed traffic}}$$

I = Cumulative Yearly Emissions Avoided from Other Modes in tonnes of emissions

T = Total Trips Estimated from Screen Line Traffic Counts

V = Vehicles Classes: Car, Truck, Taxi, Coach Bus

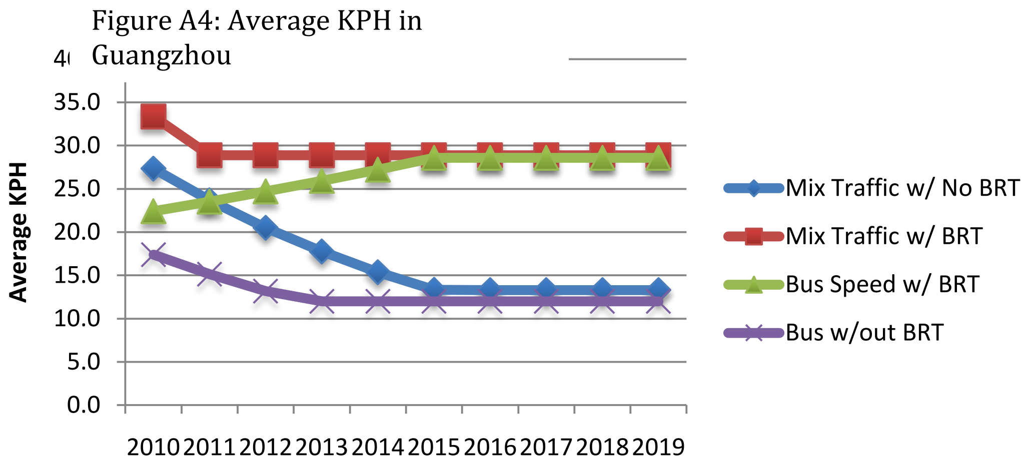
D = Average Travel Distance in Corridor

E = Emissions Factor for a given year including changes from average speed

Comprehensive corridor counts were not possible in a corridor the size of Zhongshan Avenue so total corridor trip estimates were made based on screen line counts and average trip lengths. Daily average mixed traffic speeds increased from 26 kph to 33.5 kph from before the BRT to after it.

The estimation of the emissions impact on mixed traffic from 2010-2019, is based on several projections. First, that in mixed traffic in the corridor will decline over time at the same rate observed before the BRT was implemented[156] until it reaches the speed of the BRT (28 kph) because if the speed decreased further travelers would switch modes to the BRT for a faster journey. Second, that mixed traffic in the No-BRT baseline scenario would also continue to decline at the observed rate until bottoming out at 15 kph in 2015. Without a BRT on the corridor, mixed traffic would stay subject to large decreases in average speed and associated fuel efficiency over time, thus large emissions impacts are realized near the end of the decade.

[156] Travel speed declined on trunk road is -13% per year, as measured by GMEDRI, 2008-2009.



Leakage Factors

Using the Construction Emissions Function of the TEEMP BRT emissions calculation tool, 24,000 tons of CO_2 were released from project construction emissions, based on general assumptions for cement, bitumen, and steel needed for BRT constructions. Leakage from the "Rebound Effect" on mixed traffic speeds is accounted for in mixed traffic speed projections. Leakage from the construction of new transit vehicles or the re-use of old transit vehicles is not relevant as this study claims no emissions impact for vehicle technology upgrades.

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