AOSS 480

University of Michigan Transportation

Climate Impact

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Abstract

The U.S. Environmental Protection Agency estimates that over a quarter of the CO_2 produced in the United States comes from transportation [1]. Increasing CO_2 levels have been proven to have a direct effect on climate change. In order to limit the affects of global warming it will be necessary to address the future practices of our transportation needs. This report will examine the initiatives of public transportation providers and recommend environmental and financial purchasing strategies for the University of Michigan Transportation Services.

Summary

The main purpose of this report is to offer the University of Michigan Transportation Service recommendations for future bus purchases based on relevant case studies, an emission analysis, and a financial analysis. Our motivation is to reduce the University of Michigan's buses carbon footprint in the most economical way possible. We believe that the University of Michigan has a social responsibility to invest in clean technology, promote environmental education, and protect the Earth's ecosystem.

Nomenclature

AATA	Ann Arbor Transportation Authority
B20	20% biodiesel 80% petroleum
CBD	Central Business District
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EPA	U.S. Environmental Protection Agency
GHG	Green House Gas
HC	Hydrocarbons
NB	Northbound
NO_X	Oxides of Nitrogen
OCTA	Orange County Transit Authority
PM	Particulate Matter
ULSD	Ultra Low Sulfur Diesel
UM	University of Michigan
WMATA	Washington Metropolitan Area Transit Authority

Background

Alternative Fuels for Cleaner Buses

The past decade has seen a dramatic shift in the use of alternative fuel in public transportation buses over standard petroleum diesel fuel. The most commonly used alternative fuel sources include ULSD, B20, CNG, and hybrid electric buses. ULSD was mandated for heavy-duty truck and buses in July 2006. ULSD reduces soot and PM by nearly 97 percent compared to standard diesel. B20 biodiesel utilizes the energy stored by plants such as soy beans and is a renewable resource. CNG is considered a cleaner burning fuel than diesel fuel. The use of biodiesel and CNG has also decreased the U.S. dependence on foreign oil.

Hybrid electric vehicles are often discussed as an alternative fuel source; however, hybrid electric refers to the power train consisting of electric motors and a combustion engine. The fuel for the combustion engine is not restricted to any particular type of fuel. Hybrid electric buses are more energy efficient then a standard combustion engine bus. Electric motors provide high torque to the wheels during accelerations which allow the combustion engine to be much smaller and therefore burn less fuel. The electric motors also act in reverse to capture the kinetic energy produced while braking. The energy gained from this regenerative braking can be stored in batteries and reused by electric motors. The combustion engine takes over at higher steady state speeds were it is more efficient than electric motors. Hybrid electric buses are cleaner, quieter, and require less brake maintenance; however they are more expensive than other bus options.

University of Michigan Parking & Transportation Services

The University of Michigan Parking & Transportation Services provides a variety of parking and transportation options in support of the University. The UM transportation operates the campus bus service 360 days a year, with 60 buses that connect the four main Ann Arbor campuses, as well as the East Ann Arbor Health Center. The buses provide more than 120,000 annual service hours, ran about 759,000 miles, and carried 5.8 million passengers in the fiscal year 2007.

The environmental initiatives UM transportation has utilized to reduce the environmental impact of their operations include: using B-20 ULSD biodiesel fuel in buses, installing particulate filters in buses, using zinc instead of lead wheel weights, and recycling engine fluids. Currently UM transportation has acted independently towards addressing environmental concerns and reducing their carbon footprint [2].

Case Studies

Two case studies were performed to investigate how other public transportation services were incorporating climate change into their business and purchasing strategies. Using a relatively small and local system in AATA and a large internationally recognized bus fleet in the Metro we were able to collect a fairly inclusive perspective.

Ann Arbor Transportation Authority (AATA)

The AATA is the local public transit system for the greater Ann Arbor – Ypsilanti Area in Michigan. It is a not-for-profit unit of the Ann Arbor government that was chartered in 1969. The AATA is supported through local, state, and federal funding. The operating expenses are primarily paid for by passenger fares, local funds and Michigan state operating assistance. The entire bus fleet of 69 buses consists of 5% ULSD biodiesel buses and biodiesel hybrid electric buses. There are approximately 5.6 million passengers who ride annually and there is on average an increase in ridership of 8% per year [3].

The environmental initiatives undertaken by AATA initially started in 2002 when its buses were converted to ULSD fuel. In 2006, the buses began running a blend of 5% biodiesel and ULSD [4]. In October of 2007, the first 20 hybrid electric buses were put into service in response to the mayor's initiative of Ann Arbor to make the city of Ann Arbor more environmentally friendly [5]. Over the next six months, 29% of the bus fleet is scheduled undergo replacement. AATA's long term goal is to have the entire fleet replaced with hybrid electric buses. Also, as benefit to local community, the AATA has a recycling program based out of its maintenance shop that collects and recycles lubricants, ink cartridges, cardboard, paper, and other recyclable materials [4].

With the addition of 20 hybrid electric buses, AATA projects that it will save 811,200 gallons of fuel over the next 12 years which is the expected lifetime of the hybrid buses. This savings will roughly equal $2.5 million in fuel costs. At low speeds a battery-powered electric motor provides most of the power for the bus while at higher speeds a smaller, clean-diesel engine takes over. As a result the AATA predicts the buses will reduce fuel consumption by 30%, get 50% better acceleration and reduce maintenance costs by 30% to 50% because of the buses' transmission needs less attention [4].

The hybrid buses are expected to reduce greenhouse gas emissions, which the AATA believes contribute to global warming. The AATA projects the hybrid buses will help reduce particulate matter, carbon monoxide, and hydrocarbons by up to 90% and carbon dioxide and nitrogen oxide by up to 50% [4].

To raise community awareness of environmental stewardship, the AATA unveiled an ecology writing contest in partnership with the Ann Arbor Public Schools. Third through eighth grade students were encouraged to write about environmental stewardship in their community. The AATA has also put on bus advertising about the environment and adopted a mascot named "Scooter" to be the face of the AATA's environmental initiatives [4].

Washington Metropolitan Area Transit Authority (Metro)

The Metro operates the second largest rail transit system and the fifth largest bus network in the United States. Metro was created in 1967 by an Interstate Compact and acquired four area bus systems in 1973. The Metro rail and Metro bus system serve 3.5 million people within a 1,500 square-mile area. The transit zone includes the District of Columbia, the suburban Maryland counties of Montgomery and Prince George's, and the Northern Virginia counties of Arlington, Fairfax, and Loudoun and the cities of Alexandria, Fairfax, and Falls Church. The federal government has contributed 65% of the capital costs. Fares and other revenue fund 57.6% of the daily operations while state and local governments fund the remaining 42.4%. The Metro bus fleet consists of 1,470 buses which includes compressed natural gas, hybrid electric, and advanced diesel technology buses. The Metro system saw 131.5 million bus riders in 2007 [6].

The environmental initiatives undertaken by Metro started in 2000 with their board of directors expressed the goal of improving the bus fleet by buying buses with proven technology producing the lowest levels of emissions with the ultimate goal of a bus fleet that produces zero emissions. Improvements have been made in the procurement and efficiency of the bus fleet. Metro's current plans include the purchase of 476 buses for expansion and the replacement of 417 older buses which will reduce the average fleet age of 10.1 years to 6.5 years. The new busses will consist of 250 compressed natural gas buses, 50 hybrid electric buses, and 117 advanced technology diesel buses [7].

Metro also adopted a Clean Fleet Project in which all of the buses in the fleet have received updated diesel oxidation catalysts and PM filters. Both of which provide an oxidation process to vehicle exhaust to help breakdown the stream into less harmful components. Now the entire bus fleet has the lowest/cleanest emissions possible without total fleet replacement. As a result visible exhaust has been reduced by 90% on all the buses [8].

From Metro's early experience, it is believed that compressed natural gas buses do provide the best emissions of all the currently operated buses. However the hybrid electric buses have been showing promise with a fuel savings of 20%-30% compared to the diesel fleet average. The initial mean distance between failures is well over 30,000 miles with few issues with the hybrid technology [9].

In looking into the future, Metro has been evaluating all three types of new buses previously mentioned. In Metro's opinion, when considering reliability, fuel economy, emissions, flexibility of assignment, quietness, performance and overall capital investment, the diesel hybrid electric provides the best alternative for the standard replacement technology. The summary of results of the Metro's evaluations can be found in Appendix A [10].

Metro long term goals start with continuing to add additional 100 hybrid buses annually for the next 5 years. Metro will also received an additional 25 newer compressed natural gas buses adding more compressed natural fleet. Also Metro has received two Federal Transportation Administration grants for two demonstrations of hydrogen fuel cell buses [10].

Case Study Findings

Considering the amount of time the people use public transportation, the effects public transportation has on the environment and climate change is becoming very important. As shown by the two case studies, small and large bus systems are taking climate change into account when upgrading fleets. Therefore the notion of climate change and recognizing its importance of how it will impact our future has been acknowledged by the people involved in public transportation.

Bus systems accepting the existence of climate change are doing something to help control it by giving local, national, and in some cases international exposure about for the seriousness of climate change. From this exposure, understanding by the public, corporations, and bus systems is gained and ways in which to act are being explored and understood. Larger bus systems like WMATA can act as a resource for smaller bus systems that may not have the money and resources to try out different bus technologies. Smaller bus systems need to know what option will have the greatest impact for their money and experimentation done by the larger bus systems are of great value. Specifically from the WMATA case study, FTA grant money being used to develop hydrogen fuel cell buses will be watched by many groups of people worldwide as the concern over climate change and fuel prices begin to grow.

Emissions Analysis

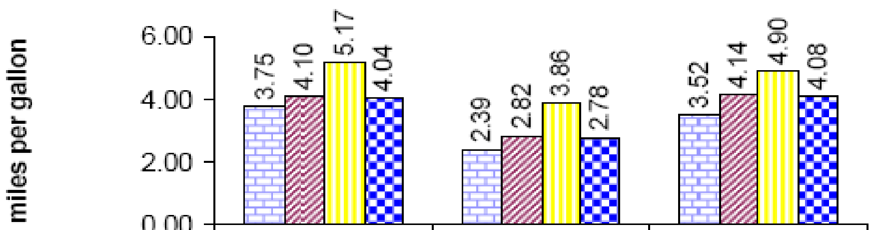
Current EPA emission regulations for transit buses are limited to PM, NO_X, HC, and, CO. The pollutants NO_2 and HC are known to be responsible for forming ground level ozone or smog and can contribute to climate change [11]. The primary GHG impacting global warming, CO_2, is also produced during the burning of fossil fuels but is unregulated by the EPA. The focus of this report is to emphasize the reduction of GHG; therefore the emission analysis section specifically highlights CO_2 reduction. In general all emissions are indirectly proportional to fuel economy therefore an improvement in fuel economy can be assumed to have an overall reduction in pollutants.

Emission Test Cycles

A common way to measure bus emissions is to analyze exhaust while running the bus on a chassis dynamometer. A chassis dynamometer is essentially a bus treadmill where the bus chassis is held stationary while its wheels are allowed to rotate on a large cylinder. This setup is critical to accurately repeat bus operating conditions in order to compare varying tests.

Fuel economy is strongly dependant on bus route and operation. Emission test cycles are simulated driving conditions performed on a chassis dynamometer. The three emission test cycles that we examined were the CBD, Manhattan, and OCTA. Figure 1 compares the fuel economy for a CNG, ULSD, Diesel Hybrid, and B20 biodiesel fuels over each emission test cycles. Figure 1 clearly demonstrates the variability of fuel economy for different test cycles.

Figure 1: Fuel Economy of Emission Test Cycles with Multiple Fuel Systems



	CBD	Manhattan	OCTA
CNG	3.75	2.39	3.52
ULSD	4.10	2.82	4.14
Diesel Hybrid	5.17	3.86	4.90
B20 Biodiesel	4.04	2.78	4.08

Provided by Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation [12]

In order to make accurate fuel economy predictions we attempted to match a UM bus route to one of the three emission test cycles. We chose to examine the Northbound Commuter route beginning at the Intramural Building on South Campus and ending at the Francois Xavier Bagnoud Building on North Campus. This route was chosen because of its expansive coverage of the UM Ann Arbor Campus which incorporated a variety of driving conditions other UM bus routes are exposed to. We conducted this experiment by following a UM bus in a chase vehicle. Between each stop we recorded time, distance, and maximum speeds along with the idle time at each stop. Complete data can be found in Appendix B.

The CBD, Manhattan, and OCTA emission test cycle data found in Appendix C along with our collected NB Commuter data allowed us to assemble Table 1 to compare each routes driving conditions.

Table 1: Comparison of Emission Test Cycles and NB Commuter Driving Conditions

Emission Test Cycle	Average Speed (mph)	Max Speed (mph)	Duration (seconds)	Length (miles)	Share of Idle	Average Stops/Mile
CBD	13	20	560	2	16%	7
Manhattan	7	25	1089	4	-	5.8
OCTA	13	41	1909	6.6	21%	5.6
NB Commuter	19	38	1175	3.9	38%	7.9

Our research indicated that average speed, maximum speed, and the average stops per mile were the strongest influence on fuel economy [12]. The NB Commuter route is characterized by a relatively high average speed, high maximum speed, and high average stops per mile. The OCTA cycle is modeled on the driving patterns of urban buses in Los Angeles, California Area and has a lower average speed but similar maximum speed to the NB Commuter route. The CBD has similar average stops per mile but lower maximum speed. There are also highly congested traffic and pedestrian areas on the NB Commuter route that may at times mimic the Manhattan cycle representing bus routes of New York City, New York.

Hybrid Adoption

Although the exact fuel economy for NB Commuter is difficult to predict it is clear that hybrid electric buses have significant fuel savings and GHG reductions over B20 biodiesel in all three emission test cycles as shown in Table 2.

Table 2: Fuel Savings and GHG Reduction of Hybrid Electric Buses

Emission Test Cycle	**Fuel Economy (mpg)**		**Fuel Savings**	**CO2 Emissions (grams/mile)**		**GHG Reduction**
	B20 Biodiesel	**Hybrid Electric**		**B20 Biodiesel**	**Hybrid Electric**	
CBD	4.04	5.17	22%	2392	1869	22%
Manhattan	2.78	3.86	28%	3473	2504	28%
OCTA	4.08	4.90	17%	2373	1972	17%

CNG and ULSD fuels offer less than 3% GHG reduction over B20 Biodiesel determined by Appendix D data. With UM Transportations current use of ULSD B20 Biodiesel it is highly unlikely that CNG and ULSD environmental benefits are practical options. Therefore, an in-depth emission analysis was reserved for hybrid electric buses only.

From Table 2 we predict fuel savings for complete hybrid electric bus adoption from 17 – 28%. These values are similar to those observed in the WMATA case study which reported 20 – 30% fuel savings and AATA case study which expects 30% fuel savings. This would reduce UM transportation fuel consumption by 51,000 to 84,000 gallons annually. This fuel savings relates to 490 to 810 Mton less CO_2 emitted annually.

The environmental impact of converting UM transportations 60 bus fleet is minimal on the global scale of climate change. However, many small scale efforts such as UM Transportation adoption of hybrid electric buses can contribute to the monumental task of reducing CO_2 emission enough to limit the amount of global warming. We examined the effect of a national 100% adoption of hybrid electric buses based on a FTA study for projected annual emissions from the national transit fleet in 2009 [13]. This study estimates that short term improvements in technology may increase hybrid electric fuel economy to over 6 mpg. With data found in Appendix E we calculated a national annual fuel savings of over 300 million gallons and 2.8 million Mtons less CO_2. This methodology could be expanded internationally as well as to other types of transportation. Investing in hybrid electric or any cleaner technology has the potential to have a boundless environmental impact.

Financial Analysis

Financial analysis was done in order to determine the monetary costs associated with different types of buses. The capital costs, operating costs, future fuel costs, and potential government grants for each type of bus were included in the analysis and discounted to 2008 dollars. The details of the analysis are detailed below.

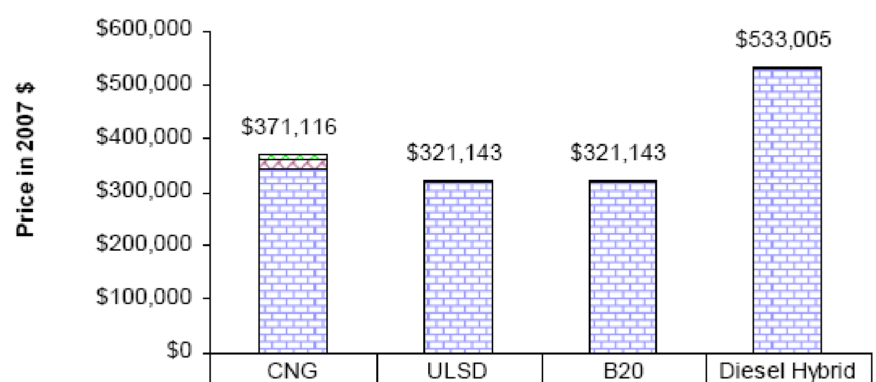
Assumptions

In order to do the financial analysis a few assumptions were made. It was assumed twenty buses were bought every twelve years and therefore the project lifetime was thirty-six years. The buses were not bought at once because the UM Transportation currently has investments in its buses and it makes financial sense to allow the buses to be used till retirement. The capital costs, operating costs, potential fuel costs were taken from *Transit Bus Life Cost and Year 2007 Emission Estimation* by the FTA [12]. It was also assumed UM Transportation qualifies for the Clean Fuels Formula Grant Program. The federal grant program gives money to mass transportation programs that use “clean fuel vehicle.” The maximum grant for a population less than 1,000,000 will cover eighty percent of the total project cost or $15,000,000, and it was assumed UM Transportation will receive the maximum grant [14]. To determine the total project cost in 2008 dollars a discount rate of five percent above inflation was used.

Capital Costs

The capital costs used in the financial analysis included the cost of the vehicle, equipment modifications, and the infrastructure costs. The costs used were found in a FTA study [12]. Figure 2 details the costs used per bus.

Figure 2: Capital Costs per Bus (100 Bus Fleet)



	CNG	ULSD	B20	Diesel Hybrid
Total	$371,116	$321,143	$321,143	$533,005
Emissions Equipment	$0	$1,434	$1,434	$0
Depot Modification	$8,750	$0	$0	$1,400
Refueling Station	$20,000	$0	$0	$0
Vehicle Cost	$342,366	$319,709	$319,709	$531,605

Figure 2 shows the most capital cost intensive bus is the diesel hybrid bus with a total capital cost of $533,005 per bus. Most of the cost is associated with the vehicle cost because not much equipment modification or infrastructure needs to be changed for the diesel hybrid bus. The second most expensive option is the CNG bus with a total capital cost of $371,116. The CNG buses require some infrastructure to be changed in order for service and refueling. The additional infrastructure cost can be found in Figure 2 under Depot Modification and Refueling Station. The least expensive bus is the B20 buses with a total capital cost of $321,143. Some new emission equipment will need to be installed on the buses to meet new emission requirements. The additional equipment modifications costs can be found in Figure 2 under Emissions Equipment.

Operating Costs

The operating costs used in the financial analysis included the cost of compression electricity, facilities maintenance, vehicle maintenance, and battery replacement. The costs used were found in a FTA study [12]. Table 3 details the costs used per bus.

Table 3: Operating Costs per Bus

Operating Costs	CNG	ULSD	B20	Diesel Hybrid
Compression Electricity	$19,003	0	0	0
Facility Maintenance	$24,433	$20,723	$21,039	$17,470
Propulsion Maintenance	$62,588	$66,394	$62,706	$63,589
Battery Replacement	0	0	0	$67,500
Total per bus	$106,024	$87,117	$83,745	$148,559
Total per bus per year	$10,749	$8,832	$8,491	$15,062

Table 3 shows values used for operating costs used for financial analysis. The compression electricity cost is associated with the CNG bus because it takes electricity to compress the natural gas for fueling. The battery replacement cost is associated with the diesel hybrid bus because the battery has to be replaced every 3-6 years. The values in Table 3 were taken from a twelve year study by the FTA; therefore, the total per bus costs were for 12 years and the analysis needed the cost per year. To determine the cost per year it was assumed the cost could be considered an annuity and thus the yearly cash flow could be found using the annuity equation below.

$$PV = C(\frac{1}{r} - \frac{1}{r(r+1)^t})$$

Where:

PV	=	present value (Total per bus)
C	=	yearly cash flow
r	=	interest rate (5 %)
t	=	years (12)

Solve the annuity equation the Total per bus per year operating cost was found and can be found in Table 3. The major operating cost missing from Table 3 is the fuel costs. The fuel costs were calculated using estimated fuel prices in the future based on the 2007 Annual Energy Outlook by Energy Information Administration [15].

Fuel Costs

The fuel costs were estimated for each year in the financial analysis by using the following equation.

Yearly Fuel Cost = Yearly Miles/MPG*Year Fuel Price

Where:

Yearly Fuel Cost	=	Yearly Fuel Cost in 2008 dollars
Yearly Miles	=	UM Transportation Yearly Miles (759,000)
Year Fuel Price	=	Year Fuel Price in 2008 dollars

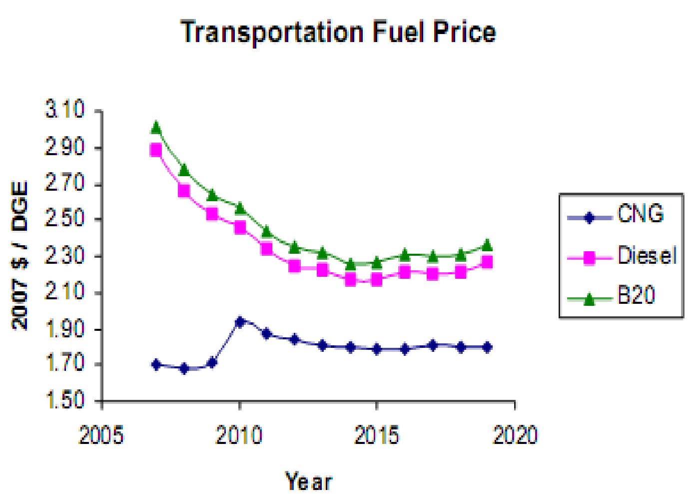
Table 4 summarizes the yearly miles and miles per gallon used to calculate the yearly fuel costs.

Table 4: Yearly Miles and Miles per Gallon

Michigan Buses	CNG	ULSD	B-20	Diesel Hybrid
Miles per gallon	3.52	4.14	4.08	4.90
Miles per year	759,000	759,000	759,000	759,000
Miles per bus per year	12,650	12,650	12,650	12,650

Figure 3 details the estimated fuel price of the future used [15].

Figure 3: Estimates of Future Fuel Prices



Combining the operating costs in Table 3 discounting them and adding in the fuel costs calculated by combining Table 4 and Figure 3, the total operating costs were calculated in 2008 dollars.

Total Project Cost

The total project cost was calculated in 2008 dollars for the thirty-six year lifetime with a discount rate of five percent. The discounted cash flows can be found in Appendix F. The total project cost breaks down into two parts, the old project costs and new project costs. The old project costs are the operating costs associated with the old buses that are being used till retirement. The new project costs are associated with the new buses capital and operating costs. Figure 4 details the total project costs if UM Transportation did not qualify for the Clean Fuels Formula Grant Program.

Figure 4: Total Project Cost No Government Grant

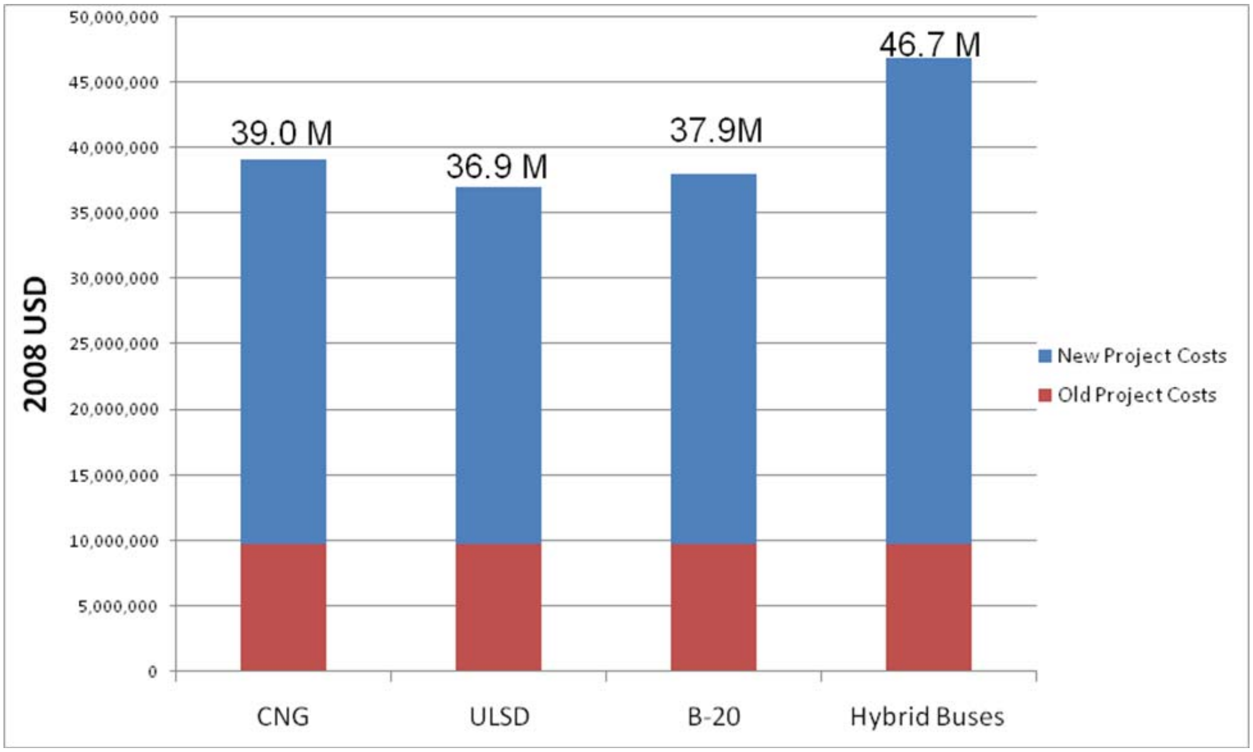
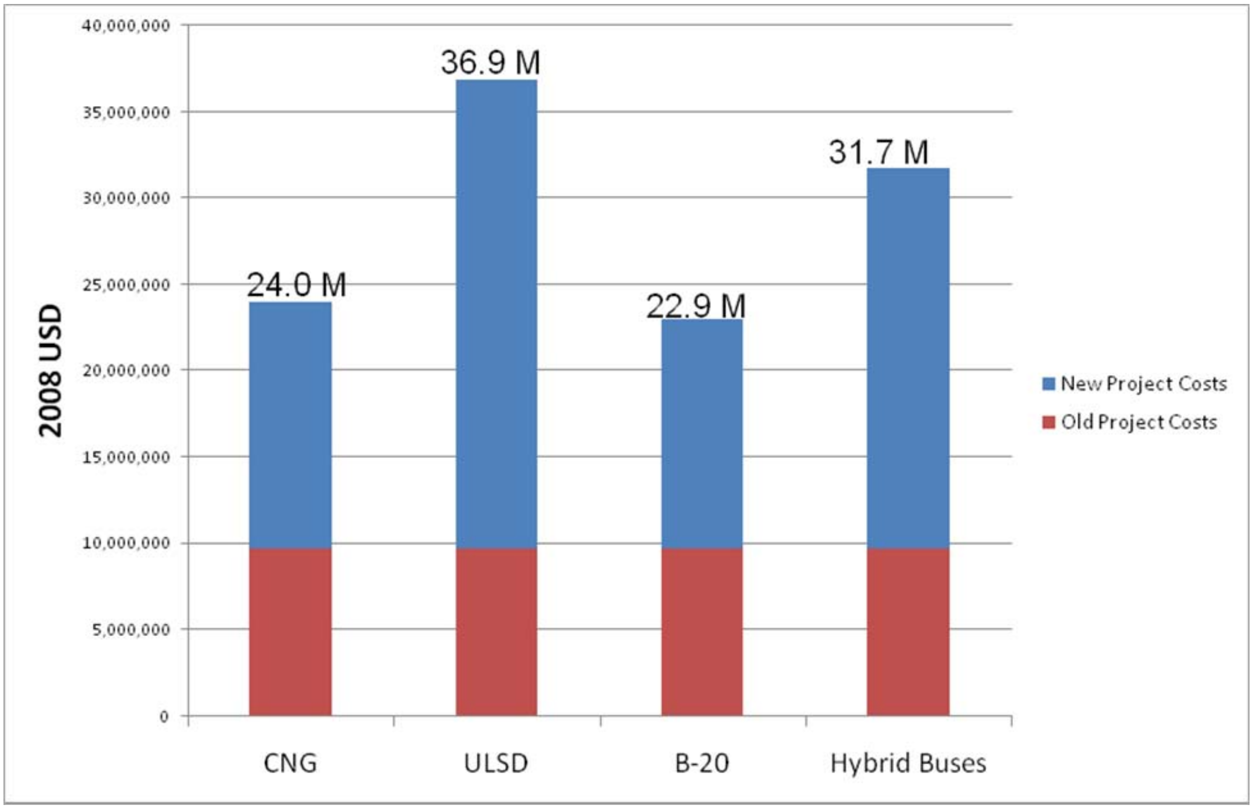


Figure 4 shows that without the Clean Fuels Formula Grant Program, all of the new projects are more expensive as regular ULSD buses. Running ULSD buses for 36 years will cost $36.9 million. The closest project cost to ULSD is B20 buses with a cost of $37.9 million. The most expensive project is the hybrid buses with a cost of $46.7 million.

It is very likely UM Transportation will qualify and receive the maximum grant from the Clean Fuels Formula Grant Program. Figure 5 details the project costs if UM Transportation received the maximum grant.

Figure 5 shows that with the Clean Fuels Formula Grant Program, all of the new projects are less expensive as regular ULSD buses. Running ULSD buses for 36 years will still cost $36.9 million because it does not qualify for the Clean Fuels Formula Grant Program. All of the other projects qualify for the grant program and receive $15 million dollars. The lowest cost project now is the B20 buses with a cost of $22.9 million. The next most expensive project is the CNG buses with a cost of $24.0 million. The most expensive project is the hybrid buses with a cost of $31.7 million.

Figure 5: Total Project Cost with Maximum Government Grant



A major question emerges when looking at Figure 5, how many miles per gallon does the hybrid bus need to get in order for its costs to be similar to B20. To find this, the hybrid buses miles per gallon were varied and it was determined the that the capital costs of the hybrid buses is so great the total cost of hybrid buses can never be below the total cost of B20 buses at the assumed fuel price. If the fuel prices increase by an order of magnitude, the total cost of hybrid buses actually goes below the total cost of B20 buses for its current miles per gallon. However, this fuel price increase is not a reasonable assumption.

Recommendations

By combining the emission analysis and financial analysis the project options for UM Transportation can be analyzed. Figure 6 combines the emission analysis with the financial analysis.

Figure 6: Emission and Financial Analysis

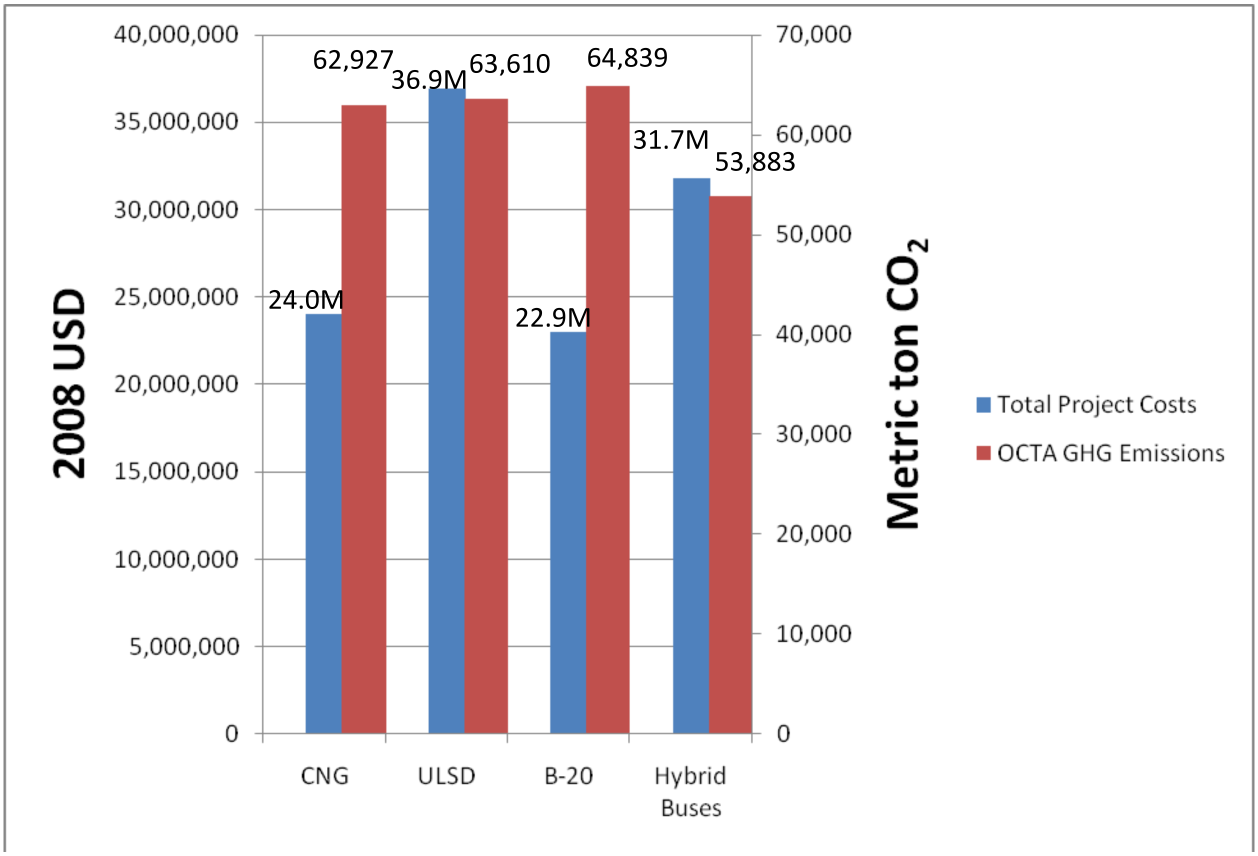


Figure 6 shows the different project costs and benefits UM Transportation have on a thirty-six year time scale. The options are summarized below.

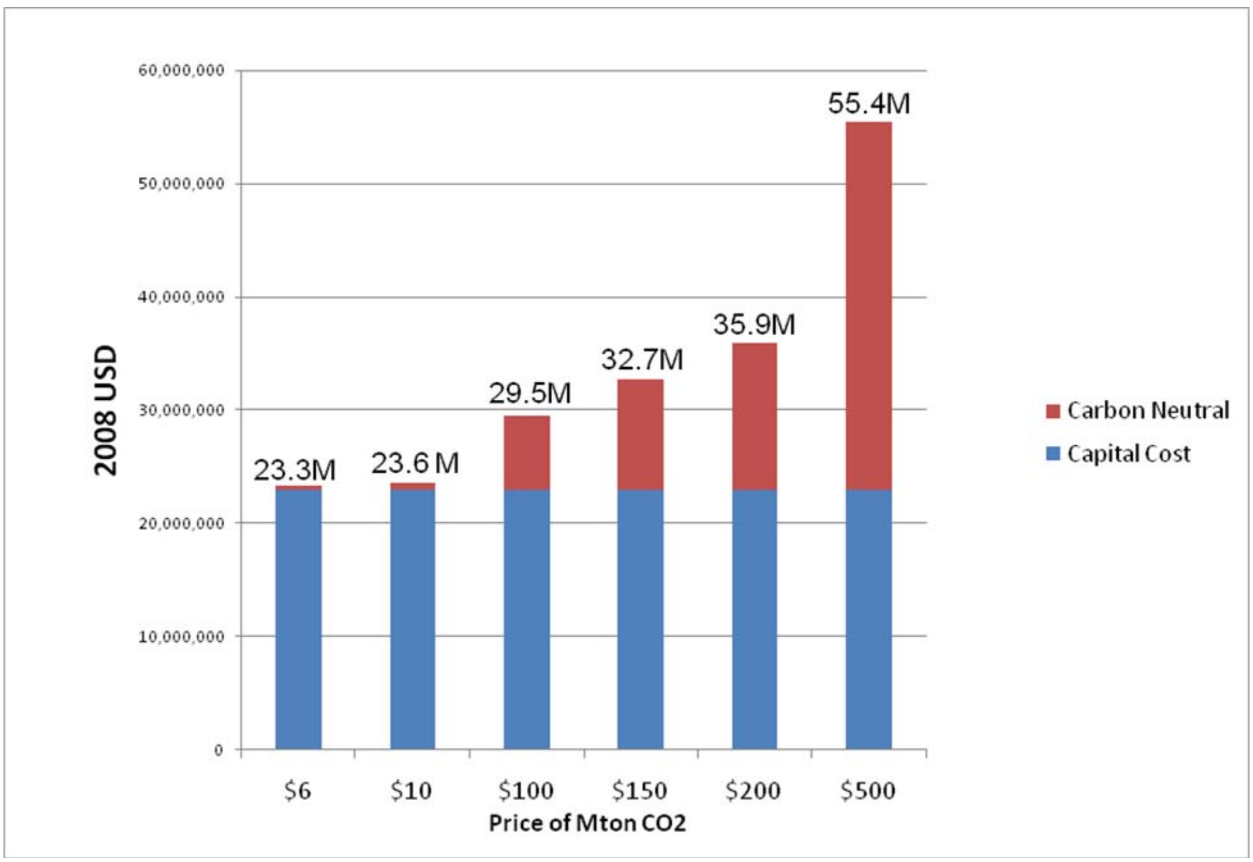
Project Options	**36 year project emissions**	**36 year project costs**
Business as Usual: B-20 Buses	64,839 Mton CO_2	$22.9 million
Compress Natural Gas Buses	62,927 Mton CO_2	$24.0 million
Diesel Hybrid Buses	53,883 Mton CO_2	$31.7 million

Currently UM Transportation is running B20 buses. By running B20 buses UM Transportation has the lowest project costs, $22.9 million, but has the highest CO_2 emissions, 64,839 Mton CO_2. If UM Transportation decided to go to CNG buses they would see a reduction of roughly 2,000 Mton CO_2 with an additional cost of $1.1 million. If UM Transportation decided to go to hybrid buses, they would see a reduction of roughly 11,000 Mton CO_2 with an additional cost of $8.8 million.

Another option UM Transportation has it to go carbon neutral with B20 buses. To go carbon neutral UM Transportation would purchase carbon credits to offset its emissions. In order to determine what the price of carbon has to be at in order undertake the project, one can divide the additional project cost by the emission savings. The price of carbon would have to be roughly $550 and $800 per Mton CO_2 for CNG and hybrid buses, respectively. However, considering the cost of carbon on the voluntary market is $6 per Mton CO_2 it doesn't make sense to consider these project options.

Running carbon neutral with B20 buses seems be the best option for UM Transportation. It makes the most financial sense and has the lowest impact on the climate. UM Transportation will have to keep an eye on the price of carbon in the future in order to estimate its total costs. Figure 7 gives an estimate of the cost of running carbon neutral with B-20 buses for different prices of carbon.

Figure 7: B-20 Buses Carbon Neutral Project Costs



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Appendix

Appendix A: Washington Metropolitan Area Transit Authority Evaluation

Legend Best ← → Worst ● ◕ ◒ ○	DIESEL 	CNG 	HYBRID 
Capital Cost-Vehicle	●	◕	○
Capital Cost-Facilities	●	○	◕
Operating Cost-Vehicle	◕	◒	●
Operating Cost-Facilities	●	◒	◕
Fuel Economy	◕	○	●
Reliability	○	◕	●
Emissions	◒	●	●

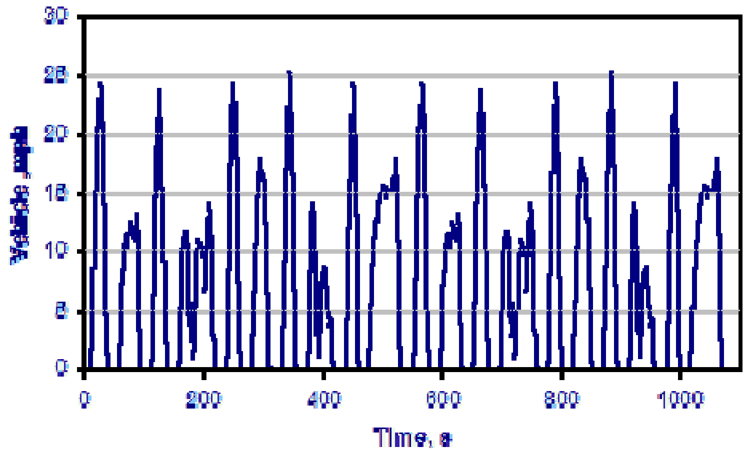
Provided by Metro: Bus Technology Selection: FY08-11, Executive Summary

Appendix B: NB Commuter Data

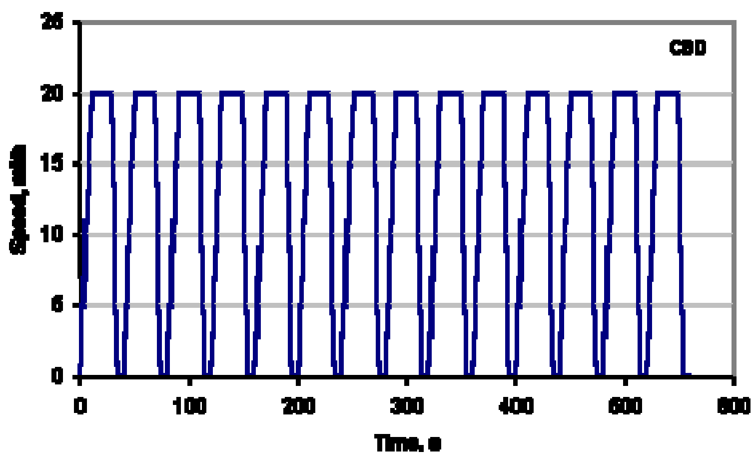
Stop	Distance (miles)	Arrive Time (s)	Depart Time (s)	Depart to Arrive (s)	Max Speed (m.p.h)	Avg. Speed (m.p.h.)
IM Building	0		0			
Hoover/State	0.095	20	54	20	20	17.1
State/Packard	0.179	70	116	16	20	18.9
State/Hill	0.244	135	135	19	20	12.31578947
State/S. University	0.48	174	181	39	23	21.78461538
Union	0.5	192	220	11	10	6.545454545
State Crosswalk	0.557	230	230	10	15	20.52
State/E. William	0.64	260	260	30	20	9.96
State/N. University	0.7	270	287	10	15	21.6
N. University/Thayer	0.76	297	305	10		21.6
N. University/Fletcher	0.9	333	343	28	20	18
C.C. Little	1	370	390	27	20	13.33333333
N. University/Church	1.05	398	402	8	15	22.5
Geddes/Washtenw	1.11	415	452	13	18	16.61538462
Washtenaw/Zina Picher	1.4	493	493	41	32	25.46341463
Zina Picher/ E. Ann	1.468	507	536	14	22	17.48571429
Cousins	1.479	541	545	5	25	7.92
Round a bout	1.58	567	567	22	7	16.52727273
Observatory/E. Medical Center	1.65	578	608	11	15	22.90909091
E. Medical Center/E. Hospital	1.8	627	629	19	32	28.42105263
Mary Markley	1.83	633	650	4	25	27
E. Medical Center/Parking Structure	2	679	681	29	25	21.10344828
Hospital Entrance 1	2.1	701	710	20	25	18
E. Medical Center/Emergency	2.2	735	738	25	27	14.4
Hospital Entrance 2	2.3	760	765	22	20	16.36363636
E. Medical Center/W. Medical Center	2.33	770	770	5	20	21.6
E. Medical Center/Fuller	2.4	791	812	21	35	12
Fuller/Cedar Bend	2.9	870	870	58	35	31.03448276
Orange Lot	2.95	872	886	2	27	90
Fuller/Bonisteel	3.13	916	985	30	30	21.6
Bonisteel/Murfin	3.31	1021	1024	36	30	18
Pierpont Commons	3.35	1036	1047	12	17	12
Nuclear Eng. Building	3.6	1079	1090	32	25	28.125
Bonisteel/Beal	3.62	1102	1105	12	10	6
FXB	3.9	1148	1160	43	29	23.44186047
Beal/Hayward	3.91	1167	1174	7	5	5.142857143
TOTAL				711		19.79746835

Appendix C: Emission Test Cycles

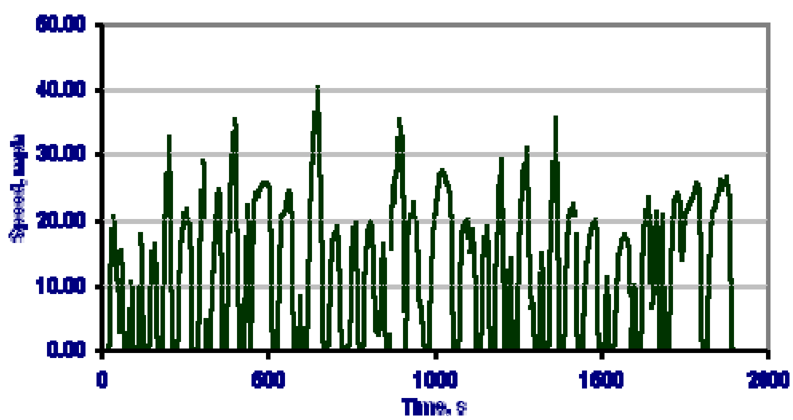
Manhattan Cycle



Central Business District (CBD) Cycle

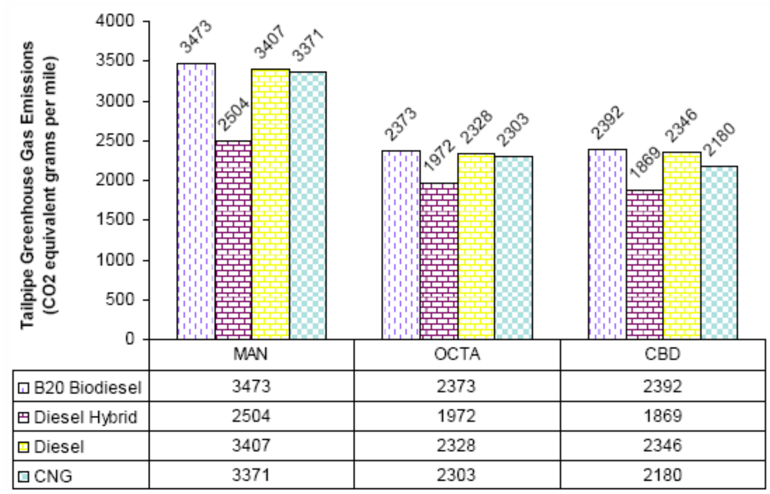


Orange County Transit Authority (OCTA) Cycle



Provided by http://www.dieselnet.com/standards/cycles

Appendix D: GHG Emissions



Provided by Transit Bus Life Cycle Cost and Year 2007 Emissions Estimation [12]

Appendix E: Projected annual emissions from the national transit bus fleet in 2009

	Number of Buses	**CO** tons	**NMHC** tons	**CH_4** tons	**NO_x** tons	**PM** tons	**CO_2** tons	**Fuel Consumed** thousands of gallons
Total Annual Emissions								
Diesel	50,003	9,577	1,667		53,981	843	6,289,918	573,989
CNG/LNG	10,064	1,331	364	6,902	7,229	9	1,003,149	125,818
Diesel Hybrid	1,525	12	2		489	1	107,814	9,805
Total	**61,592**	**10,920**	**2,032**	**6,902**	**61,699**	**853**	**7,400,881**	**709,612**
Average Emissions Levels per Bus								
		CO g/mile	**NMHC** g/mile	**CH_4** g/mile	**NO_x** g/mile	**PM** g/mile	**CO_2** g/mile	**Fuel Economy** mile/gal
Diesel		4.31	0.75		24.32	0.38	2,833	3.51
CNG/LNG		2.98	0.81	15.45	16.18	0.02	2,245	3.22
Diesel Hybrid		0.18	0.03		7.22	0.02	1,592	6.26

Provided by Environmental Benefits of Alternative Fuels and Advanced Technology in Transit [13]

Appendix F: Financial Analysis

CNG Buses				
Cash Flows	**Year number**	**CNG New Capital Costs**	**New Operating Costs**	**Old Operating Costs**
2008	0	$7,422,320	$337,175	$705,482
2009	1		$326,938	$664,506
2010	2		$331,563	$642,902
2011	3		$320,121	$615,831
2012	4		$309,840	$595,660
2013	5		$297,824	$576,154
2014	6		$289,802	$563,482
2015	7		$282,163	$532,811
2016	8		$274,887	$527,518
2017	9		$267,958	$528,974
2018	10		$261,359	$524,750
2019	11		$255,074	$514,821
2020	12	$4,133,026	$498,177	$252,683
2021	13		$486,775	$248,180
2022	14		$475,917	$243,892
2023	15		$465,576	$239,808
2024	16		$455,727	$235,918
2025	17		$446,347	$232,213
2026	18		$437,414	$228,685
2027	19		$428,906	$225,325
2028	20		$420,803	$222,125
2029	21		$413,087	$219,078
2030	22		$405,737	$216,175
2031	23		$398,738	$213,411
2032	24	$2,301,423	$588,108	$0
2033	25		$578,585	$0
2034	26		$569,515	$0
2035	27		$560,877	$0
2036	28		$552,651	$0
2037	29		$544,817	$0
2038	30		$537,355	$0
2039	31		$530,249	$0
2040	32		$523,481	$0
2041	33		$517,036	$0
2042	34		$510,897	$0
2043	35		$505,051	$0
			Total Cost	$39,033,681
			New project	$29,263,297
			Subsidy	$15,000,000
			Total Cost After Subsidy	$24,033,681

B-20 Buses

Cash Flows	Year number	CNG New Capital Costs	New Operating Costs	Old Operating Costs
2008	0	$6,422,860	$352,741	$705,482
2009	1		$332,253	$664,506
2010	2		$321,451	$642,902
2011	3		$307,916	$615,831
2012	4		$297,830	$595,660
2013	5		$288,077	$576,154
2014	6		$281,741	$563,482
2015	7		$266,405	$532,811
2016	8		$263,759	$527,518
2017	9		264486.938	528973.8759
2018	10		$262,375	$524,750
2019	11		$257,411	$514,821
2020	12	$3,576,489	$505,366	$252,683
2021	13		$496,360	$248,180
2022	14		$487,783	$243,892
2023	15		$479,615	$239,808
2024	16		$471,836	$235,918
2025	17		$464,427	$232,213
2026	18		$457,371	$228,685
2027	19		$450,651	$225,325
2028	20		$444,251	$222,125
2029	21		$438,156	$219,078
2030	22		$432,351	$216,175
2031	23		$426,822	$213,411
2032	24	$1,991,523	$632,335	$0
2033	25		$624,813	$0
2034	26		$617,649	$0
2035	27		$610,827	$0
2036	28		$604,329	$0
2037	29		$598,141	$0
2038	30		$592,247	$0
2039	31		586634.1509	0
2040	32		$581,288	$0
2041	33		$576,197	$0
2042	34		$571,349	$0
2043	35		$566,731	$0
			Total Cost	$37,975,228
			New project	$28,204,844
			Subsidy	$15,000,000
			Total Cost After Subsidy	$22,975,228

Hybrid Buses

Cash Flows	Year number	CNG New Capital Costs	New Operating Costs	Old Operating Costs
2008	0	$10,660,100	$440,646	$705,482
2009	1		$415,974	$664,506
2010	2		$399,731	$642,902
2011	3		$381,557	$615,831
2012	4		$366,584	$595,660
2013	5		$352,201	$576,154
2014	6		$340,961	$563,482
2015	7		$322,512	$532,811
2016	8		$314,900	$527,518
2017	9		310353.7651	528973.8759
2018	10		$303,689	$524,750
2019	11		$294,882	$514,821
2020	12	$5,935,943	$572,991	$252,683
2021	13		$557,015	$248,180
2022	14		$541,801	$243,892
2023	15		$527,311	$239,808
2024	16		513510.8258	235917.9041
2025	17		$500,368	$232,213
2026	18		$487,851	$228,685
2027	19		$475,930	$225,325
2028	20		$464,577	$222,125
2029	21		$453,764	$219,078
2030	22		$443,466	$216,175
2031	23		$433,659	$213,411
2032	24	$3,305,355	$636,477	$0
2033	25		$623,134	$0
2034	26		$610,426	$0
2035	27		598323.0771	0
2036	28		$586,797	$0
2037	29		$575,819	$0
2038	30		$565,364	$0
2039	31		$555,407	$0
2040	32		$545,924	$0
2041	33		$536,893	$0
2042	34		528291.2447	0
2043	35		$520,100	$0
			Total Cost	$46,770,969
			New project	$37,000,585
			Subsidy	$15,000,000
			Total Cost After Subsidy	$31,770,969