I. Foreword

Pollution caused due to buses has become a matter of discussion and great concern in our society. The government is enacting stricter rules to reduce the level of pollution caused by diesel buses, forcing bus manufacturers and users to look for fuel alternatives that are environment friendly, meet the EPA standards, are cost effective, and are reliable. Our group was asked by the Suburban Mobility Authority for Regional Transportation (SMART) to recommend the best possible fuel alternative for their buses. Therefore our team researched six possible options, compared them to one another, and selected the best power technology. The purpose of this report is to discuss the final design of the alternative fuel that we recommend to SMART.

II. Summary

We recommend clean diesel as the best fuel alternative for SMART. Our group has come to this conclusion after having investigated six technologies (clean diesel, biodiesel, compressed natural gas, liquid natural gas, hybrid-electric, and fuel cells) and compared them to one another. The criteria used for our selection included: emissions reduction, cost, performance, safety, availability, and ease of implementation. After having evaluated the above aspects of each fuel alternative we concluded that clean diesel best met the needs of SMART because it meets the 2004 EPA standards, meets SMART's power requirements, is cheap, and is easy to implement. Clean diesel is simply a more refined version of standard petroleum diesel with the sulfur removed. This allows for advanced exhaust aftertreatment to reduce emissions to acceptable levels, and has the same energy content as regular diesel. It is also cheap and simple to implement because it is practically the same.

III. SMART Bus Requirements

SMART requires buses that meet certain specifications. We selected as our primary physical requirements from their "Technical Specifications" document that any bus to be considered must be "capable of seating fifteen (15) ambulatory passengers and two (2) wheelchair passengers;" that the chassis must be "heavy-duty Ford E350, or equivalent, to meet [gross vehicle weight (G.V.W.)] requirements [of 11,000 lbs];" it must have a "minimum 7.3 liter diesel" engine with enough power to go 61 m.p.h. on a level road, "maintain a speed of forty five (45) m.p.h. on a two and one half percent (2-1/2%) grade and seven (7) m.p.h. on a sixteen percent (16%) grade," "obtain a speed of forty (40) m.p.h. in no more than thirty-four (34.0) seconds;" and it must hold enough fuel to "operate a minimum of 300 miles on a fill-up of fuel." Not only must a bus meet these requirements, it must also meet applicable emissions standards: in our case, the 2004 and 2007 EPA emissions standards. We compared six alternative fuels using these criteria (Fig. 1) as most important, but also looking at availability, efficiency, ease of implementation, cost, and safety. We found that clean diesel is the best fuel.

Figure 1: Evaluation Matrix

	Scalar Weight	**Bio-diesel**	**Fuel Cells**	**CNG**	**LNG**	**Hybrid Electric**	**Clean Diesel**
Availability	7	10	5	9	9	8	10
Power Requirements	10	10	10	10	10	8	10
Emissions	10	6	10	9.5	9.5	9	8
Efficiency	8	9	10	5	6	8	9
Implementation	9	7	5	6	6	6	10
Cost	9	9	4	7	8	6	9
Safety	9	9	7	6	6	8	8
Totals	**620**	**527**	**459**	**469**	**486**	**470**	**565**

IV. Clean Diesel Meets Power And Fuel Requirements

To calculate how much power is actually required to meet the specifications, we used the equation:

$$P = (0.5\rho A C_d v^2 + \mu W\cos\theta + W\sin\theta)v$$

where P is the power required at the wheels, ρ is the air density, A is the frontal area of the bus, C_d is the coefficient of air resistance, v is the speed, μ is the coefficient of rolling friction, W is the weight, and is the inclination angle of the road. Although the bus is only required to meet the acceleration and gradability specifications at the seated low weight, we used the gross vehicle weight to ensure full compliance.

We found that a typical bus that meets these requirements has a frontal area of about 6.9 m^2, a coefficient of air resistance of about 0.65 (1), a coefficient of rolling resistance of about 0.008 (2), and a weight of about 62 kN; the density of air 1.25 kg/m^3. Substituting these values into the equation, we find that it takes about 48 HP to climb a 2-1/2% grade hill at 45 MPH, 24 HP to climb a 16% hill at 7 MPH, and 53 HP to climb a 15° hill at 61 MPH. Exact values are given in Table 1.

Table 1: Power Requirements for Specific Buses

	G.V.W. (N)	**Width (m)**	**Height (m)**	**P 2-1/2% (HP)**	**P 16% (HP)**	**P 15° (HP)**
Glaval Unverisal 450 (3)	62,700	2.44	2.82	48.0	24.3	52.5
Diamond Coach PT 2000 (4)	62,700	2.44	2.84	48.1	24.3	52.8
Collins Grand Bantam 450 (5)	62,400	2.41	2.90	48.2	24.2	53.1

We found that for the typical bus of the type we recommend, the maximum power required at the wheels is a little over 50 horsepower. A typical 7.3 liter diesel engine, as required by SMART, offers 175+ horse power, plenty of power to meet these specifications. These buses are essentially the same as the ones currently in use by SMART, so this is not a major change in technology on that end. Currently SMART's buses get about 6.5 miles per gallon (Appendix A), so since each of these buses has a 55 gallon fuel tank, they will be able to 360 miles on a tank of fuel, which meets SMART's requirement of 300 miles per tank of fuel.

V. Clean Diesel Meets 2004 EPA Emissions Standards

Clean diesel, as implied by the name, produces much less emissions than conventional diesel. Not only does the reduction in sulfur directly eliminate much undesirable emissions, it also allows for the use of aftertreatment in the form advanced catalytic converters and particulate filters, which reduces emissions considerably. The EPA regulates engine emissions, and in 2004 it will limit combined hydrocarbon and nitrous oxide (HC + NOx) emissions to 2.5 grams per brake-horsepower-hour (g/bhp-hr). Particulate matter (PM) will me limited to 0.05 g/bhp-hr at that time. Then in 2007, NOx emissions will be reduced to 0.20 g/bhp-hr, HC emissions to 0.14 g/bhp-hr, and PM emissions to 0.01 g/bhp-hr (6). Currently, with full aftertreatment, clean diesel meets all 2004 EPA emissions standards (Fig. 2) with HC emissions of 0.0019 g/bhp-hr, NOx emissions of 2.40 g/bhp-hr, and PM emissions of 0.0013 g/bhp-hr (7). Unfortunately, it does not meet the 2007 EPA standards for nitrous oxide emissions (Fig. 3). However, we are hopeful that further development of aftertreatment technologies will allow the buses to meet all EPA standards..

Figure 2: Clean Diesel Meets 2004 EPA Standards

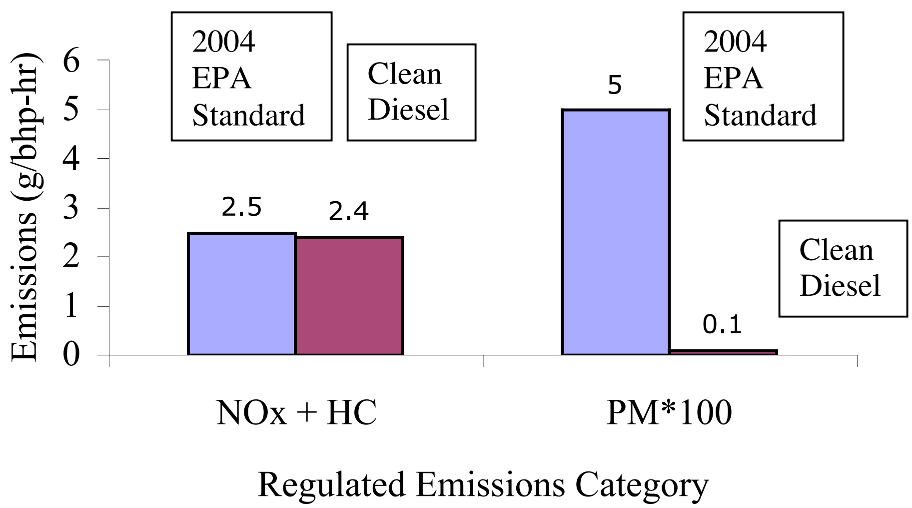
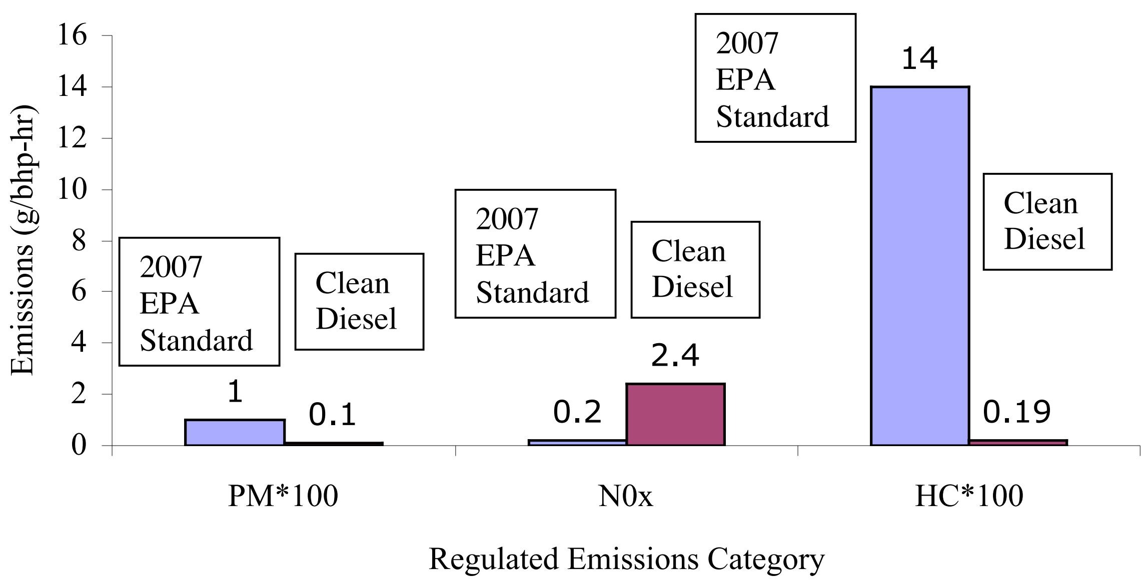


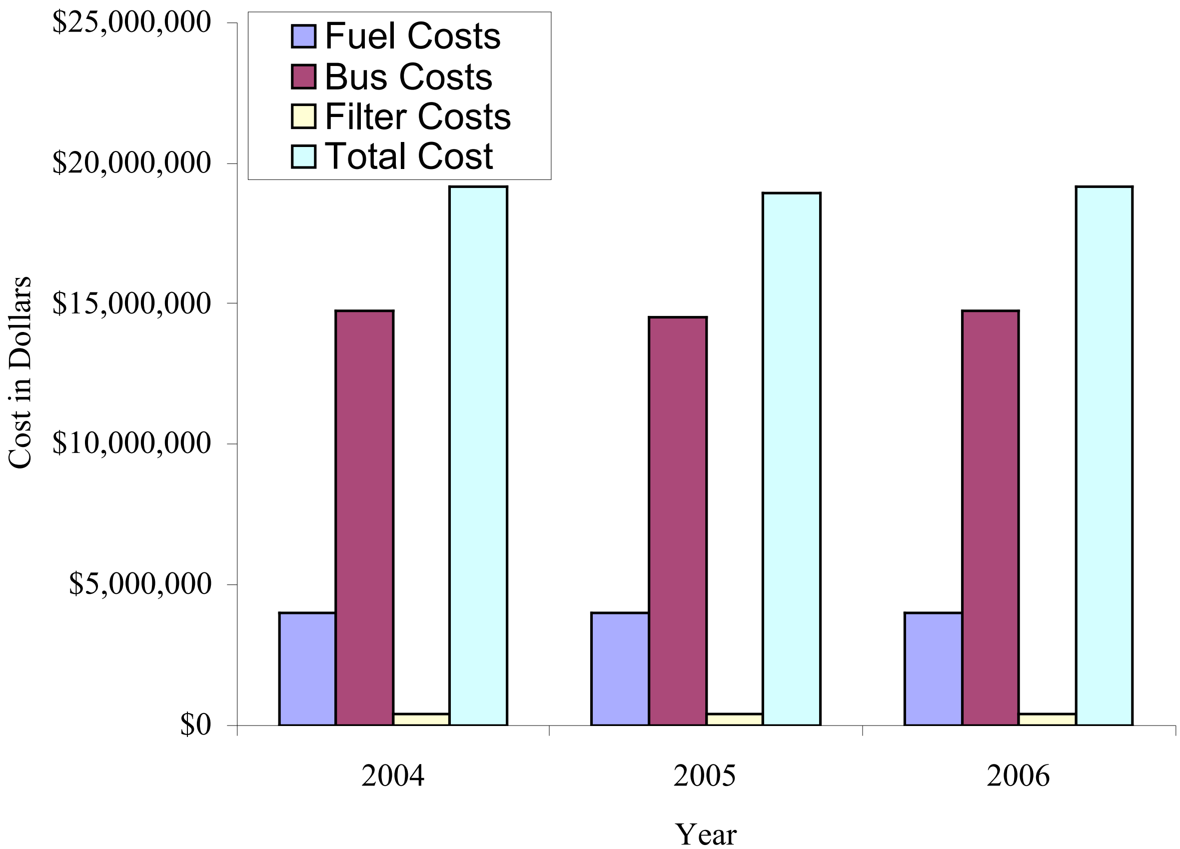
Figure 3: Clean Diesel Meets All 2007 EPA Standards Except NOx



VI. Costs Of Clean Diesel

Clean diesel has a small increase in price compared to traditional diesel. The fuel itself costs about 10 cents more per gallon than traditional diesel fuel (8, 9). This cost should go down in the future when the supply of ultra low sulfur diesel increases. The cost of the new buses is about $220,000 per bus plus an additional cost of $6,000 per bus for new catalytic converters (10, 11, 12). There is a minimal maintenance cost associated with the filter; it requires annual cleaning (11). Figure 4 shows annual costs over a three-year period. Because clean diesel and traditional diesel share many of the same properties, clean diesel has some cost benefits. There will be no cost to build new storage facilities because clean diesel can be stored in existing storage tanks. Money will also be saved on training because employees already know how to handle the fuel. If the same storage facilities are used then there will be additional cost increases. These costs are due to fact that all of SMART's fleet would have to be fueled with clean diesel. Since clean diesel is more expensive, this would increase the total amount the company spends on fuel. The cost of the fuel would be about 4 million dollars per year. (see Appendix B)

Figure 4: Costs Associated With Clean Diesel



There are also costs associated with training SMART employees about the new buses. The employees will need to learn how to operate and maintain the new buses. The benefit of these buses is that they are similar to buses that SMART currently operates; consequently, there is not as much training needed compared with other options.

A. Using Clean Diesel Has Cost Benefits

There are several cost benefits associated with switching to clean diesel. First, the Internal Revenue Service is offering a $100,000 credit per year for the purchase of "clean buses," for which clean diesel buses qualify (14). Also these buses will be exempt from Michigan property taxes and emissions testing (14). The largest benefit of using clean diesel is SMART's relationship with the public. SMART can now advertise the it is a "green" company, and possibly increase its ridership.

VII. Clean Diesel Will Be Available

Although not available everywhere, ultra-low sulfur diesel is being produced by several companies, including ConocoPhillips, ARCO, Tosco, and BP. Ultra-low sulfur diesel is, unfortunately, not practicably available in Detroit, MI. However, the Environmental Protection Agency is targeting the area for ULSD availability by the end of 2003 (15).

VIII. Clean Diesel Is Simple To Implement

Clean diesel is easy to implement because it has nearly the same characteristics as traditional diesel. Clean diesel is different in only one way: it has low sulfur content. Because the two fuels are so similar, not much will have to be changed to use clean diesel. Clean diesel can be stored in the same tanks that were previously used to store diesel. Of course, the tanks will have to be completely emptied of the traditional diesel before the clean diesel is put in them, but no new storage will be needed. In addition to the same storage, clean diesel runs in the same engine as traditional diesel. The only major change that will be needed is the installation of an advanced particulate filter and catalytic converter. This will take a minimal amount of time. Maintenance will be the same as it was for traditional diesel with the addition of a yearly cleaning of the particulate filter.

IX. A Three-Year Schedule of Implementation

The schedule for implementing clean diesel into the old SMART buses and using them in the new buses is relatively clear (Fig. 5). The buses should be bought before 2007 so they do not have to follow the 2007 EPA emissions regulations. Buying one third of the desired fleet of buses a year will be enough to purchase all of them before 2007. In time, the filtration system for the particulate mater filtration will hopefully better itself to the point of clean diesel following the 2007 EPA standards. As stated earlier, the same storage can be used as soon as the traditional diesel has been completely removed from it. Clean diesel can be introduced gradually to the buses as you begin to run out of traditional diesel.

Figure 5: Schedule for Implementation

	YEAR											
TASK	2004				2005				2006			
Train Mechanics	■											
Order 1/3 of the buses	■											
Use traditional diesel in old buses	■	■	■	■								
Use clean diesel in new buses			■	■	■	■	■	■	■	■	■	■
Use clean diesel in old buses					■	■	■	■	■	■	■	■
Order 1/3 more of the buses					■							
Clean storage tanks of diesel (as they are emptied)	■	■	■	■								
Use same storage tanks for clean diesel			■	■	■	■	■	■	■	■	■	■
Order last 1/3 of the buses									■			

X. Reasons Other Fuels Were Rejected

In order to narrow the six propulsion technologies down to the best option, we had to consider the strengths and weaknesses of each of the technologies. While doing so, our group noticed that each of the technologies had strengths and weaknesses, but the five technologies (compressed natural gas, liquid natural gas, hybrid electric, fuel cells and biodiesel) other than clean diesel all had major flaws. These flaws made it obvious that the clean diesel would be the best option.

A. Flaws Of Compressed Natural Gas

Although the emissions of compressed natural gas are very low, the overall price required to make the transition to this technology is too high. In order to implement compressed natural gas, all new buses and new storage tanks would be needed. Both of these things would be very expensive, and would cost too much money towards the SMART budget. The refueling costs of compressed natural gas are eight times as high as for diesel due to the need to buy compressors and new storage tanks (16). In addition to this, the overall safety of compressed natural gas in the buses is very low. The gas would have to be stored in large tanks on the buses at extremely high pressures (3000-3600psi). If an accident was to occur, the tank could explode, which would cause the deaths of many people on the bus and the people surrounding the area. Due to these flaws, compressed natural gas is not a viable option for SMART.

B. Flaws Of Liquid Natural Gas

Similar to compressed natural gas, the emissions are very low, but the overall price required to make the transition to the technology is too high. In order to implement liquid natural gas, all new buses and new storage tanks would be needed. The price of these requirements would be very high. The refueling costs would be three times as high as it is for diesel (16), which is due to the need to buy all new storage tanks. In addition to this, the safety of the technology is also not too high. The liquid natural gas has to be stored at extremely low temperatures (-150°C). If an accident was to occur, the low temperature liquid could be dangerous to any surrounding people. Due to these flaws, liquid natural gas is not a viable option for SMART.

C. Flaws Of Hybrid-Electric

This technology has one of the lowest emissions of all the possible technologies, but the price of implementation is way too high. At this point in time, scientists have not perfected the science required to make hybrid electric buses useable. Due to this, the technology is not readily available, and is also extremely expensive. The average price per mile of the buses would be $2.33 for the hybrid electric bus compared to $1.52 per mile for the diesel buses (18). This is partially due to the buses costing more than double the price ($500k) of the standard diesel buses ($250k). This price conflict does not comply with the SMART budget. Due to this conflict, the hybrid electric technology is not a viable option for SMART at this time. However, in the future, the technology could be perfected and would be a more considerable option.

D. Flaws Of Fuel Cells

This technology has the lowest emissions of all the possible technologies, which made our team look into it thoroughly. When doing so, we saw that scientists have not perfected the technology, which made the price of implementation extremely high. No exact numbers can be calculated for the price of fuel cells, but it would be more than double the price of diesel buses (17). In addition, we calculated that the amount of greenhouse gases released in the production of the hydrogen which would go into the fuel cells is equal to the amount of greenhouse gases released by diesel buses in use. This means the life cycle of the greenhouse gases for diesel buses is the same for fuel cells, which makes fuel cells no better in emissions than diesel (17). These issues make the technology not a viable option, but years in the future, the technology may be a considerable option.

E. Flaws Of Biodiesel

This technology was one of the most considerable options that we researched. However, we found that it had some problems with implementation. First of all, it tends to solidify at cold (0°C) temperatures (19, 20), which is important to consider because these temperatures are attained in Michigan. In addition to this, the NOx emissions of bio-diesel do not meet the 2004 EPA, nor the 2007 EPA standards for emissions. Due to these flaws, biodiesel is not a viable option for SMART.

XI. Conclusion

Our research group has completed all of our research objectives. We have researched all the technologies in great depth, and based on the information, we have narrowed the six technologies to clean diesel. We found that clean diesel is overall the best technology; although some other alternative fuel technologies came out ahead in certain areas, they all had major flaws, making clean diesel the best choice. Consequently, although clean diesel is not perfect, we strongly recommend that SMART go with this fuel technology because it has low emissions, good performance, and is simple to implement.

XII. References

(1) Horowitz, A., “Propulsion Resistance”,
http://www.uwm.edu/~horowitz/PropulsionResistance.html , (December, 2003)

(2) Rolling Resistance, HowStuffWorks.com
http://science.howstuffworks.com/question523.htm , (December, 2003)

(3) Glaval Universal 350/450 Specifications
http://www.forestriverinc.com/glaval/default.asp?page=universal&choice=specs, (December, 2003)

(4) Diamond Coach PT-2000 Specifications
http://www.diamondcoach.com/VIPOptions.pdf, (December, 2003)

(5) Collins Ford Type A-1 Grand Bantam Specifications
http://www.collinsbus.com/pdf_files/grandbantam.pdf, (December, 2003)

(6) EPA "Heavy-Duty Vehicle and Engine Standards", December, 2000,
http://www.epa.gov/otaq/regs/hd2007/frm/f00057.pdf, December, 2003

(7) "INTERIM REPORT: Emissions Results from Clean Diesel Demonstration Program with CRT™ Particulate Filter at New York City Transit," April, 2001, p. 10,
http://www.epa.gov/otaq/retrofit/documents/ny_crt_presentation.pdf, (December, 2003)

(8) Environmental Conservation, August, 2000
http://www.osti.gov/fcvt/deer2000/gibbspap.pdf, (December, 2003)

(9) Field Experience with Diesel Retrofits, New York City Transit Department of Buses, October, 2003, http://bronze.nescaum.org/retrofitworkshop/Lowell.pdf, (December, 2003)

(10) Diesel Technology Forum
http://www.dieselforum.org/statements/jan_17_2001.html, (December, 2003)

(11) Specialty Equipment Market Association
http://www.sema.org/content/?id=25809, (December, 2003)

(12) Un-Regulated Emissions from CRT-Equipped Transit Buses, New York Department of Environmental Conservation, August, 2000
http://www.osti.gov/fcvt/deer2000/gibbspap.pdf, (December, 2003)

(14) Vehicle Buyers’ Guide: Incentives and Laws
http://www.ccities.doe.gov/vbg/progs/laws.cgi, (December, 2003)

(15) LSD Availability
January, 2003, http://www.epa.gov/otaq/retrofit/fuelsmap.htm, (December, 2003)

(16) Papagiannakis, R., “Experimental investigation concerning the effect of natural gas percentage on performance and emissions of a DI dual fuel diesel engine”
Applied Thermal Engineering, 2003, vol: 23 iss: 3 pg: 353

(17) MacLean, H., “Evaluating automobile fuel/propulsion system technologies”
Progress in Energy and Combustion Science, 2003 vol: 29 iss: 1 pg: 1

(18) Oh, S., “Emission characteristics in ultra low sulfur diesel”
International Journal of Automotive Technology, 2003 vol: 4 iss: 2 pg: 95

(19) BiodieselBasics, GoBiodiesel Cooperative
http://www.gobiodiesel.org/tiki-index.php?page=BiodieselBasics, (December, 2003)

(20) Diesel Fuel Cold Flow Properties, Iowa State University Biodiesel
http://www.me.iastate.edu/biodiesel/Pages/bio18.html, (December, 2003)

XIII. Appendix A: Calculations

SMART said they spend $0.11/mile for fuel. Since they said their diesel costs about $0.70/gallon, they must get about 6.5 miles/gallon of fuel.

XIV. Appendix B: Cost Calculations

Cost for buses:
Year 1: 67 buses at $220,000 = $14,740,000
Year 2: 66 buses at $220,000 = $14,520,000
Year 3: 67 buses at $220,000 = $14,740,000

Cost for fuel
15,000,000 miles x $0.22/mile= $3,300,000 x 114% cost increase = $3,762,000
2,000,000 miles x $0.11/mile = $220,000 x 114% cost increase = $250,800
Total cost = $3,762,000 + $250,800= $4,012,800

Cost for filters
Year 1: 67 filters at $6,000 = $402,000
Year 2: 66 filters at $6,000 = $396,000
Year 3: 67 filters at $6,000 = $402,000

Table 2: Total Costs for First Three years ($1,000)

2004	2005	2006
19154.8	18928.8	19154.8

Table 3: Benefits and Costs from 2004-2017

Year	Benefits $	Costs $	Benefits-Costs $	Discount Benefits-Costs $*	Cumulative Benefits $
2004	100000	19154800	-19054800	-19054800	-19054800
2005	100000	18928800	-18828800	-17932190	-36986990
2006	100000	19154800	-19054800	-17283265	-54270255
2007		4012800	-4012800	-3466407	-57736662
2008		4000000	-4000000	-3290809	-61027471
2009		4000000	-4000000	-3134104	-64161575
2010		4000000	-4000000	-2984861	-67146436
2011		4000000	-4000000	-2842725	-69989161
2012		4000000	-4000000	-2707357	-72696518
2013		4000000	-4000000	-2578435	-75274953
2014		4000000	-4000000	-2455653	-77730606
2015		4000000	-4000000	-2338717	-80069323
2016		4000000	-4000000	-2227349	-82296672
2017		4000000	-4000000	-2121285	-84417957
		Sum	**-19,054,800**	**-84,417,957**	

* Assuming a discount rate of 5%