

The Electric Rail Dilemma

Clean Transportation from Dirty Electricity?

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EXECUTIVE SUMMARY

Poor air quality continues to plague many communities. Much of this pollution is attributable to the transportation sector.

Enhancing mass transit capacity is regarded as one of the best strategies to reduce the pollution impact of transportation. But which technology will provide the greatest benefits?

It is commonly assumed that electric trains carry the greatest potential to reduce air pollution. After all, electric trains move large numbers of people and have no exhaust pipes.

This assumption, however, usually is made without accounting for the source of the electricity that powers the train. And more than half of the nation's electricity is derived from coal, making coal-fired generation one of the leading sources of air pollution in the United States. When power plant emissions are counted, most of the assumed air quality benefits of rail vanish.

Moreover, planners and air quality regulators appear to be ignoring the environmental impact of electricity generation in evaluating transit projects, creating the false impression that electric rail projects do not contribute to regional pollution problems.

It is important to note that this report merely provides a snapshot of emissions related to transit propulsion power. It is not a justification to cut funding for existing or planned transit systems. In fact, we found that transit can be significantly less polluting than driving, suggesting that we should increase funding for transit.

We do believe that transit and air quality planners ought to take the relative emission benefit into account in evaluating local transit options.

We believe that for most local transit systems today, Bus Rapid Transit (BRT), which operates like a rail system but utilizes advanced buses, is a better choice, environmentally and economically, and thus deserves serious consideration in any transit planning process.

Electric rail becomes a more attractive environmental option in areas with clean electricity generation or in areas where transit operators have the option of buying "green" or renewable power. BRT will have access to truly zero emission propulsion systems powered by fuel cell technology in coming decades.

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Methodology

This study takes an objective look at the air pollution impacts from three modes of transit: electric heavy rail, electric light rail, and bus rapid transit (BRT). It relies exclusively on publicly available data.¹

The report examines emissions associated with the energy required to propel the transit vehicle. The report then translates the emissions into grams per passenger mile, enabling an easy comparison among modes. It does not examine emissions associated with other components of a transit system, such as stations and parking lots.²

Limiting the analysis to propulsion power is important for several reasons.

- It provides an apples-to-apples comparison of emissions directly attributable to different transit technologies.
- Power plant emissions data are available from state and regional agencies of government, enabling transit planners to conduct an accurate analysis on their own, if they choose.
- Propulsion power emissions are directly related to the fundamental purpose of building transit in the first place – moving people.

Conclusions

Based upon our focused analysis, we reached the following conclusions.

- While all three mass transit options provided an environmental benefit compared to private passenger cars, the benefit was often small for rail systems. For example, CO₂ emissions were potentially higher for rail and there are other emissions not attributable to gasoline powered automobiles, such as mercury and sulfur dioxide.
- Even using a conventional bus driving cycle with relatively ‘old’ bus technologies, a well-designed BRT system can emit substantially less pollution than either a light or heavy rail system, on a per passenger mile basis.

¹ The data was derived from a variety of sources, including the Environmental Protection Agency (EPA), utility industry filings, the Federal Transit Administration (FTA), the Washington Metropolitan Area Transit Authority (WMATA), and the American Public Transportation Association (APTA).

² We did evaluate a “parking penalty” to recognize that, where a transit system is built with significant parking instead of compact, transit-oriented development, the transit system may induce passengers to drive their cars to transit stations, instead of walking, biking, or taking other forms of transit. Our analysis is included in an appendix.

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- BRT systems powered by low emission bus technology offer the greatest reduction, by far, in carbon dioxide emissions per passenger mile.
- This does not mean that electric rail is inherently dirty. Rather, it suggests that we must take a harder look at where the electricity is generated to power electric rail systems.
- Buses have a bad public image in part because of their high polluting diesel engines. Now, however, new technologies are significantly reducing vehicle pollution. In the near future, hydrogen powered vehicles may reduce tail pipe emissions to zero.

Recommendations

- To maximize the benefits of existing electric rail systems, we need a stronger commitment to cleaner sources of electric power. Otherwise, we are doing little more than trading tailpipes for smokestacks.
- Transit agencies should seek to purchase renewable power wherever that option is available.
- To ensure that existing rail systems are as efficient as possible, we need to adopt transit supportive land use policies that place high density, mixed use development around transit stations. Currently, many trains operating in the non-peak direction are nearly empty. This increases the per passenger emissions of rail systems, because trains are running without an adequate passenger load.
- All new transit projects should begin with an objective analysis of the relative environmental benefits of competing technologies.
- We must develop a better way to compare transit technologies. It makes no sense to consider the environmental impacts of rubber-tired vehicles, yet completely ignore the environmental impacts of steel-wheeled vehicles. This is particularly true given that BRT technology offers the performance of rail, yet at a fraction of the cost.
- In its current review of federal transit policy, Congress should close the loophole that allows transit planners to ignore the emissions impact of their systems in evaluating overall costs and benefits.

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Tables

Transit Mode Emissions (grams per passenger mile)³

	Metrorail PJM & Dominion	Metrorail DC Regional	Light Rail PJM & Dominion	Light Rail DC Regional	BRT High Loading Low NOx	BRT High Loading Low CO2	BRT Low Loading Low NOx	BRT Low Loading Low CO2	Private Vehicles DC Regional
NOx	.4173	0.7756	.3910	.6123	.3708	.558	.6124	.922	1.15
SO2	1.352	2.182	1.036	1.728	--	--	--	--	--
CO2	177.85	359.24	154.54	284.66	106.46	79.84	175.82	131.8	248.01
Mercury	.00000544	.00000446	.00000429	.00000354	--	--	--	--	--
PM10	.027	.02921	.0214	.0232	--	--	--	--	--
PM2.5	.0144	.01859	.0114	.01473	.000765	.000956	.00126	.0016	--
VOC	.006314	.011358	.00499	.0898	--	--	--	--	.619
CO	.0338	.00448	.0268	.0355	.4128	.000612	.6818	.001	--

The following charts show the results broken down by oxides of nitrogen (NOx), carbon dioxide (CO2), and fine particulate matter. For comparison, we also included NOx and CO2 emissions attributable to a passenger car.

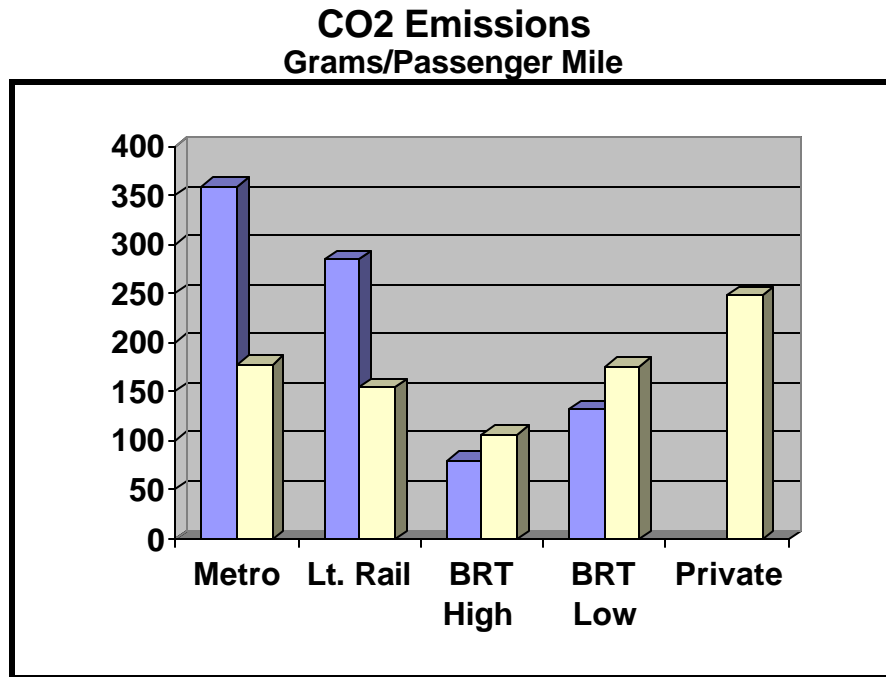
We did not include charts for the other pollutants (SO2, Mercury, PM10, and hydrocarbons [VOC's]) because we were unable to locate data establishing these pollutants for BRT. We also did not include a chart for CO because there was an extremely wide range of CO results for the vehicles tested. For example, one CNG vehicle had CO results that were nearly 800 times higher than the CO results for one low sulfur diesel bus. Thus, the level of CO would depend heavily on the vehicle technology selected.

³ The following define the terms used in the table and throughout the report:

- *PJM and Dominion:* A scenario whereby the rail system analyzed purchases its power from a broad, multistate energy market with a wide mix of fuels used to generate the electricity.
- *DC Regional:* A scenario whereby the rail system analyzed purchases its power from a mix of power plants equivalent to the power plants that currently exist in the Washington, DC metropolitan region. For private vehicles, the term refers to the mix of vehicles and driving patterns in the Washington DC region.
- *High Loading:* A scenario whereby the BRT vehicle has passenger loadings equivalent to a light rail system. *Low Loading:* A scenario whereby the BRT vehicle has passenger loadings equivalent to a conventional city bus system. As with the high loading scenario, we selected two vehicles to display.
- *Low NOx and Low CO2:* Although we examined test results from a number of buses, we chose to display results from only two vehicles: one with the lowest NOx emissions and one with the lowest CO2 emissions. We felt this was appropriate because, in choosing vehicle technologies, transit agencies can consider the emissions for particular pollutants and make purchase decisions accordingly.

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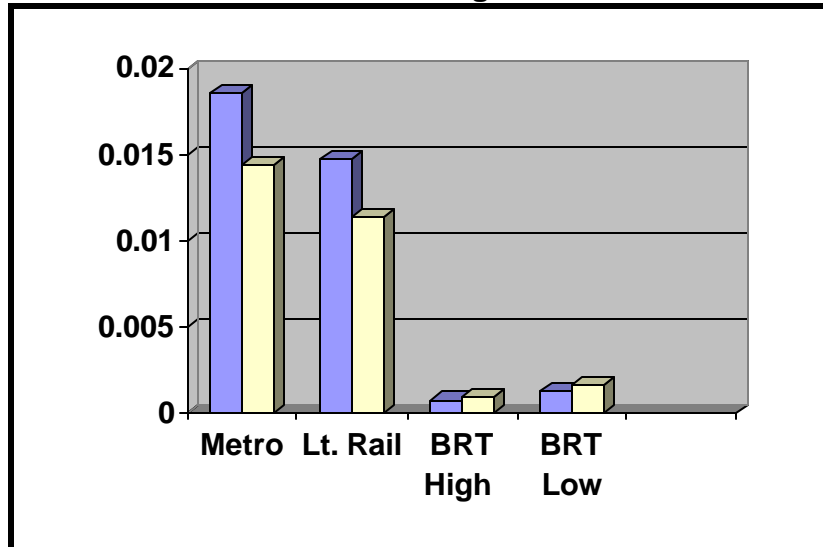
As shown by this table, BRT generally performs significantly better than either heavy rail or light rail on CO2 emissions. CO2 is a leading greenhouse gas and contributes to global warming.

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PM2.5 Emissions

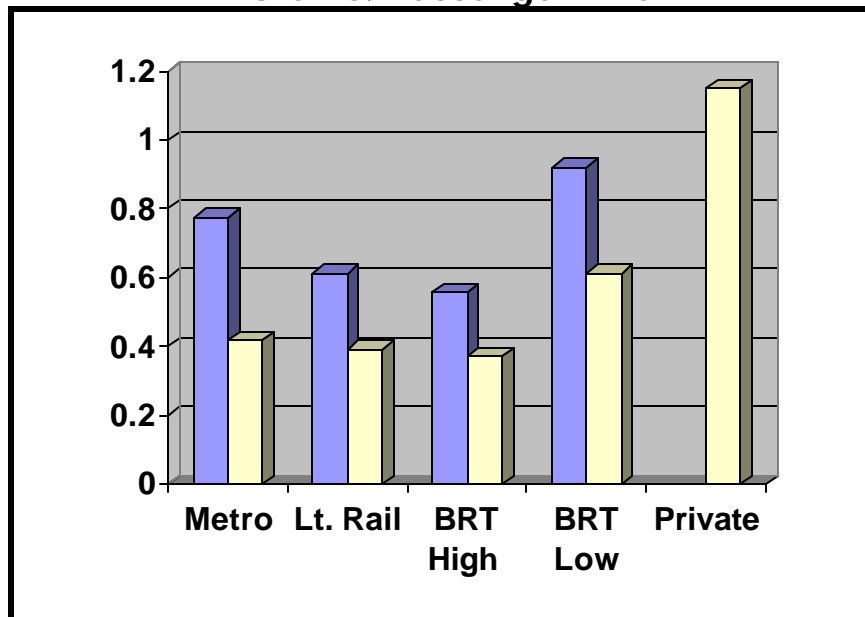
Grams/Passenger Mile



As shown by this table, BRT generally performed better than rail on small particulate matter. These tiny particles can lodge deeply in the lungs and cause a variety of health problems, including lung cancer.

NOx Emissions

Grams/Passenger Mile



Here, rail performed a little better than it did with other pollutants we analyzed. Nevertheless, it appears that BRT can be very competitive with rail on NOx emissions. Both BRT and rail perform significantly better than private vehicles on NOx. NOx is a necessary precursor to ozone smog.

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1. Introduction

Congestion and air quality are major concerns in most US cities. Building new transit capacity is one of the best strategies to address these concerns.

Communities seeking new transit capacity are faced with many choices. Selecting the best transit system is not easy and requires careful consideration of the costs and benefits of competing technologies.

Supporters of various transit technologies often tout their system's ability to improve air quality. For example, in their application justifying federal funding for a \$4 billion extension of Washington DC's Metrorail, Congressional requesters list "air quality enhancement" as the first reason to support the project.⁴ Similarly, the American Public Transportation Association (APTA) issued a report concluding, among other things, that the "greatest environmental and economic benefits would be derived from greater use of public transportation, especially rail..."⁵

While supporters of rail investment tout environmental benefits, significant concerns are being raised about emissions from power plants. For example:

- The Clean Air Task Force estimates that 250 deaths per year are caused by pollution from five power plants in the Washington DC region. Roughly one hundred of these deaths are caused by a single plant (Chalk Point in Maryland).⁶
- The State of New York sued Virginia Power to reduce emissions from the Mount Storm coal power plant, because those emissions are causing acid rain in New York.
- The Environmental Protection Agency has identified coal-fired power plants as a significant source of mercury pollution, and legislation has been introduced in Congress to reduce mercury levels in the environment.
- According to the American Lung Association of Virginia, 80 percent of Virginia's coal plants are so old that they are exempt from meeting modern emission standards.⁷ As a result, electricity generation in Virginia creates significant air pollution, causing 17 percent of NOx emissions and 60 percent of sulfur dioxide (SO₂) emissions on a statewide basis.⁸

⁴ Transportation Project Evaluation Criteria, Committee on Transportation and Infrastructure, Subcommittee on Highways and Transit (March 2003).

⁵ Shapiro, Hasset, and Arnold: Conserving Energy and Preserving the Environment: The Role of Public Transportation (July 2002).

⁶ Health Impacts of Air Pollution from Washington DC Area Power plants, Clean Air Task Force (May 2002)

⁷ American Lung Association of Virginia, Electric Generation Principles (January 2003).

⁸ Id.

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The concern over power plant emissions and the claims of electric rail supporters appear to be at odds: how can electric-powered rail systems have substantial air quality benefits when electric power production, particularly production using coal and other fossil fuels, creates so many air quality problems? Electric rail systems, like Metrorail, consume substantial amounts of electricity, and much of this electricity is generated by fossil fuel power plants.

The existence of this apparent contradiction can be explained in a number of ways. Transportation planners claim that emissions from power generation are not required to be included in environmental impact statements of new rail systems.⁹ Thus, little study has been done to document the emissions attributable to rail systems.

Moreover, power plant emissions often are created far from the transit facility, creating the illusion that the system is emission-free.¹⁰ This illusion ignores the health and environmental impacts of the displaced pollution upon the regions receiving the pollution.

This report examines the emissions attributable to both rail and bus rapid transit (BRT), a new transit technology that performs as well as rail yet costs a fraction to build and operate. It looks exclusively at emissions attributable to propulsion power, because data on energy consumption for propulsion was readily available. Information about other sources of pollution were not included.

As an example of heavy rail, this report focuses upon Washington DC's Metrorail, which is held up as a model transit system. It analyzes the sources of electricity for Metrorail and calculates per passenger emissions based upon those sources.

The report next examines the power consumption of a light rail system and measures per passenger emissions based upon the same mix of generating facilities used to power Metrorail. As a model for power consumption and passenger loading, this report uses Salt Lake City's well-regarded TRAX system.

Finally, this report examines the per passenger emissions of BRT.

⁹ For example, In the Draft Environmental Impact Statement (DEIS) to extend Metrorail to Loudoun County, power plant emissions were not considered because, according to staff, EPA rules "do not require" that they be considered (Correspondence from Corey Hill, Northern Virginia Project Manager, Virginia Department of Rail and Public Transportation (April 9, 2003). See also Dulles Corridor Rapid Transit Project Draft Environmental Impact Statement at 4-83 (June 2002)(stating that "potential air quality impacts would occur as a result of motor vehicle traffic associated with the project," not from the project itself.

¹⁰ For example, the APTA report concluded, among other things, that electric rail has significant air quality benefits because emissions are "physically removed from ... highly populated areas."

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About BRT

FTA defines BRT as “a rapid mode of transportation that can combine the quality of rail transit and the flexibility of buses.”

A more detailed definition is that “BRT is a flexible, rubber tired rapid transit mode that combines stations, vehicles, services, running ways, and intelligent transportation system (ITS) elements into an integrated system with a strong positive image and identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings and can be incrementally implemented in a variety of environments.”¹¹

In short, BRT essentially is rubber-tired light rail transit but with greater operating flexibility and lower capital and operating costs. A reading of actual case studies shows that, among other things:

- Where BRT vehicles operate on exclusive rights-of-way, the level of service can be similar to that of full Metro rail rapid transit.
- Where buses operate in combinations of exclusive rights-of-way, median reservations, bus lanes, and street running, the level of service provided is similar to light rail transit.
- Where buses operate mainly on city streets in mixed traffic, the service provided is similar to a tram or streetcar system.¹²

BRT is being promoted by the Federal Transit Administration and others as a cost-effective alternative to rail. BRT systems may include a number of features not associated with traditional bus systems, including:

- dedicated rights of way over some or all of the route;
- low emission, high capacity vehicles;
- station platforms that are even with the floor of the vehicle, enabling easy entry and exit from the vehicle;
- intelligent transportation systems that, among other things, track vehicles enroute and provide passengers with real-time travel information;
- route structures and maps that are similar to rail systems;
- fare collection at the station entrance, instead of on the vehicle;
- signal priority and signal pre-emption systems that enable vehicles to move quickly when operating off of a dedicated right of way; and
- service that is sufficiently frequent that passengers do not need schedules.

¹¹ Transit Cooperative Research Program, Report # A-23

¹² Herbert Levinson, Samuel Zimmerman, Jennifer Clinger, James Gast; Bus Rapid Transit, Synthesis of Case Studies; 2003 Annual Meeting Transportation Research Board.

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2. Heavy Rail – Metrorail

To examine emissions from electric heavy rail, we selected Washington DC's Metrorail as our sample system. Metrorail often is touted as one of the nation's best electric rail systems. At the same time, the Washington metropolitan region has extremely poor air quality, and there are a substantial number of power plants in the region. Finally, there is a vigorous debate within the region regarding whether to extend the Metrorail system or to build a complementary BRT system to address growing air quality and congestion concerns.

We found that the Metrorail system is a significant consumer of electric power, and that this power is derived mainly from fossil fuel power plants. As a result, unless a commitment is made to cleaner sources of energy, heavy rail systems like Metrorail create significant levels of pollution, and this pollution needs to be considered when assessing whether to invest in new heavy rail technology.

2.1. Energy Consumption and Emissions

Calculating the emissions caused by any particular consumer of electricity is difficult. Power producers “pool” their electricity into massive, multi-state energy markets. At any one time, a consumer may purchase electricity from a number of power plants, some of which might be hundreds of miles away.

In the case of Metrorail, the task is even more complicated. The system operates in Maryland, Virginia, and the District of Columbia and thus obtains power from many different sources.¹³ The information available from these jurisdictions varies.

Nevertheless, conversations with Metrorail staff confirmed that power is purchased from the Potomac Electric Power Company (PEPCO), Baltimore Gas & Electric, and Dominion Power.¹⁴ The Maryland and District of Columbia portions of the system purchases power from PJM and PJM West, the largest electricity clearing house in the country, which includes PEPCO and Baltimore Gas & Electric.¹⁵ The Virginia portion of the system purchases power from Dominion Power.

¹³ The Metrorail system covers 103.06 miles and has 83 stations. Based upon track miles, 37.2 percent of the system is located in the District of Columbia, 28.6 percent in Virginia, and 34.2 percent in Maryland.

¹⁴ April 30, 2003 personal communication with Metro Rail Operations Office 202-962-2010

¹⁵ PJM and PJM West include 614 generation sources producing 298,011 gigawatts of electricity annually (www.pjm.org).

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Based upon this information, we created two scenarios. Under the first scenario, we assumed that the electricity to power Metrorail was derived proportionally from all of the power plants in PJM , PJM West, and Dominion. Many of these plants are located hundreds of miles from Washington. Some of these plants emit large amounts of pollution and were the subject of a recent lawsuit settlement alleging that they cause acid rain as far away as upstate New York. We refer to this scenario as “PJM and Dominion.”

Under the second scenario, we assumed that the electricity for Metrorail was derived from power plants located in the Washington region. These power plants are a significant source of regional pollution. We refer to this scenario as “DC Regional.”

Under both scenarios, we used Federal Transit Administration data for electricity consumption. According to this data, Metrorail consumed 401,161,070 kilowatt hours (kWh) to power its trains in 2001.¹⁶ That’s enough electricity to power more than 50,000 average single family homes for a year.¹⁷

We then added an estimate for “line loss” – the power lost through the transmission of electricity. Adding ten percent as a rough estimate of line loss, we estimated that 441.28 million kWh was generated in 2001 to provide propulsion to Metrorail trains.¹⁸ We ignored other significant sources of power consumption, such as stations and escalators, because data on this consumption is not readily available.

We also ignored design features that contribute to total pollution levels attributable to the transit system. For example, poor land use planning around transit stations may encourage driving to the transit station instead of walking or using other forms of transit.¹⁹

¹⁶ Federal Transit Administration, National Transit Database.

¹⁷ Energy Information Administration "Annual Electric Utility Report" (1999) (finding that annual residential kWh consumption in the mid-Atlantic is roughly 7600 kWh). By comparison, the one hundred square miles that make up the District of Columbia and Arlington County, Virginia currently contain roughly 61,000 single family homes. (The Greater Washington Initiative (www.greaterwashington.org) (based upon 2000 census data for single family detached homes)).

¹⁸ One report estimates that line losses, poor power factors and general inefficiencies waste 10% to 15% of the electricity generated, representing a potential loss of up to \$33 billion worth of electricity annually. *Power Quality Equipment and Services Market - A Growing 21st Century Industry (December 2001)*

¹⁹ The Metrorail system currently has 57,000 parking spaces that are filled by commuters every business day. Many of the commuters drive significant distances in heavy traffic to reach the parking space, thus adding significantly to regional congestion and pollution. For informational purposes only, an analysis of this pollution is presented in Appendix E.

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2.1.1. PJM and Dominion Scenario

The PJM energy market has more than 600 generating facilities operating on a wide range of fuel types and at various levels of capacity throughout the year. To determine the emissions from these facilities, we used an annual average within the PJM market.²⁰ Table 1 shows the emission rates associated with PJM's facilities.²¹

Table 1. PJM Energy Market Emission Rates
(lbs per kWh)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
0.0028441	0.010103	1.18389	.0000000410	.000177	.0000985	.000049	.000239

As noted above, Maryland and DC have 71.4 percent of Metrorail's track miles. Therefore, we assumed that 71.4 percent of the total propulsion energy consumption could be attributed to PJM. This amounts to roughly 315,073,920 kWhs.

Using the emission rates in Table 1 and the energy usage described above, we calculated Metrorail's total emissions for the DC and Maryland portions. The results are presented in Table 2.

Table 2. Total Emissions Attributed to DC & MD Metrorail Based Upon PJM
Generation Fuel Mix (lbs)

Nox	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
896,101.74	3,183,191.8	373,012,863.15	12.918	55768.08	31034.78	15438.62	75302.67

²⁰ The mix of generation fuel types is contained in Appendix B. All data was compiled from PJM documents.

²¹ CO2, SO2, NOx emissions were taken from the PJM Regional Average Disclosure Label for 2002, which used data from 2000 (see Appendix B). Mercury (Hg) emissions were taken directly from the US EPA's E-GRID2000 State Data MS-Excel tables (U.S. EPA E-GRID2002 Version 1.0 Released January 2003. (<http://www.epa.gov/airmarkets/egrid/index.html>)). E-GRID calculated state average annual output emission rates (lbs/MWh) by dividing annual net generation by state by annual emissions by pollutant type. Appendices A and B show the emissions as reported by PJM, as well as the mercury, PM10, PM2.5, VOC, and CO emission rates per state covered in PJM and PJM West.

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To determine emissions attributable to the Virginia portion of the system, we obtained Dominion Virginia Power's emission rates from the EPA's 2000 E-GRID database, as shown in Table 3.²²

Table 3. Average emission rates for Dominion Virginia Power PCA. (lbs/kWh)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
.002835	.006976	1.2786	.000000268	.000201	.000097	.000028	.000208

We next assumed that 28.6 percent of Metrorail's energy consumption is attributable to Virginia, because 28.6 percent of the track miles are located in Virginia. Based upon this assumption, Virginia consumption is roughly 126,206,080 kWh. Using the emission rates in Table 3 and the energy usage described above, we calculated Metrorail's total emissions for the VA portion. The results are presented in Table 4.

Table 4. Total Emissions Attributed to VA Metrorail Based Upon Dominion Virginia Power PCA (lbs)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
357794.24	880413.61	161,367,093.89	3.382	25367.42	12241.99	3533.77	26250.86

Next, we combined the PJM and Dominion emissions to calculate totals for the entire Metrorail system. The results are presented in Table 5.

Table 5. Emission Totals for the Entire Metrorail System (lbs.)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
1253895.98	4063605.41	534379957.04	16.3	81135.5	43276.77	18972.39	101553.53

According to the FTA, Metrorail traveled 1,362,866,338 passenger miles in 2001. Using this number, we calculated the emissions per passenger mile for each pollutant.

²² The PM10, PM2.5, VOC, and CO emission data was calculated by dividing E-GRID's annual net generation for Virginia and West Virginia by the annual emissions by state from EPA's National Emission Trends (NET) database.

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Table 6. Metrorail Emissions Per Passenger Mile
(lbs./passenger mile and gram/passenger mile)

	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
lbs./mile	.00092	.00298	.3921	.000000012	.00005953	.00003175	.00001392	.00007451
gram/mile	.4173	1.352	177.85	.00000544	.027	.0144	.006314	.0338

2.1.2 DC Regional Scenario

As with the previous scenario, we calculated the average emissions from all of the power plants in the Washington DC region,²³ as shown in Table 7.

Table 7. Average Power Plant Emissions By Washington DC Regional Jurisdiction (lbs/kWh)

	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
DC	.005746	.01502	2.929	N/A	.000189	.000172	.000172	.00059
MD	.00499	.01472	1.9351	.000000057	.000298	.000142	.000024	.000154
VA	.005032	.01477	2.430	.000000038	.000094	.000049	.000018	.000116

Next, we apportioned the emissions according to the number of track miles in each jurisdiction, as shown in Table 8.

Table 8. Average Emissions for Regional Power Plants Weighted to Reflect Proportion of Metrorail System in Each Jurisdiction (lbs/kWh)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
.00528	.01485	2.446	.0000000304	.000199	.0001266	.00007734	.000305

Next, we multiplied 441.28 million kWh by the average emissions presented in Table 8. The results are presented in Table 9.

²³ See Appendix D for a list of the power plants and their emissions. As with the previous scenario, PM10, PM2.5, VOC, and CO emission rates were calculated using E-GRID's annual net generation for DC, MD, and VA divided by annual emissions by state from EPA's National Emission Trends (NET) database.

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Table 9. Total Emissions Attributable to Metrorail Based Upon Regional Generation Fuel Mix (lbs)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
2,329,958.4	6,553,008	1,079,370,880	13.415	87814.72	55866.05	34128.60	13459.04

Based upon 1,362,866,338 passenger miles in 2001, we converted the total emissions into pounds and grams per passenger mile, as shown in Table 10.

Table 10. Per Passenger Mile Emissions Attributable to Metrorail Based Upon Regional Generation Fuel Mix
(lbs/passenger mile and grams/passenger mile)

	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
Pounds	.00171	.00481	0.7920	.0000000984	.0000644	.00004099	.00002504	.000009876
Grams	0.7756	2.182	359.24	.00000446	.02921	.01859	.011358	.00448

The emissions under the DC regional scenario are significantly higher than the emissions under the PJM and Dominion scenario. Power plants in the DC region are mainly fossil fuel, while a significant portion of the power plants in PJM are nuclear. Although nuclear provides zero emission electricity by conventional pollutant measures, it creates other problems, such as how to dispose of nuclear waste.

3. Light Rail

To provide a comparison to Metrorail, we next looked at emissions from another popular electric rail system – light rail. To make an accurate comparison, we assumed that the light rail system is powered from the same mix of fuels associated with the Metrorail scenarios, as discussed above.

To get the power consumption and passenger loading numbers for light rail, we again used the performance of an actual, operating system in the United States. We selected Salt Lake City's TRAX system for this purpose.

Opened in 1999, TRAX is a new system touted by light rail supporters as a great success story. According to LightRailNow!, “[f]rom the start, TRAX was a hit ... total project cost came in millions of dollars under budget [and] [r]idership exceeded projections by 40-50%.”²⁴ Given its enthusiastic support among light rail advocates, TRAX seemed an appropriate model.

²⁴ www.lightrailnow.org

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3.1 Energy Consumption and Emissions

TRAX used 10,392,425 kWh of electricity for propulsion in 2001.²⁵ Calculating a 10 percent line loss, we know that TRAX induced roughly 11,431,668 kWh in electricity generation for propulsion.

3.1.1 PJM and Dominion Scenario

To be consistent with the Metrorail analysis, we assumed that our hypothetical light rail system would derive its power from the same mix of generating facilities as Metrorail. Thus, we used the same emission rates as used in the Metrorail analysis.

Next, we multiplied the total energy consumption for propulsion of TRAX by these average emissions rates. The results are presented in Table 11.

Table 11. Total Emissions Attributable to TRAX Model Powered by Metrorail's Fuel Mix (lbs)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
38,410.4	101,741.85	15,181,255.1	.4218	2102.28	1116.874	491.56	2629.28

According to the FTA, TRAX traveled 44,555,900 passenger miles in 2001. Using this number, we converted the total emissions into pounds and grams per passenger mile, as shown in Table 12.

Table 12. Per Passenger Mile Emissions Attributable to TRAX Model Powered by Metrorail's Fuel Mix (lbs/passenger mile and grams/passenger mile)

	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
Pounds	.000862	.002283	.3407	.00000009467	.00004718	.0000251	.0000110	.0000590
Grams	.3910	1.036	154.54	.00000429	.0214	.0114	.00499	.0268

3.1.2 DC Region Scenario

Again, we used the same methodology that we used for the DC Region Metrorail Scenario. The results are presented in Table 13.

²⁵ Federal Transit Administration, 2001 National Transit Database

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Table 13. Total Emissions Attributable to TRAX Model Powered by the DC Region Fuel Mix (lbs)

NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
60,359.21	169,760.27	27,961,859.93	.3475	2274.90	1447.25	884.125	3486.66

Given that TRAX traveled 44,555,900 passenger miles in 2001, we converted the total emissions into pounds and grams per passenger mile, yielding Table 14.

Table 14. Per Passenger Mile Emissions Attributable to TRAX Model Assuming DC Regional Generation Fuel Mix (lbs/passenger mile and grams/passenger mile)

	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
Pounds	.00135	.00381	0.6276	.0000000078	.0000511	.00003248	.0000198	.0000783
Grams	.6123	1.728	284.66	.00000354	.0232	.01473	.0898	.0355

4. Bus Rapid Transit (BRT)

Developing a methodology to fairly compare required us to make a number of assumptions. There are no fully operating BRT systems in the United States, yet there are many operating rail systems. For example, we needed to assume what type of fuel would power the bus. We also needed to assume an average number of passengers on the bus, so that we could derive an estimate of emissions per passenger mile (the more passengers on the bus, the lower the estimate, because the bus is carrying more people each mile that it travels).

To address the fuel issue, we looked at a range of low emission technologies, including compressed natural gas, low sulfur diesel, and hybrid-electric. We then selected the best performing vehicle for two pollutants, NOx and CO2, and compared these against the rail options.²⁶

To address the passenger loading issue, we developed a range for evaluation. On the low end of the range, we assumed that the BRT system would perform no better than a conventional bus system. On the high end of the range, we assumed that the BRT system would perform as well as a light rail system. In both cases, we found that using low emission vehicles enables development of a

²⁶ We did this because a transit agency may base its purchasing decision, at least in part, on the vehicle's performance for a particular pollutant. We recognize, however, that there are tradeoffs with every vehicle – i.e., it may be extremely low in one pollutant and higher in another pollutant. In the future, it may be important to develop a methodology to assess vehicles based upon their overall pollution profile, rather than based upon individual pollutants.

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system that emits less pollution than an electric rail system is powered by fossil fuels.

4.1 Emissions

To calculate emissions, we used data from two reports: 1) *Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project, Final Emissions Report* (February 2000) prepared by the Northeast Advanced Vehicle Consortium (NAVC), M.J. Bradley & Associates, Inc., and West Virginia University; and 2) *California Air Resources Board (CARB) Heavy-Duty Emissions Laboratory Report No. 01-01* (July 30, 2001).

This NAVC study evaluated several conventional 40-foot buses using various fuels and a typical driving cycle for normal transit systems.²⁷ The CARB study evaluated New Flyer Hybrid Electric diesel buses using low sulfur fuel and the same driving cycle used in the NAVC study. Tables 16 and 17 shows the equipment and fuel types evaluated by the NAVC and CARB studies. Appendix F contains the test results for these vehicles.

²⁷ It is important to note that the NAVC study may overstate the amount of pollution from an actual BRT system. A BRT system likely would use larger capacity buses and thus would be more efficient. For example, the Los Angeles County Wilshire Bus Rapid Transit project is proposing to use 60 foot, articulated, low floor buses with up to 50% more capacity than current 40 foot vehicles. Among other things, these buses have multiple door boarding, providing faster entry and exit times and thus greater efficiency. See e.g., Timothy Nicholas Papandreou, "Wilshire Bus Rapid Transit – More than Just a Dedicated Bus Lane" Los Angeles County Metropolitan Transportation Authority (August 1, 2002).

The study evaluated technology that is currently about five years old, and cleaner technologies may now be available. Fuel cell vehicles may soon offer a zero emission alternative.

Moreover, the driving cycles used in both studies are out-dated and assume very low average speeds, which increase pollution levels. A BRT system would have a much higher average speed and thus would be more efficient and less polluting.

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Table 16:²⁸ Vehicles Evaluated by NAVC Study

Bus OEM	Bus Chassis	Size	Drive	Engine/Model Year	Fuel	After Treatment
NovaBUS	RTS	40 ft.	3 speed	DDC Series 50 / 1998	D1 Diesel	Oxidation Catalyst
Neoplan	AN440T	40 ft.	5 speed	Cummins L10 280G / 1998	CNG	Oxidation Catalyst
New Flyer	C40LF	40 ft.	5 speed	DDC Series 50G / 1999	CNG	Oxidation Catalyst
Orion	V	40 ft.	5 speed	DDC Series 50G / 1998	CNG	Oxidation Catalyst
Orion	VI Hybrid	40 ft.	LMCS Hybrid with regenerative braking	DDC Series 30 / 1997 & 1998	Diesel – Electric using D1 Diesel	NETT Particulate Filter Trap
NovaBus	RTS Hybrid	40 ft.	Allison Hybrid with regenerative braking	DDCVMM 642 DI / 1991 (1998 engine)	Diesel – Electric using low sulfur D1 diesel	Johnson Matthey Regenerative Particulate Trap

Table 17:²⁹ Vehicles Evaluated by 2001 CARB Study

Bus OEM	Bus Chassis	Size	Drive	Engine/Model Year	Fuel	After Treatment
New Flyer	Hybrid Electric	40 ft.	Hybrid with regenerative braking	Cummins ISB 5.9 liter / 1999	Low sulfur (<15 ppm) diesel	Diesel Particulate Filter (Englehard)

²⁸ This study utilizes the Central Business District Driving Cycle testing results for these buses, which is typically used to evaluate conventional transit buses. It is made up of 14 identical sections containing an acceleration to 20 mph, a cruise at 20 mph, breaking to a stop, then dwell. The total cycle covers 2.0 miles over 600 seconds. The average speed for this cycle is 12.6 mph. The attributes of a BRT system are designed to enable the bus to travel significantly faster, and thus create fewer emissions. A BRT system would have a significantly higher speed, and thus the emissions would be substantially lower. Information provided in Recommended Practices for Measuring Fuel Economy and Emissions of Hybrid Electric and Conventional Heavy Duty Vehicles supports the inadequacy of the CBD cycle and concludes that an updated cycle called the Orange County test cycle is more reflective of actual rapid bus transit and is likely to provide more accurate estimates of intermediate mid-speed transit bus operation. Nevertheless, we used CBD.

²⁹ This CARB study used the Urban Dynamometer Driving Schedule test cycle (UDDS) driving cycle as well as the Central Business District Driving (CBD) Cycle. For consistency and proper comparisons, this study will only use results from the CBD testing; however, the results from the UDDS testing are significantly lower.

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To determine emissions per passenger mile, we needed to make some assumptions about the passenger loading of each of these vehicles. In other words, how many passengers, on average, would a BRT system carry?

Ample data exists on the per vehicle passenger loading of existing bus systems. Given the experience with BRT where it has been implemented, we know that it will perform at least as well as a conventional bus system. Thus, an appropriate base case is to use the passenger loading numbers from an existing bus system.

As our base case, we selected Los Angeles. We recognize that the Los Angeles system is under a court order to limit passenger loading due to over crowding. At the same time, however, Los Angeles has an extensive bus network and is beginning to develop some BRT corridors. Thus, we think Los Angeles provides an appropriate starting point.

As our high loading case, we assumed that passenger loading would equal a light rail system. BRT was designed to provide a cost-effective alternative to light rail. Experience overseas shows that it can perform at least as well as light rail. Plus, the United States General Accounting Office found that overall BRT and light rail ridership are roughly the same, based upon the limited experience with BRT-like systems in the United States at the time of the study.³⁰ To be consistent with our previous analysis, we selected TRAX.

4.1.1 Base Case – LA MTA

The first step in our analysis was to determine the average number of passengers per bus. To determine this, we found out how many passenger miles were traveled by bus, and we divided this by the number of vehicle miles that were traveled during the same year. The LA MTA logged 1,316,461,900 passenger miles and 83,112,200 vehicle revenue miles in 2001.³¹ Thus, on average, an MTA bus carried 15.84 passengers throughout the year for each vehicle mile traveled.

Using the emissions data from the NAVC and CARB studies, we calculated the emissions per passenger mile of a hypothetical BRT system with an annual average passenger loading of 15.84 for each mile traveled. The results are presented in Table 18.

³⁰ *Bus Rapid Transit Shows Promise*, US GAO (September 2001)

³¹ 2003 APTA Fact Book

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Table 18: Per Passenger Mile Emissions of BRT System with Annual Average Passenger Loading of 15.84 (grams per mile)

Conventional D1 Diesel Fuel (300-ppm sulfur content)

	CO	NOx	PM	CO2
Orion-LMCS VI Hybrid Diesel	.00631	1.212	.00758	142.80
NovaBUS RTS Diesel Series 50	.1894	1.900	.0152	175.44

Low Sulfur D1 Diesel Fuel (<20 ppm sulfur content)

	CO	NOx	PM	CO2
Nova-Allison RTS Hybrid Low Sulfur Diesel	.0253	1.749	Below detection	156.06
New Flyer	.001	.922	.0016	131.8

Compressed Natural Gas (CNG) Fuel

	CO	NOx	PM	CO2
Neoplan AN440T CNG L10 280G	.0379	1.578	.00126	151.01
New Flyer C40LF CNG L10 280G	.8018	.9407	.00126	147.92
Orion V CNG Series 50G	.6818	.6124	.00126	175.82

Under this scenario, a BRT system using advanced engines and fuels has some advantages over rail. Both CO₂ and particulate matter emissions tend to be lower than for rail. NO_x emissions generally are a little higher for BRT, except for the Orion CNG bus.

Given the slow driving cycle used for testing of the buses (which will increase certain pollutants), as well as the low passenger loading assumptions, we found these results encouraging for BRT. We believe that these results present a “worst case” scenario, and that actual results from an operating BRT system will be better.

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4.1.2 Light Rail Case – Salt Lake City Passenger Loading

Next we calculated the emissions per mile based upon an assumed passenger loading comparable to a light rail system. We again used TRAX as our model.

TRAX logged 44,555,900 Annual Passenger Miles and 1,703,300 Annual Vehicle Revenue Miles in FY2001.³² By dividing these two numbers we calculated the average vehicle passenger loading for the year to be 26.16. The results based upon this loading are included in Table 19 below:

Table 19: Per Passenger Mile Emissions of BRT System with Annual Average Passenger Loading of 26.16 (grams per mile)

Conventional D1 Diesel Fuel (300-ppm sulfur content)

	CO	NOx	PM	CO2
Orion-LMCS VI Hybrid Diesel	.0038	.7339	.00459	86.48
NovaBUS RTS Diesel Series 50	.1147	1.151	.00917	106.23

Low Sulfur D1 Diesel Fuel (<20 ppm sulfur content)

	CO	NOx	PM	CO2
Nova-Allison RTS Hybrid Low Sulfur Diesel	.0153	1.0589	Below detection	94.50
New Flyer	.000612	.558	.000956	79.84

Compressed Natural Gas (CNG) Fuel

	CO	NOx	PM	CO2
Neoplan AN440T CNG L10 280G	.0230	.9557	.000765	91.44
New Flyer C40LF CNG L10 280G	.4855	.5696	.000765	89.56
Orion V CNG Series 50G	.4128	.3708	.000765	106.46

As one would expect, the emissions under this scenario are significantly better than the emissions under the low loading scenario. Taken as a whole, the results appear very encouraging for BRT. CO₂, small particulate matter, and NO_x generally have lower numbers than either of the rail scenarios.

³² 2003 APTA Fact Book

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We would expect real world performance to be even better, because BRT would offer higher driving speeds and the technology has advanced since the vehicles in our sample were tested.

5. Personal Vehicles

As a final step, we compared the emissions of all three modes of transit with the emissions from typical passenger cars and light trucks.³³ To determine these emissions, we needed to make some assumptions about average speeds and vehicle loadings.

Regional travel speeds were obtained from the Metropolitan Washington Council of Governments. Regional travel speed assumptions are 39 mph during commuting hours and 40 mph otherwise (MWCOG's Program Solicitation Document, 2002).³⁴

Based on these assumptions, regionally specific emission rates for VOC and NOx are presented in Table 20.

Table 20. Regionally Specific Emission Rates for VOC and NOx³⁵

VOC	NOx	CO2
0.7 g/mile	1.3 g/mile	280.25

Because CO2 is not a "criteria pollutant," it is not addressed in EPA's MOBILE model and consequently not addressed in the regional MWCOG analysis. To represent mobile CO2 emissions, and thus provide a comparison to transit, we used emissions data provided by the US EPA for personal vehicles.

³³ For the most accurate comparison, we used regional specific mobile emission data, since these vary from area to area because of fleet characteristics, roadway speeds, fuel types, temperatures, as well as the presence and quality of an inspection and maintenance (IM) program.

Area-specific emission rates for VOC and NOx are available in the Metropolitan Washington Council of Government's (MWCOG) *Air Quality Conformity Determination of the 2002 Constrained Long Range Plan and the FY2003-2008 Transportation Improvement Program for the Washington Metropolitan Region*, July 2002 (FY2003-2008 TIP/Conformity Determination). This report is available online at http://www.mwcog.org/transportation/publication/x3_conformity_report.pdf - Emission curves illustrating total composite emission rates for VOC and NOx by vehicle speed are presented in the report on pages 30-31.

³⁴ These estimates are averages for the entire metropolitan area.

³⁵ Source: MWCOG FY2003-2008 TIP/Conformity Determination

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The EPA calculates a national average for cars as 259.69 CO2 grams/mile and 326.02 CO2 grams/mile for light trucks in 2001. COG's Conformity report shows that in the DC region, 69% of commuting vehicles are light duty gasoline vehicles (cars), 21% are light duty gasoline trucks, and 10% are other types of vehicles including heavy duty trucks and motorcycles. Since the 'other' vehicles are likely to pollute more than cars and even light trucks, we added that 10% to the light duty gas truck category. We recognize that this assumption masks distinctions between diesel and gasoline vehicle emissions, and between motorcycles and four-wheeled vehicles, but we believe it provides a reasonable benchmark.³⁶

With this assumption, we have 69% cars and 31% trucks and other. To calculate a regional specific CO2 emission rate, we used these regional specific percentages with the EPA national average emission rates, as shown:

$$69\%(259.69) + 31\%(326.02) = 280.25 \text{ grams/mile CO}_2$$

Next, we adjusted the data to account for the average number of passengers per car. This is the same adjustment we made for the BRT scenarios. Based on the 1994 COG/TPB Household Travel Survey, the overall average auto occupancy for the surveyed DC metropolitan area is 1.28.³⁷ The vehicle occupancy estimate for commuting trips has been revised for use in the latest Conformity analysis and is 1.13 for 2002.³⁸ The occupancy rate for community trips is slightly higher but not likely to have a large impact on the emissions calculation, so we will use the 1.13 vehicle occupancy estimate to calculate the personal mobile emissions per passenger mile.

Table 21. DC Region Cars and Light Trucks³⁹ Emission per Passenger Mile
(1.13 passengers per vehicle)(grams per passenger mile)

VOC	NOx	CO2
.619	1.15	248.01

³⁶ As a check, we conducted an alternative analysis that only looked at cars and light trucks in the region and did not make an assumption about other vehicles. Under this analysis, we found that CO2 emissions were 243.51 grams per passenger mile, a difference of about 1.8 percent. We believe this difference is so small that it has no impact on the final analysis.

³⁷ From <http://www.mwcog.org/uploads/committeedocuments/Blhd20030301013141.pdf>

³⁸ (FY2003-2008 TIP/Conformity Determination). This estimate is presented in Exhibit 9 of the report and is corrected for a typographical error that is in the table (Personal communication with Michael Clifford, Project Manager MWCOC/Conformity/TIP analysis, May 14, 2003.)

³⁹ Light Truck consists of SUVs and Minivans

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6. Final Comparisons

Table 22 provides a comparison of the best performing BRT vehicles with the results previously discussed for light and heavy rail. We selected best performing by taking, per scenario, one result with the lowest NOx emissions and one result with the lowest CO2 emissions. We think it is appropriate to use the best performing bus because, when transit agencies purchase vehicles, they can base their purchase decisions, at least in part, on emissions performance.

Table 22. Comparison of BRT Results with Results of Heavy Rail, Light Rail, and Passenger Cars
(grams/passenger mile)

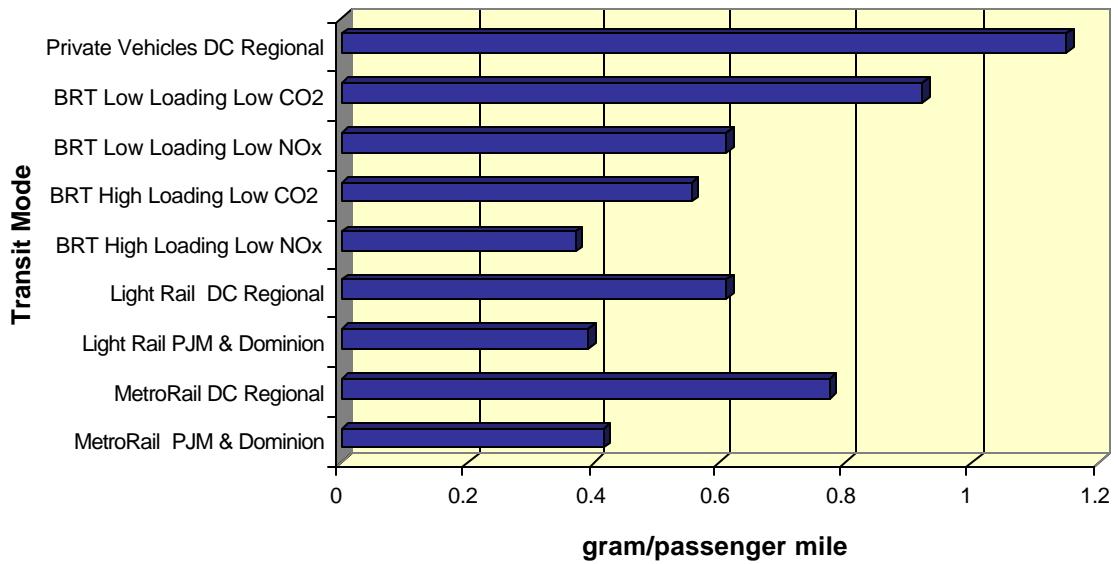
	NOx	SO2	CO2	Mercury	PM10	PM2.5	VOC	CO
Heavyrail (Metrorail)								
Metrorail	.4990	1.306	195.09	.00000544	.027	.0144	.006314	.0338
Metrorail 1	.7756	2.182	359.24	.00000446	.02921	.01859	.011358	.00448
Lightrail (TRAX)								
TRAX	.3910	1.036	154.54	.00000429	.0214	.0114	.00499	.0268
TRAX 1	.6123	1.728	284.66	.00000354	.0232	.01473	.0898	.0355
BRT								
Low loading (LA MTA) Low NOx	.6124 (CNG)	--	175.82 (CNG)	--	--	.00126	--	.6818
Low loading (LA MTA) Low CO2	.922 (low sulfur diesel)	--	131.8 (low sulfur diesel)	--	--	.0016	--	.001
High loading (Salt Lake City) Low Nox	.3708 (CNG)	-	106.46 (CNG)	--	--	.000765	--	.4128
High loading (Salt Lake City) Low CO2	.558 (low sulfur diesel)	-	79.84 (low sulfur diesel)	--	--	.000956	--	.000612
Passenger Vehicles								
Car / Light Truck	1.15	--	248.01	--	--	--	.619	--

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Next, we created charts to graphically depict the data for three specific pollutants.

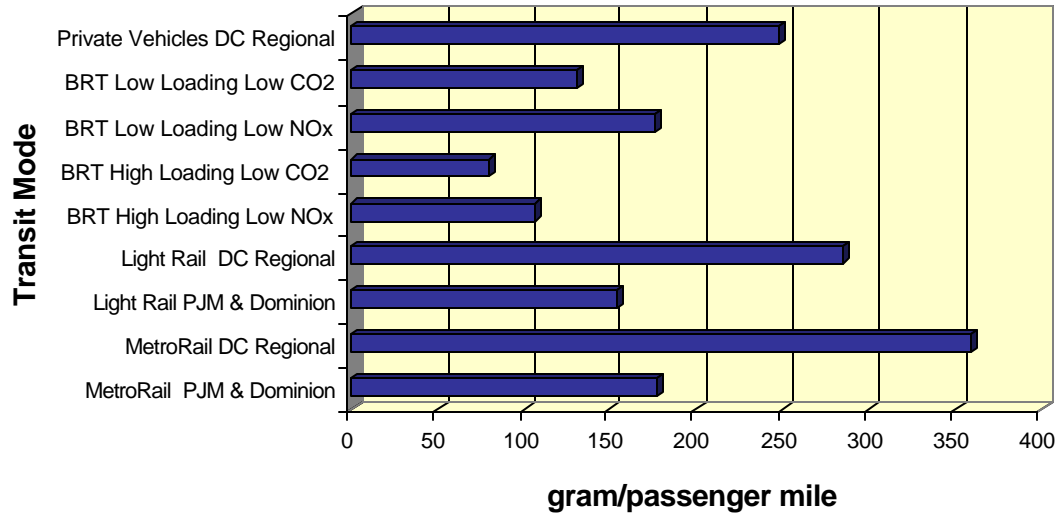
NOx Emission Results



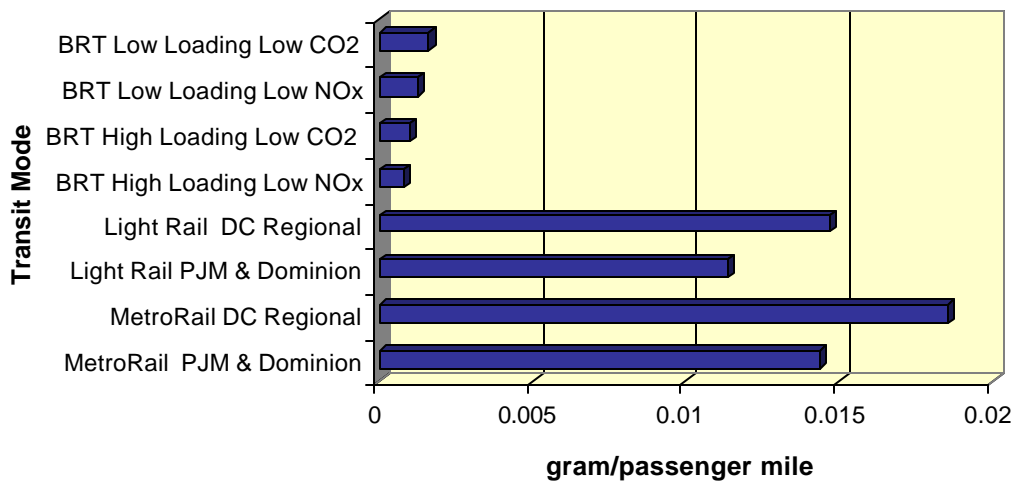
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CO2 Emission Results



PM2.5 Emission Results



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7. Conclusion

The results of this analysis are compelling. Even using a conventional bus driving cycle with relatively 'old' bus technologies, a well-designed BRT system can emit substantially less pollution than either a light or heavy rail system, on a per passenger mile basis. This does not mean that electric rail is inherently dirty. Rather, it suggests that we must take a harder look at where the electricity is generated to power electric rail systems.

We also must take a harder look at new technologies that are powering BRT vehicles. Buses have a bad public image in part because they have been powered by high polluting diesel engines. Now, however, new technologies are significantly reducing vehicle pollution. In the near future, hydrogen powered vehicles may reduce tail pipe emissions to zero.

Finally, we must develop a better way to compare transit technologies. It makes no sense to consider the environmental impacts of rubber-tired vehicles, yet completely ignore the environmental impacts of steel-wheeled vehicles. This is particularly true given that BRT technology offers the performance of rail, yet at a fraction of the cost.

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Appendix A

PJM Emissions Data For PJM Scenario

Electricity Supplied from January 1, 2002 through December 31, 2002:

2002 PJM Supply Mix	%
Coal	48.0086
Oil	3.2129
Natural Gas	10.9187
Nuclear	35.9645
*Geothermal	0.0000
*Solar Voltaic	0.0000
*Solar Thermal	0.0000
*Waste	0.8907
*Water	0.8284
*Wind	0.0144
*Wood	0.1619
TOTAL	100.000
*Renewable Energy Resources Subtotal	1.8953

SOURCE: PJM Regional Average Disclosure Label for 2002 Document #202816, v1

Benchmark Emission Levels for all Electricity Generation in the PJM Region:

Emissions Type	Lbs. per kWh	% of PJM Regional Average
NOx ⁴⁰	0.0028441	100.0
SO2 ⁴¹	0.010103	100.0
CO2 ⁴²	1.18389	100.0

⁴⁰ SO2 & NOx released into the atmosphere react to form acid rain; nitrogen oxides also react to form ground level ozone, an unhealthy component of 'smog'

⁴¹ SO2 & NOx released into the atmosphere react to form acid rain

⁴² CO2 is a Greenhouse Gas which may contribute to global climate change

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Appendix B

PJM and PJM West have 614 generating facilities operating on a wide range of fuel types and at various levels of capacity throughout the year. PJM covers Central and Eastern Pennsylvania, virtually all of New Jersey, Delaware, Western Maryland, and Washington DC.

A new control area called PJM West is now also covered by PJM Interconnect and covers the Northern two thirds of West Virginia, portions of Western and Central Pennsylvania, Western Maryland, and small areas of Southeastern Ohio.⁴³ A fairly accurate approximation to the PJM and PJM West area can be represented DC, DE, MD, PA, VA, and WV.

The emission factors for CO₂, SO₂, NO_x, were taken from the PJM Regional Average Disclosure Label for 2002, which used data from 2000 and came directly from PJM, as shown in Appendix A. This is the first disclosure label for PJM that incorporates the April 2002 inclusion of PJM West.

Mercury (Hg) emissions were taken directly from the US EPA's E-GRID2000 State Data MS-Excel tables⁴⁴. E-GRID calculated state average annual output emission rates (lbs/MWh) by dividing annual net generation by state by annual emissions by pollutant type.

PM₁₀, PM_{2.5}, VOC, and CO data was calculated by using E-GRID's annual net generation by state divided by annual Electrical Utility Point Source Air Emissions by state from EPA's National Emission Trends (NET) database for the states of DC, DE, MD, PA, VA, and WV, as shown below.

	Hg lbs/kWh	PM10 lbs/kWh	PM2.5 lbs/kWh	VOC lbs/kWh	CO lbs/kWh
DE	.000000498	.000116	.000059	.000037	.000235
DC	N/a	.000189	.000172	.000172	.000590
MD	.000000334	.000298	.000142	.000024	.000154
PA	.00000005	.000125	.00006	.000018	.000123
VA	.000000181	.000094	.000049	.000018	.000116
WV	.000000535	.000239	.000109	.000025	.000214
Mean	.000000410	.000177	.0000985	.000049	.000239

⁴³ <http://energycrisis.lbl.gov/pjm>

⁴⁴ U.S. EPA E-GRID2002 Version 1.0 Released January 2003.
(<http://www.epa.gov/airmarkets/egrid/index.html>)

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Appendix C

Dominion Virginia Power's Power Control Area (PCA)

NOx (lbs/MWh)	SO2 (lbs/MWh)	CO2 (lbs/MWh)	Mercury (lbs/GWh)	PM10 (lbs/kWh)	PM2.5 (lbs/kWh)	VOC (lbs/kWh)	CO (lbs/kWh)
2.835	6.976	1278.586	.0268	.000201	.000097	.000028	.000208

NOx, SO2, CO2, and Mercury data was gathered from the US Environmental Protection Agency's (EPA's) EGRID database using year 2000 data for Dominion Virginia Power PCA.

PM10, PM2.5, VOC, and CO data was calculated by using E-GRID's annual net generation by state divided by annual Electrical Utility Point Source Air Emissions by state from EPA's National Emission Trends (NET) database for the states of Virginia and West Virginia and the averaging them.

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Appendix D

Power Plants and Emissions Data for DC Regional Scenario

All DC Power Plants

Plant Name	Plant annual net generation (MWh)	Plant annual NOx emissions (tons)	Plant annual SO2 emissions (tons)	Plant annual CO2 emissions (tons)	Plant annual mercury emissions (lbs)	Plant Primary Fuel
Benning	130,532.6	273.29	957.70	173185.90	N/A	Fossil Fuel - Oil
Buzzard Point	13841.1	102.98	25.62	18611.25	N/A	Fossil Fuel - Oil
DC TOTAL	144373.7	376.27	983.32	191797.15	N/A	N/A

SOURCE: 2000 US EPA EGRID: <http://www.epa.gov/airmarkets/egrid>

	DC Plants Average NOx Emission (lbs./kWh)	DC Plants Average SO2 Emission (lbs./kWh)	DC Plants Average CO2 Emission (lbs./kWh)	DC Plants Average Mercury Emission (lbs./kWh)	PM10 (lbs/kWh)	PM2.5 (lbs/kWh)	VOC (lbs/kWh)	CO (lbs/kWh)
DC Area Average Rates ⁴⁵	.005212	.013622	2.657	N/A	.000189	.000172	.000172	.000590

PM10, PM2.5, VOC, and CO electricity generation emissions were made using E-GRID's annual net generation by state divided by annual Electrical Utility Point Source Air Emissions by state from EPA's National Emission Trends (NET) database.

⁴⁵ Calculated by converting total DC emission tonnage (for each emission type shown) to pounds (2000 lbs. = 1 short ton) and dividing this by total DC plant net generation in kWh.

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All PEPCo Owned Power Plants in Montgomery & Prince Georges Counties, MD

Plant Name	Plant annual net generation (MWh)	Plant annual NOx emissions (tons)	Plant annual SO2 emissions (tons)	Plant annual CO2 emissions (tons)	Plant annual mercury emissions (lbs)	Plant Primary Fuel
Chalk Point	5385030.9	12976.08	35488.60	5270061.10	286.00	Fossil Fuel - Coal
Panda Brandywine LP	759917.1	75.69	2.14	136908.93	N/A	Fossil Fuel - Natural Gas
Gude	18120.2	17.196	0.122	0.00	N/a	Land Fill Gas
Montgomery County Resource Recovery Facility	329402.2	1074.42	52	141525.249	0.038	Municipal Waste
Dickerson	2900634.3	7118.678	29214.9	2962098.9	253.401	Fossil Fuel - Coal
MD TOTAL	9393104.7	21262.064	64757.762	8510594.179	Incompl.	N/A

SOURCE: 2000 US EPA EGRID: <http://www.epa.gov/airmarkets/eGRID/>

	MD Plants Average NOx Emission (lbs./kWh)	MD Plants Average SO2 Emission (lbs./kWh)	MD Plants Average CO2 Emission (lbs./kWh)	MD Plants Average Mercury Emission (lbs./kWh)	PM10 (lbs/kWh)	PM2.5 (lbs/kWh)	VOC (lbs/kWh)	CO (lbs/kWh)
MD Area Average Rates ⁴⁶	.00453	.01379	1.812	.0000000334	.000298	.000142	.000024	.000154

PM10, PM2.5, VOC, and CO electricity generation emissions were made using E-GRID's annual net generation by state divided by annual Electrical Utility Point Source Air Emissions by state from EPA's National Emission Trends (NET) database.

⁴⁶ Calculated by converting total DC emission tonnage (for each emission type shown) to pounds (2000 lbs. = 1 short ton) and dividing this by total DC plant net generation in kWh

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All Dominion Virginia Power Owned Power Plants in Fairfax, Arlington, and Prince William Counties, VA

Plant Name	Plant annual net generation (MWh)	Plant annual NOx emissions (tons)	Plant annual SO2 emissions (tons)	Plant annual CO2 emissions (tons)	Plant annual mercury emissions (lbs)	Plant Primary Fuel
Alexandria Arlington Resource Recovery Facility	152399.3	686.78	56.62	86136.10	0.00	Municipal Waste
Potomac River	2124912.7	5693.81	13947.90	2679520.20	64.12	Fossil Fuel – Coal
Church Street Plant	736.0	11.39	0.72	567.72	N/A	Fossil Fuel – Oil
Dominion/Lo-Mar Gen.	1402.0	24.31	1.53	1211.38	N/A	Fossil Fuel – Oil
Gateway Gen.	180.0	2.78	0.18	138.30	N/A	Fossil Fuel – Oil
Godwin Drive Plant	746.0	11.54	0.73	575.22	N/A	Fossil Fuel – Oil
Possum Point	2864750.0	5276.55	20570.84	2918557.73	129.55	Fossil Fuel – Coal
Prince William County Landfill	13517.9	14.24	0.05	0.00	N/A	Land Fill Gas
VMEA Peaking Gen.	748.0	11.58	0.73	577.09	N/A	Fossil Fuel – Oil
VMEA-1 Credit Gen.	3206.0	49.63	3.13	2472.93	N/A	Fossil Fuel – Oil
VA TOTAL	5162597.9	11782.61	34582.43	5689756.67	Incompl.	N/A

SOURCE: 2000 US EPA EGRID: <http://www.epa.gov/airmarkets/eGRID>

	VA Plants Average NOx Emission (lbs./kWh)	VA Plants Average SO2 Emission (lbs./kWh)	VA Plants Average CO2 Emission (lbs./kWh)	VA Plants Average Mercury Emission (lbs./kWh)	PM10 (lbs/kWh)	PM2.5 (lbs/kWh)	VOC (lbs/kWh)	CO (lbs/kWh)
VA Area Average Rates ⁴⁷	.004565	.01340	2.204	.000000181	.000094	.000049	.000018	.000116

⁴⁷ Calculated by converting total DC emission tonnage (for each emission type shown) to pounds (2000 lbs. = 1 short ton) and dividing this by total DC plant net generation in kWh

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PM10, PM2.5, VOC, and CO electricity generation emissions were made using E-GRID's annual net generation by state divided by annual Electrical Utility Point Source Air Emissions by state from EPA's National Emission Trends (NET) database.

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Appendix E

“Parking Penalty”

In building transit systems, communities have a choice: they can encourage people to drive to transit stations or they can encourage people to use other means, such as walking, biking, and other transit service. To encourage driving, communities build massive parking facilities. To encourage alternative forms of access, build high density, mixed use communities around the transit station.

If a community chooses to encourage driving, it is appropriate to apportion the emissions from that driving to the transit system. Thus, in analyzing Metrorail, we took into account the fact that many Metrorail stations are surrounded by parking facilities.

Estimating an emissions impact from parking is important. Land use policy significantly impacts the performance and air quality benefits of a transit system. For example, in dense, urban areas, such as the District and the Rosslyn-Ballston Corridor, there is very little parking capacity at Metro stations. As a result, a greater percentage of people find alternative means of getting to Metro, including walking, biking, and riding other forms of transit.

In the outer suburbs, however, land use planning for Metro has been poor. Many existing and planned Metro stations are surrounded by parking lots or are located in the median strip of interstate highways. This makes transit-oriented development difficult or impossible and encourages more driving to Metro stations.

To determine this “penalty,” we used parking spaces as a proxy. Metrorail currently has about 57,000 parking spaces. These spaces generally are filled to capacity on work days and are less frequently used on weekends and holidays.

The number of parking spaces tells us that roughly 57,000 vehicles drive to Metrorail stations on any given work day. The next issue question is: how far did they drive?

To answer this question, we used national journey-to-work data to estimate how far the average vehicle is driven to reach a parking space. According to 1995 data, the average one-way commute to work was 11.8 miles. The average trip length, regardless of purpose, was 9.1 miles.⁴⁸

⁴⁸ See e.g., US Department of Energy, *Transportation and Energy Data Book*, Edition 22 (September 2002)

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Using the lower number of 9.1 miles, we assumed an average commuter would travel substantially less than that distance, perhaps half, to reach a Metrorail parking space. This means that, on average, every car in a Metrorail parking space will have traveled roughly 4.5 miles to reach that space, based upon our assumption. Of course, many will have traveled much further, such as 30 or 50 miles, and many will have traveled much less, perhaps just a mile or two.

Based on 57,000 spaces and an average of 4.5 miles driven each way, we determined that, on a typical work day, roughly 513,000 miles are driven to and from Metrorail stations. Because there are roughly 250 working days in a given year, the total annual workday mileage to and from Metrorail is roughly 128,250,000 miles.⁴⁹

The total number of miles driven to and from Metrorail on work days is the equivalent of going to the moon and back more than 267 times per year. If the average car gets 20 miles per gallon, that's roughly 6.5 million gallons of gasoline.

Next, we calculated the emissions attributable to driving to and from Metrorail stations. The emission rates are the same as used in Table 10 of this study and uses DC region specific data on emission rates and ratios of personal vehicle type. This gave us a total amount of annual emissions attributable to driving to and from Metrorail, and this data is presented in Table A.

Table A: Total Emissions from Annual Workday Trips To and From Metrorail ("Parking Penalty") (grams)

VOC	NOx	CO2
89775000	166725000	35101312500

Now we can add this "Parking Penalty" to the PJM Scenario and DC Regional Metrorail scenarios, calculating new emissions per passenger mile in Table B.

Table B: Metrorail Emissions Gram Per Passenger Mile w/ Parking Penalty

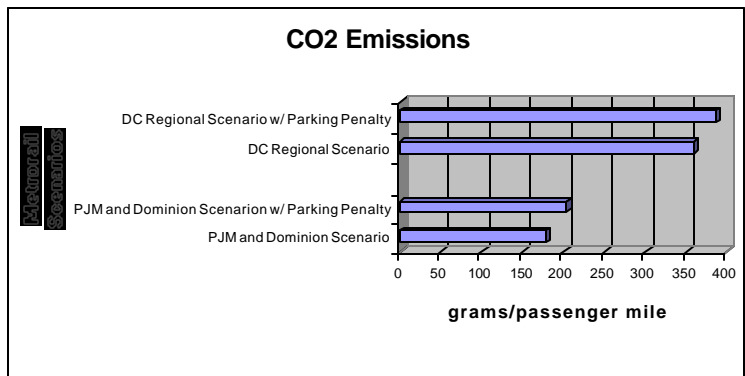
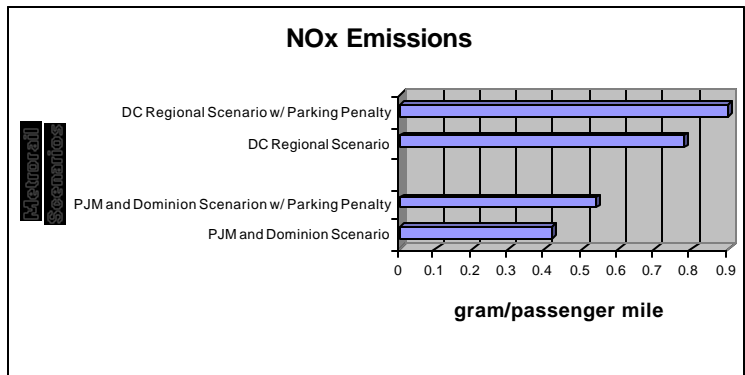
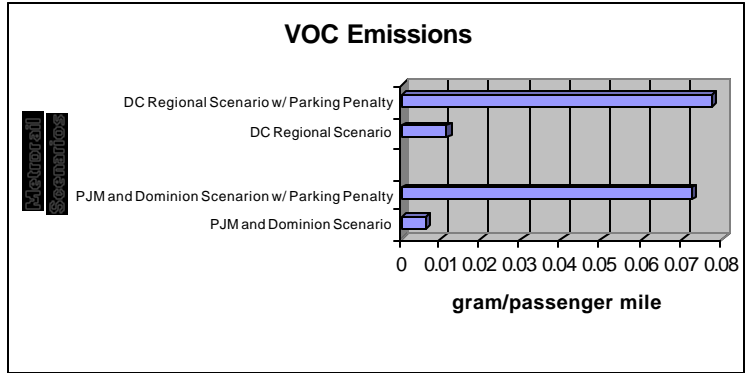
	VOC	NOx	CO2
PJM and Dominion Scenario w/ Parking Penalty	.07219	.5397	203.61
DC Regional Scenario w/ Parking Penalty	.07723	.8978	384.99

⁴⁹ Although parking lots are used on the remaining 115 days of the year, we decided to ignore this travel. A certain number of parking spaces is inevitable on most transit systems, so ignoring the remaining 115 days will help account for those.

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The following graphs show the dramatic increase in emissions when a Parking Penalty is included into the analysis.



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Appendix F

NAVC Test Results In Grams Per Mile Based Upon Central Business District Driving Cycle.

Conventional D1 Diesel Fuel (300-ppm sulfur content)

	CO	NOx	PM	CO2
Orion-LMCS VI Hybrid Diesel	0.1	19.2	0.12	2,262
NovaBUS RTS Diesel Series 50	3.0	30.1	0.24	2,779

Low Sulfur D1 Diesel Fuel (<20 ppm sulfur content)

	CO	NOx	PM	CO2
Nova-Allison RTS Hybrid Low Sulfur Diesel	0.4	27.7	Below detection	2,472

Compressed Natural Gas (CNG) Fuel

	CO	NOx	PM	CO2
Neoplan AN440T CNG L10 280G	0.6	25.0	0.02	2,392
New Flyer C40LF CNG L10 280G	12.7	14.9	0.02	2,343
Orion V CNG Series 50G	10.8	9.7	0.02	2,785

2001 CARB Test Results In Grams Per Mile Based Upon Central Business District Driving Cycle.

	CO	NOx	PM	CO2
Average CBD (g/mile)	0.016	14.6	0.025	2088.5