COMMERCIAL WASTE MANAGEMENT STUDY

VOLUME VI

WASTE VEHICLE TECHNOLOGY ASSESSMENT

March 2004

Prepared for:

New York City Department of Sanitation
for submission to the New York City Council

Prepared by:

Henningson, Durham & Richardson
Architecture and Engineering, P.C.'s
Subconsultant, Urbitran, Inc.

This report was prepared for

HDR

Henningson, Durham & Richardson
Architecture and Engineering, P.C.

by its
Subconsultant

URBITRAN

TABLE OF CONTENTS

EXECUTIVE SUMMARY ES-1

1.0 INTRODUCTION........ 1

1.1 THE GROWING NEED FOR CLEAN FUEL TECHNOLOGIES........ 1

1.1.1 Pollutants from Fossil Fuel Combustion 1

1.1.2 Dependence on Foreign Oil Supplies 2

1.2 EFFORTS TO PROMOTE CLEAN FUEL TECHNOLOGIES 3

1.2.1 Federal Mandates That Promote Clean Fuel Technologies........ 3

1.2.2 Federal Agencies' Role in Promoting Clean Fuel Technologies........ 4

1.2.3 State and Local Initiatives and Mandates 5

2.0 CLEAN FUEL TECHNOLOGIES BEST SUITED FOR NEW YORK CITY REFUSE HAULERS 7

2.1 CLEAN DIESEL TECHNOLOGIES........ 7

2.1.1 Engine Tune-Ups 8

2.1.2 Ultra-Low-Sulfur Diesel Fuel and Low-Sulfur Diesel Fuel 10

2.1.3 Diesel Oxidation Catalysts........ 11

2.1.4 Diesel Particulate Filters........ 13

2.1.5 Exhaust Gas Recirculation........ 14

2.1.6 Selective Catalytic Reduction Devices 14

2.1.7 NO_X Catalysts 15

2.1.8 New Engine Technology 16

2.1.9 Implementation Issues 16

2.1.10 Clean Diesel Case Studies 18

2.2 NATURAL GAS 19

2.2.1 Fuel Characteristics........ 19

2.2.2 CNG vs. LNG 20

2.2.3 Safety 21

2.2.4 Costs........ 22

2.2.5 Fuel Emissions........ 23

2.2.6 Incentives and Disincentives 24

2.2.7 CNG Case Studies 25

2.3 CNG VS. CLEAN DIESEL (COST COMPARISON)........ 28

2.3.1 Capital Costs 28

2.3.2 Operating Costs........ 33

2.3.3 Programs and Incentives........ 36

3.0 OTHER CLEAN FUEL TECHNOLOGIES AVAILABLE........ 38

3.1 BIODIESEL 38

3.1.1 Fuel Characteristics........ 38

3.1.2 Use and Development........ 39

3.1.3 Costs........ 39

3.1.4 Fuel Emissions........ 40

3.1.5 Incentives and Disincentives 41

3.1.6 Biodiesel Case Studies........ 42

TABLE OF CONTENTS (Continued)

3.2 FUEL CELLS 45
3.2.1 Fuel Characteristics........ 46
3.2.2 Use and Development........ 46
3.2.3 Costs........ 46
3.2.4 Fuel Emissions........ 47
3.2.5 Incentives and Disincentives 47
3.3 BATTERY ELECTRIC........ 48
3.3.1 Fuel Characteristics........ 48
3.3.2 Use and Development........ 49
3.3.3 Costs........ 49
3.3.4 Fuel Emissions........ 50
3.3.5 Incentives and Disincentives 50
3.4 PROPANE........ 51
3.4.1 Fuel Characteristics........ 51
3.4.2 Use and Development........ 51
3.4.3 Costs........ 53
3.4.3 Fuel Emissions........ 54
3.4.4 Incentives and Disincentives 54
3.5 ETHANOL 54
3.5.1 Fuel Characteristics........ 54
3.5.2 Use and Development........ 55
3.5.3 Costs........ 56
3.5.4 Fuel Emissions........ 56
3.5.5 Incentives and Disincentives 57
3.6 METHANOL........ 57
3.6.1 Fuel Characteristics........ 57
3.6.2 Use and Development........ 58
3.6.3 Costs........ 58
3.6.4 Fuel Emissions........ 59
3.6.5 Incentives and Disincentives 59
3.7 HYBRID ELECTRIC VEHICLES 60
3.7.1 Fuel Characteristics........ 60
3.7.2 Use and Development........ 61
3.7.3 Costs........ 61
3.7.4 Emissions........ 62
3.7.5 Incentives and Disincentives 63
4.0 SUMMARY OF FINDINGS AND OPTIONS 65
4.1 NEED TO PROMOTE CLEAN FUELS 65
4.2 TYPES OF CLEAN FUELS 65
4.2.1 Clean Diesel........ 65
4.2.2 Natural Gas 65
4.2.3 Biodiesel 66
4.2.4 Fuel Cells 66

TABLE OF CONTENTS (Continued)

4.2.5 Battery Electric 66
4.2.6 Propane 66
4.2.7 Ethanol 66
4.2.8 Methanol 67
4.2.9 Hybrid Electric 67
4.3 OPTIONS 67
4.3.1 New York City Department of Sanitation 67

LIST OF TABLES

Table 1.2.2-1 Select USEPA Emission Certification Standards (grams/brake hp-hr) for Newly Manufactured Heavy-Duty Trucks over 33,000 pounds
Table 2.1-1 USEPA Cost Projections for Heavy-Duty Diesel 2004 & 2007 Emissions Standards (1991 dollars)
Table 2.1-2 Clean Diesel Enhancement Options and Projected Emission Reductions
Table 2.3.1.1-1 Vehicle Comparison (CNG vs. Conventional Diesel)
Table 2.3.1.1-2 DSNY Vehicle Cost Comparison (CNG vs. Clean Diesel)
Table 2.3.1.1-3 INFORM Vehicle Cost Comparison (CNG vs. Clean Diesel)
Table 2.3.1.1-4 Waste Management Vehicle Cost Comparison (CNG vs. Clean Diesel)
Table 2.3.1.2-1 Cost of Natural Gas Garbage Trucks and Refueling Infrastructure
Table 2.3.2.1-1 Regional Fuel Prices (2002)

LIST OF FIGURES

Figure 2.1.3-1 Diesel Oxidation Catalyst
Figure 2.1.4-1 Particulate Filter
Figure 2.1.6-1 Cutaway View of a Catalytic Converter
Figure 2.1.9-1 School Bus Retrofitted with a Particulate Trap

List of Acronyms/Definitions

Acronyms	
AFV	alternative fuel vehicle
CAA	Clean Air Act
CH_4	methane gas
CMAQ	Congestion Mitigation and Air Quality Improvement Program
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DOC	diesel oxidation catalyst
DOE	Department of Energy
DPF	diesel particulate filter
DSNY	New York City Department of Sanitation
EGR	exhaust gas recirculation
EPACT	Energy Policy Act
ETBE	ethyl tertiary butyl ether
GVWR	gross vehicle weight rating
HAP	hazardous air pollutant
HC	hydrocarbon
HEV	hybrid electric vehicle
hp	horsepower
hp-hr	horsepower-hour

Acronyms	
LL74	Local Law 74, effective December 19, 2000, enacted by the City Council, requiring a comprehensive assessment of commercial solid waste management in New York City
LNG	liquefied natural gas
MTA	Metropolitan Transportation Authority
NO_X	nitrogen oxide
NYCDEP	New York City Department of Environmental Protection
NYCDOT	New York City Department of Transportation
NYCT	New York City Transit
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
O_3	ozone
OEM	original equipment manufacturer
PM	particulate matter
ppm	parts per million
psi	pounds per square inch
SCR	selective catalytic reduction
SO_2	sulfur dioxide
TEA-21	Transportation Equity Act for the 21st Century
USDA	United States Department of Agriculture
ULSD	ultra-low-sulfur diesel fuel
USEPA	United States Environmental Protection Agency

Definitions	
City	New York City
B5	A blend of biodiesel fuel, made up of 95% petroleum-based diesel fuel and 5% biodiesel fuel
B20	A blend of biodiesel fuel, made up of 80% petroleum-based diesel fuel and 20% biodiesel fuel
B100	Biodiesel fuel in its pure form with no petroleum diesel fuel added
Consultant	The DSNY's Consultant Team, including Henningson, Durham & Richardson Architecture and Engineering, P.C.; Parsons Brinckerhoff Quade and Douglas, Inc.; Ecodata, Inc.; Franklin Associates, Ltd.; Urbitran Associates, Inc.; HydroQual, Inc.; and Cambridge Environmental, Inc., who prepared the Commercial Waste Management Study
E10	Ethanol blend of 10% ethanol and 90% gasoline
E85	Ethanol blend of 85% ethanol and 15% gasoline
E95	Ethanol blend of 95% ethanol and 5% gasoline
Final Study Scope or Final Scope of Work	Commercial Waste Management Study Final Scope of Work issued on July 31, 2003
M85	Mixture of 85% methanol and 15% gasoline
M100	Pure methanol
New SWMP	The new comprehensive Solid Waste Management Plan to be developed in 2004 for both DSNY-managed Waste and commercial waste for the planning period 2004 through 2024
New SWMP Planning Period	The 20-year period from 2004 to 2024 addressed by the City's New Solid Waste Management Plan
Study	Commercial Waste Management Study

EXECUTIVE SUMMARY

PREFACE

Local Law 74 of 2000 (LL74) mandated a comprehensive study of commercial waste management (Commercial Waste Management Study or Study) in New York City (City) by a Consultant funded by the City Department of Sanitation (DSNY). This Study undertaken to comply with LL74 will assist the City in managing the commercial waste stream in the most efficient and environmentally sound manner, and to assist in the development of the City's Solid Waste Management Plan (New SWMP) for the New SWMP Planning Period.

Among the topics that LL74 requires the Study to address are: *". . . the size and type of vehicles that should be authorized to transport sold waste to or from putrescible and non-putrescible solid waste transfer stations and fuel type requirements for such vehicles."* The Commercial Waste Management Study Final Scope of Work elaborates on this requirement, stating: *"Under almost any scenario for the future, the movement of solid waste in the City will remain heavily dependent upon diesel-powered trucks. The ideal and most effective measure to reduce air pollution would be to reduce the emissions by these trucks. The main objective of this Task is to determine if particulate traps, alternate fuels, or truck types might be feasible and lawful means of reducing truck emissions. In consultation with DSNY, which has extensive experience in testing alternative fuels and emissions control equipment on its collection fleet, the Consultant Team will provide an overview of the different options for alternative fuels and vehicle types/retrofits. The focus will be on proven technologies and vehicle types. If regulations are to be imposed or incentives provided, they must represent realistic emission reduction technology and options that would not create undue hardship for truck fleet operators. . . . An evaluation will be performed to determine if a particular type or types of vehicle would be more economically and environmentally feasible. To assess whether alternatives can be implemented, the following will be examined: Regulatory Options . . . [and] . . . Institutional Barriers."*

In addition to this Volume VI, this Study consists of five other volumes:

- Volume I: Private Transfer Station Evaluations;
- Volume II: Commercial Waste Generation and Projections;
- Volume III: Converted Marine Transfer Stations – Commercial Waste Processing and Analysis of Potential Impacts;
- Volume IV: Evaluation of Waste Disposal Capacity Potentially Available to New York City; and
- Volume V: Manhattan Transfer Station Siting Study.

This volume, Volume VI: Waste Vehicle Technology Assessment, reports on a survey of alternative fuels, new engine technologies and vehicle emission retrofit options that are appropriate for use on waste collection vehicles and profiles the innovative DSNY programs and initiatives implemented to evaluate alternative fuels, engine technologies and retrofit options. The volume provides an assessment of the advantages and disadvantages of the various options to reduce consumption of fossil fuels and/or reduce vehicle emissions, and recommends cleaner technologies, including technologies that DSNY had previously tested and, in some cases, targeted for implementation.

EXECUTIVE SUMMARY

Scope of Analysis/Approach

The purpose of this evaluation is to explore the different types of alternative and clean fuel technologies available to determine which clean and alternative fuel technologies are most feasible for the unique demands of heavy-duty refuse haulers operating in the City. The review presented in the Waste Vehicle Technology Assessment report weighs the economic, environmental and logistical advantages and disadvantages of various clean and alternative fuel technologies. After thorough research and analysis of all available viable options, including several case studies, options that are best suited for heavy-duty refuse haulers operating in the City are presented.

Findings

The report found that clean diesel technology is best suited for the City's refuse hauling vehicles. It provides substantial emission reduction benefits without having a major impact on fuel efficiency and cost. Natural gas technologies are also well suited for the City's refuse hauling vehicles. However, the use of this technology entails significant infrastructure investment, and, because of high demand for natural gas, has greater cost uncertainties.

Clean Diesel Options

The clean diesel options discussed in the report can cut vehicle emissions by 90% or more.

Engine tune-ups are the least expensive way to reduce particulate matter (PM) emissions. This emission reduction strategy can also lower operating costs, extend engine life and improve fuel economy. However, it should be noted that repairs and maintenance of diesel engines tend to increase nitrogen oxide (NO_X) emissions.

In addition to tune-ups, in certain circumstances, the **replacement of older diesel engines and equipment** may be the most sensible and cost-effective emissions improvement options. When old vehicles are replaced, fleet managers can substitute their oldest and worst emissions performers with new technology present in new diesel engines that are designed to produce much lower emissions.

Sulfur found in fuel degrades the effectiveness and life of after-treatment devices by inhibiting the function of existing filters and catalysts. By using **ultra-low-sulfur diesel** (ULSD) (which has a sulfur content of 15 parts per million [ppm] or less) and/or low-sulfur diesel fuel (sulfur content between 30 ppm and 15 ppm), there can be improvements in the performance of after-treatment technologies seeking to reduce emission levels. However, ULSD fuel only reduces PM and sulfur dioxide (SO_2) emissions. Without after-treatment devices, it does not reduce emissions such as hydrocarbons (HC), carbon monoxide (CO) or NO_X emissions. Some operating and maintenance concerns associated with ULSD fuel include a slightly lower fuel economy as compared with regular diesel, and concerns regarding the lubrication properties of the fuel. DSNY, a leader in experimenting with heavy-duty refuse vehicles, currently has 600 of its 2,040 refuse collection trucks using low-sulfur diesel fuel.

Diesel oxidation catalysts (DOCs) devices are considered the most proven of after-treatment options and can be used with existing or used engines to pollute less by retrofitting them.[1] According to the Diesel Technology Forum, emissions benefits include reductions of total PM by 20% to 50% and CO and HC by 60% to 90%.[2] They do not reduce NO_X emissions.

Diesel particulate filters (DPFs), when used with ULSD fuel, can reduce PM emissions by 50% to 90%, and HC and CO emissions by as much as 90%. However, like oxidation catalysts, these devices do not reduce NO_X emissions.

---

[1] Diesel Technology Forum, *Clean Air, Better Performance*, 2003.
[2] *Ibid.*

Although the use of DOCs and DPFs is not yet widely available for waste collection trucks, tests are ongoing that are assessing the use of these after-treatment options. DSNY is taking the lead in testing these technologies.

Another emission reduction strategy is to use **exhaust gas recirculation** to decrease NO_X levels. With the new, lower-sulfur diesel fuels, production of sulfuric acid will be minimized. This technology can reduce NO_X emissions by as much as 40%, and can also be used with engines being retrofitted.

Selective catalytic reduction (SCR) has been used for over 15 years to reduce NO_X emissions from stationary sources. Emission reductions include NO_X by 75% to 90%, HC reductions up to 80% and PM reductions of 20% to 30%.

Currently, **NO_X catalysts** are being experimented with in the United States on retrofitted vehicles. Two NOx catalyst technologies, "lean NO_X catalyst" and "NO_X absorber," are currently being developed, and can reduce NO_X emissions up to 70%.

Natural Gas

The main incentive for choosing natural gas as an alternative fuel for heavy-duty refuse trucks is the emissions benefits. Studies of heavy-duty engines running on compressed natural gas (CNG) and diesel have shown that engines fueled with CNG emit significantly less PM (80% to 90% less) and NO_X (50% to 60% less) emissions than diesel engines. Another benefit of using a CNG engine is the reduction of engine noise, as CNG engines are significantly quieter than diesel engines. Furthermore, investing in CNG facilities now will ease future transitions to hydrogen fuel cells as a vehicle-fueling source.[3]

[3] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

One of the major disincentives to creating a CNG refuse truck fleet is the cost related to purchasing the trucks and the infrastructure needed for a CNG facility. A CNG trash hauler can cost up to $70,000 more than a conventional diesel truck. In addition, the cost of a CNG facility with fueling, proper ventilation and leakage alarms can cost $500,000 to $1,250,000 to construct.[4] Another disadvantage of CNG is that most of the natural gas used in CNG engines comes from reserves in North America. Due to unmet demand for natural gas in the U.S., natural gas has seen extreme price fluctuations. In addition to the high costs, other issues, such as lower fuel efficiency than conventional diesel garbage trucks (due to heavier weight and longer size of vehicles), limited vehicle range, and high methane (CH_4) and CO_2 emissions, must be considered.

Other Available Technologies

The report also evaluates the costs and benefits of other alternatives, including biodiesel, fuel cells, battery electric, propane, ethanol, methanol, and hybrid electric vehicles (HEVs), but none were deemed as promising and cost effective to DSNY as the clean diesel and natural gas options.

Based on this report, DSNY should consider the following options:

- Continuing to utilize and experiment with ULSD fuel and clean diesel technology in existing vehicles with the goal of all diesel vehicles, currently in operation, utilizing clean diesel technology to meet United States Environmental Protection Agency (USEPA) 2004 and 2007 emissions standards.
- Continuing to make clean diesel technology the preferred vehicle standard for new heavy-duty refuse vehicle purchases.
- Continuing to test and compare alternative fuel exhaust emissions in order to evaluate hybrid electric refuse vehicles.

[4] *Ibid.*

- Continuing to pursue its CNG heavy-duty program, so that DSNY will be able to take advantage of potential advancements in CNG technology and fuel cell technology.
- Continuing to develop partnerships with fuel suppliers, original equipment manufacturers (OEMs) and infrastructure providers in order to help reduce the cost of clean fuel implementation.
- For light-duty vehicles, continuing with ethanol purchase and plans for ethanol fueling facilities.
- Utilizing government grants and economic incentives to offset the higher costs associated with natural gas, hybrid electric and ethanol vehicles.

Private waste haulers in the City should consider these options:

- Retrofitting old diesel vehicles with clean diesel technology.
- Beginning to use ULSD ahead of June 2006 mandate.
- Deploying and purchasing clean diesel vehicles now to avoid future expenses that will be needed to meet new strict USEPA emission standards.
- Utilizing government grants and economic incentives to help offset the incremental capital costs associated with natural gas refuse vehicles.
- In conjunction with infrastructure supplier and engine manufacturers, exploring the future option of CNG heavy-duty refuse vehicles.

---

[5] Diesel Technology Forum, *Clean Air, Better Performance*, 2003.
[6] *Ibid.*
[7] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[8] *Ibid.*

WASTE VEHICLE TECHNOLOGY ASSESSMENT

1.0 INTRODUCTION

1.1 The Growing Need For Clean Fuel Technologies

After the Second World War, petroleum began to replace coal as the primary energy source in the United States. Engineering developments and increased availability of petroleum resulted in a greater supply and lower cost of gas and oil. This fact, coupled with a post-war economic boom and increased U.S. investment in roads and highways, including the development of an interstate highway system, helped to spur greater automobile usage in this country. U.S. dependence on petroleum-based fuels grew as the automobile helped families migrate from cities to the suburbs, municipalities replaced trolley-car public transportation systems with buses, and trucks supplanted trains as the main transporter of goods.

The increased usage of petroleum-fueled vehicles did not come without a cost. Pollution levels began to rise, particularly in and around American cities, leading to heightened public concern about the relationship between emissions from petroleum fuel combustion and degraded air quality, acid rain and global warming. A by-product of petroleum fuel combustion is the release of gases and minute particles that pollute the atmosphere and create a public health concern. These health and pollution concerns are the primary reason for the push to convert fleets to alternative and clean low emissions fuels in the United States and much of the world.

1.1.1 Pollutants from Fossil Fuel Combustion

Among the gases emitted from fossil fuel combustion is carbon dioxide (CO_2). CO_2 is a naturally prevalent gas in the atmosphere and is as important to plant growth as oxygen is to animal growth. However, CO_2 is also responsible for absorbing radiation and helping to keep the planet warm. The release of CO_2 from fossil fuel combustion in recent decades has caused increased concentrations of CO_2 in the earth's atmosphere. Because CO_2 is an absorber of infrared radiation, it tends to restrict heat loss to space, and this has raised concerns about possible global warming, known as the "greenhouse effect."

Another gas emitted from petroleum fuel combustion is nitrogen oxide (NO_X). The release of NO_X is of particular concern to residents of large cities because it reacts with hydrocarbons (HC) in the presence of sunlight to create ground level ozone (O_3), more commonly referred to as smog. High levels of smog can cause lung and respiratory disorders; even short-term exposure can cause health problems, particularly in children and the elderly.

Particulate matter (PM) is released in the emission of petroleum fuel combustion. PM is the term for particles found in the air, including dust, dirt, soot, smoke and liquid droplets. PM can be large enough to be seen, as is the case with soot, or so fine that it is invisible to the naked eye. High levels of PM in the air can cause respiratory ailments, damage buildings and structures, and pollute water and soil. PM emitted from heavy-duty vehicles' diesel fuel combustion, such as trucks and buses, is of particular concern in dense metropolitan areas. Studies have shown that associations exist between airborne pollutants generated by diesel-powered vehicles and health risks, such as reduced lung function, lung damage, increased asthma attacks and premature mortality.

Other pollutants emitted from fossil fuel combustion are sulfur dioxide (SO_2) and carbon monoxide (CO). SO_2 escapes into the atmosphere where complex chemical reactions take place, converting the SO_2 into sulfuric acid. The sulfuric acid returns to the earth in the form of acid rain. Acid rain can adversely affect certain water bodies and forests, especially those with limited natural acid buffering capacity. CO, the by-product of the incomplete combustion of petroleum fuel, is emitted directly from vehicle tailpipes. CO is a poisonous gas that can affect the cardiovascular and central nervous system by limiting the ability of hemoglobin to carry oxygen.

1.1.2 Dependence on Foreign Oil Supplies

In addition to pollution, the limited supply of crude oil worldwide and the United States dependence on foreign oil sources are additional concerns related to fossil fuel use by transportation vehicles and fleets. Worldwide crude oil production is approaching its peak. Conservative estimates, made by experts associated with oil companies, indicate that the world's crude oil supply will peak around the year 2025.[1] After peaking, petroleum production will begin to decline, causing the price of petroleum to increase. Serious implications for the U.S. economy are likely to result, as currently over 97% of the fuel used for transportation is petroleum-based. Over the past 20 to 30 years, the United States has become more and more dependent on foreign sources of oil. Domestic petroleum production peaked in the early 1970s and as a result the U.S. economy has become increasingly reliant on foreign sources of oil, particularly from the politically volatile Middle East.[2] World oil reserves nearing their peak and increased U.S. dependence on foreign oil supplies have underscored the need for a transition from petroleum-based fuels to alternative and more efficient fuels or sources of energy.

1.2 Efforts To Promote Clean Fuel Technologies

In order to spur use of clean fuel technologies, federal, state and local governments have passed legislation and set requirements that mandate the use of clean alternative fuels in public and private vehicle fleets. In some cases, government agencies have also subsidized purchases of alternative fuel vehicles (AFVs). The purpose of these efforts is to create a greater market for clean and alternative fuel technologies and foster a wider use of clean and alternative fuels throughout the country.

1.2.1 Federal Mandates That Promote Clean Fuel Technologies

The Clean Air Act (CAA) was first passed in 1970, with significant amendments occurring in 1977 and 1990. The CAA and its implementing regulations are intended to reduce stationary and mobile source air pollution nationwide. CAA regulations set emissions and air quality standards to reduce human and environmental exposure to pollutants. Among the requirements of the CAA are stipulations for certain centrally-fueled vehicle fleets in cities that are in non-attainment areas for CO or O_3 (as defined by the CAA), and to phase in a percentage of new vehicles that meet CAA emission standards.[3]

---

[1] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August 1999.
[2] *Ibid.*
[3] Section 246 of the Clean Air Act as amended 1990, http://www.epa.gov/air/caa/caa246.txt.

1.2.2 Federal Agencies' Role in Promoting Clean Fuel Technologies

The United States Environmental Protection Agency (USEPA) sets the standards for the amount of pollution vehicles can emit and tests heavy-duty engines for emissions certification. The USEPA has recently established a national program to further regulate heavy-duty vehicle emissions, with new standards to become effective in 2007. To comply with the new standards, the USEPA is requiring diesel fuel to have reduced sulfur amounts by 2006.[4] Table 1.2.2-1 summarizes some of the USEPA standards for newly manufactured heavy-duty trucks with a gross vehicle weight rating (GVWR) over 33,000 pounds.

Table 1.2.2-1
Select USEPA Emission Certification Standards (grams/brake hp-hr) for Newly Manufactured Heavy-Duty Trucks over 33,000 pounds

Pollutant	1998-2003	2004-2007	2007+
Non-Methane Hydrocarbons	1.3	*	0.14
NO_X	4.0	*	0.2
Carbon Monoxide	15.5	15.5	15.5
Particulates	0.10	0.10	0.01

Source: INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
*2004 Standards set total NO_X + non-methane hydrocarbons limit of 2.4 grams/brake hp-hr.

The Department of Energy (DOE) is responsible for providing federal leadership on clean fuels technologies by encouraging the purchase and use of AFVs. The DOE provides, through its voluntary Clean Cities program, information and funding for the purchase of alternative fuels. The DOE also manages the State and Alternative Fuel Provider Fleets Credits Program. This program allows credits to be taken for AFV purchases to prove AFV acquisition requirements.

The Federal Department of Transportation provides funding for the acquisition and use of AFVs. Through the Congestion Mitigation and Air Quality Improvement Program (CMAQ), it provides funding to states and cities in non-attainment areas for projects or programs that aim to reduce vehicle emissions and improve air quality. CMAQ funding is authorized through the Transportation Equity Act for the 21st Century (TEA-21).[5]

[4] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Heavy Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements (EPAA420-F-00-057), December 2000.
[5] U.S. Federal Highway Administration, Office of Environment, *CMAQ Congestion Brochure*, http://www.fhwa.dot.gov.environment/cmaq/funding.htm.

1.2.3 State and Local Initiatives and Mandates

New York City (City) and New York State also have initiatives aimed at stimulating the use of alternative fuels. New York City Local Law 6, passed in 1991, requires the City to purchase AFVs. After passage of this law, the City implemented a multi-agency program with New York City Department of Environmental Protection (NYCDEP), New York City Department of Transportation (NYCDOT), and New York City Administrative Services to buy alternative vehicles and help to develop necessary fueling infrastructure. However, Local Law 6, as with the case of the federal Energy Policy Act of 1992 (EPACT), does not mandate the actual use of alternative fuels but rather the purchase of AFVs. EPACT has mandated the purchases of AFVs for federal government and state government agencies.[6]

The NYCDOT and the New York State Energy Research and Development Authority (NYSERDA) provide grant funding that seeks to offset the incremental costs associated with the purchase of new or converted AFVs. This program is known as the New York City Private Fleet Alternative Fuel Program. Covered under this program are incremental costs (above diesel costs) of vehicle acquisition, conversions and fueling infrastructure, and medium- and heavy-duty natural gas, electric and hybrid electric vehicles (HEVs). However, funding is not available for any additional fuel costs. The City and NYSERDA use federal CMAQ funds for this program.[7] Manhattan Beer, the first private company in the Bronx to use heavy-duty compressed natural gas (CNG) vehicles, received funding under the City's Alternative Fuel Program in 2002.[8]

Funds to purchase AFVs, such as alternative fuel garbage trucks, are also available through the Clean Air Communities program. This program was established in 1999 by the New York State Department of Environmental Conservation (NYSDEC), Northeast States Clean Air Foundation, Northeast States Coordinated Air Use Management and members of the private and non-profit sectors. The program funds clean air transportation programs in the City.[9]

---

[6] Alternative Fuel Vehicles Summit, Outcomes & Recommendations, April 11, 2002.
[7] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[8] Alternative Fuel Vehicles Summit, *Outcomes & Recommendations*, April 11, 2002.
[9] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

The New York City Department of Sanitation (DSNY) has also been successful at obtaining funding for its use of alternative fuel programs. DSNY has been able to acquire CMAQ funding to help purchase CNG refuse trucks; there are currently 26 CNG refuse trucks in its fleet.[10]

Federal tax code allows federal income tax deductions for businesses that purchase AFVs or build a refueling facility that utilizes alternative fuels. These tax deductions are only for the incremental costs compared with diesel vehicles and diesel fueling facilities. The deductions are for converted or retrofitted vehicles and vehicles purchased from original equipment manufacturers (OEMs). The fueling deduction is applicable to each fueling station installed by a business at a single location.

Along with federal tax deductions that target the incremental costs associated with clean fuel vehicles and clean fuel facilities, New York State provides tax credits for AFVs and infrastructure. In addition, New York State has a sales tax exemption for AFVs.[11]

[10] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[11] *Ibid.*

2.0 CLEAN FUEL TECHNOLOGIES BEST SUITED FOR NEW YORK CITY REFUSE HAULERS

2.1 Clean Diesel Technologies

Due to more stringent USEPA regulations concerning diesel engine tailpipe emissions, since the 1970s the diesel engine industry has produced technology innovations that have reduced the emissions produced by heavy-duty diesel engines. Diesel engines produced today emit 83% less PM and 63% less NO_X than comparable engines did in 1988. Furthermore, for on-highway heavy-duty diesel engines built in model year 2007 and beyond, USEPA regulations require reductions of 98% from 1988 levels in both PM and NO_X. Reductions in these emissions are important because diesel engines emit significantly higher levels than gasoline engines. However, diesel engines emit less CO, HC and CO_2 than gasoline engines.[12]

USEPA estimates indicate that the incremental costs of retrofitting a diesel heavy-duty truck to meet 2004 standards will include an average hardware cost of $8,000. This increase in cost will likely add 3% to 8% to the cost of a new garbage truck. Table 2.1-1 indicates that the 2007 standards will also result in new hardware and life-cycle operating cost increases.[13]

Table 2.1-1
USEPA Cost Projections for Heavy-Duty Diesel
2004 & 2007 Emissions Standards (1991 dollars)

Standards (Year)	Hardware Costs	Life-Cycle Operation Costs	Total Incremental Costs
2004 Standards	$5,200-$16,500	$0	$5,200-$16,500
2007 Standards	$2,020-$3,230	$4,180-$4,630	$6,200-$7,860

Source: INFORM, Inc., Greening Garbage Trucks: New Technologies for Cleaner Air.[14]

[12] Diesel Technology Forum, *Cleaner Air, Better Performance Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[13] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[14] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; See also U.S. Environmental Protection Agency, Nonconformance Penalties for Heavy-Duty Diesel Engines, Environmental Fact Sheet, EPA420-F-01-034, December 2001, http://www.epa.gov/otaq/regs/hd-hwy/ncp/f01034.htm; Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, Regulatory Announcement, EPA420-F-00-57, December 2000, http://www.epa.gov/otaq/regs/hd2007/frm/f00057.htm; U.S. Environmental Protection Agency, *Regulatory Impact Analysis: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements*, EPA-420-R-00-026, December 2000, http://www.epa.gov/otaq/regs/hd2007/frm/exec-sum/pdf.

Because well-maintained diesel engines can be operated for 20 to 30 years, this section outlines clean diesel technologies that can be applied to the engines comprising the nation's existing fleet of more than five million diesel trucks not covered under the 2004 and 2007 USEPA emission regulations. Engines built prior to 2007 will still be used up until 2035. Furthermore, 41% of the waste collection vehicles currently in service are more than 10 years old. These vehicles become more polluting as they age and can generate tens or hundreds of times more pollution than their newer engines. Clean fuel technology is a cost-effective way of meeting future regulatory mandates and reducing emissions from older and existing engines that are not covered under the new 2004 and 2007 USEPA emissions standards.[15]

The clean diesel options discussed in this section include advanced exhaust after-treatment, engine modification technologies and ultra-low-sulfur diesel (ULSD) fuel. These technologies can cut vehicle emissions by 90% or more. The remainder of this section will discuss the options and enhancements available to reduce emissions produced from diesel engines. These options and emission reductions are summarized in Table 2.1-2.

2.1.1 Engine Tune-Ups

Proper diesel engine maintenance helps ensure fuel is completely burned during combustion. Fuel that is incompletely burned is emitted as exhaust PM. Proper maintenance and tuning is the least expensive way to reduce PM emissions. This emission reduction strategy can also lower operating costs, extend engine life and improve fuel economy. Common maintenance problems that when fixed improve emissions include improper fuel injection timing, problems with fuel injectors and injection pumps, clogged air filters, poor fuel quality, low air box pressure and malfunctioning turbochargers and after-coolers. Studies looking at the results of repair and maintenance of diesel engines indicate that HC emissions can be reduced 78%, CO 17%, and PM 40%.[16]

---

[15] Diesel Report Outlines five R's for Cleaner Air, *Mass Transit*, July/August 2003; Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[16] *Ibid.*

Table 2.1-2
Clean Diesel Enhancement Options and Projected Emission Reductions

Enhancement Option	Particulate Matter	NO_X	Hydro-carbons	Carbon Monoxide	Unit Cost
Basic Emissions Tune-Up[17]	40%	Return to Certification Levels	78%	17%	$500-$2,500
Low-Sulfur Diesel Fuel[18]	17%	---	---	---	$0.01-$0.02/gal[19]
Diesel Oxidation Catalysts (DOCs)[20]	20%-50%	---	60%-90%+	90%+	$465-$1,750
Diesel Particulate Filters (DPFs)[21]	50%-90%	---	90%	90%	$7,500
Exhaust Gas Recirculation (EGR)[22]	---	40%	---	---	$13,000-$15,000
Selective Catalytic Reduction (SCR)[23]	20%-30%	75%-90%	80%	---	$10,000-$15,000
NO_X Catalysts	---	10%-70%	---	---	Under Development
2002 Model Year Engine[24]	83%	63%	---	---	$30,000-$40,000[25]
2004 Model Year Engine[26]	83%	81%	---	---	---
2007 Model Year Engine[27]	98%	98%	---	---	---

Source: Diesel Technology Forum, *Cleaner Air, Better Performance Strategies for Upgrading and Modernizing Diesel Engines*, 2003.

[17] Colorado Institute for Fuels and Engine Research, Colorado School of Mines and Energy and Environmental Analysis, Inc, *Quantifying the Emissions Benefit of Opacity Testing and Repair of Heavy-Duty Diesel Vehicles*, June 2000.
[18] Estimate for switching from off-road diesel, which averages around 3,000 ppm sulfur to today's federal highway diesel, which averages around 300 ppm sulfur. This percentage is based on data from emission test data from a study conducted by the USEPA. USEPA Office of Mobile Sources, *Exhaust Emission Factors for Non-Road Emission Modeling-Compression Ignition*, June 1998.
[19] The marginal costs increase will vary according to supplier, delivery location, market price, and any pre-negotiated pricing contracts. *Hart's Diesel Fuel News*, May 27, 2002.
[20] Manufacturers of Emission Controls Association, *Retrofitting Emissions Controls on Diesel-Powered Vehicles*, March 2002; MECA Retrofit Fact Sheet, http://www.meca.org/retrofitFAQ.PDF.
[21] *Ibid*.
[22] *Ibid*.
[23] *Ibid*.
[24] Reductions are based on USEPA heavy-duty diesel engine certification standards for new on-highway engines. Percent reductions compared to new engine standards for base model year of 1988. Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[25] Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003; Michael D. Jackson and Fanta Kamakate, NOx Emissions Reduction Technology Status and Solutions, October 2002.
[26] Reductions are based on USEPA heavy-duty diesel engine certification standards for new on-highway engines. Percent reductions compared to new engine standards for base model year of 1988. Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[27] Ibid.

It should be noted that repairs and maintenance of diesel engines tend to increase NO_X emissions. This is expected because engine strategies and repairs that lower PM by increasing combustion efficiency and temperatures increase NO_X emissions. Deterioration of engine equipment that lowers combustion temperature and reduces engine efficiency tends to increase PM emissions and lowers NO_X emissions.

According to a study co-sponsored by the USEPA, repair costs and tune-ups can range from $500 to $2,500, with the average repair cost of $1,088 per vehicle.[28]

2.1.2 Ultra-Low-Sulfur Diesel Fuel and Low-Sulfur Diesel Fuel

Sulfur found in fuel degrades the effectiveness and life of after-treatment devices by inhibiting the function of filters and catalysts found in these devices. Diesel fuel with reduced sulfur content is known as ULSD (sulfur content of 15 parts per million [ppm] or less); low-sulfur diesel fuel contains sulfur content between 30 ppm and 15 ppm. The main purpose of lower sulfur content in diesel fuel is to improve the performance of after-treatment technologies that seek to reduce emission levels. USEPA regulations call for reducing the maximum allowable sulfur in on-road diesel fuel from the current level of 500 ppm to the ultra-low level of 15 ppm by 2006 – a 97% reduction.[29]

It should be noted that ULSD only reduces PM and SO_2 emissions. Used alone without after-treatment devices it does not reduce emissions such as HC, CO or NO_X emissions.

Some operating and maintenance concerns associated with ULSD include a slightly lower fuel economy and concerns regarding the lubrication properties of the fuel. ULSD can result in a slightly lower fuel economy when compared with regular diesel. When sulfur is removed from diesel, the fuel has a slightly lower energy content. Precise measurements of the ULSD fuel economy impacts are challenging because fuel energy content can vary depending on the

[28] Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[29] New York City Department of Sanitation, *Alternative Fuels/Emissions Reduction Program*; Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.

refinery and exact diesel blend used. In addition, operation conditions need to be taken into account when comparing fuel economies. Studies indicate that the energy content of ULSD can be from 2.4% to 2.8% lower than ordinary highway diesel. Correspondingly the fuel economy of trucks using ULSD is roughly 3% lower than trucks running on regular diesel.[30]

The lubricating properties of diesel degrade when sulfur is removed from the fuel. To address this issue, oil refiners add lubricity additives. Industry lubricity standards are currently being developed for ultra-low diesel fuels. In general, in order to determine if the ULSD fuel is compatible with engine part components, operators should contact their OEMs before using ULSD in pre-1994 engines. In the past, ULSD fuel was causing problems with certain fuel injection devices; these problems have been eliminated for engines built since 1993.[31]

USEPA estimates indicate that new sulfur standards will increase the cost of producing and distributing diesel fuel by $0.045 to $0.05 cents per gallon. Low-sulfur diesel is currently used and being tested in locations in the United States that have significant air quality problems, such as California and the City. DSNY currently uses low-sulfur fuel in approximately 30% of its refuse truck fleet and pays slightly more per gallon (approximately $0.15 on average) for the low-sulfur fuel than for conventional diesel fuel. In 2001, the Metropolitan Transportation Authority (MTA) paid an extra $0.12 cents per gallon for low-sulfur diesel fuel and the Massachusetts Bay Transportation Authority (Boston) paid an additional $0.17 cents per gallon.[32]

2.1.3 Diesel Oxidation Catalysts

Diesel oxidation catalysts (DOCs) have been used for over 30 years; more than 1.5 million units have been installed on heavy-duty trucks built since 1994. They've also been used extensively on urban buses in the United States. These devices are considered the most proven of after-treatment options and can be used with existing or used engines to pollute less by retrofitting them.[33]

---

[30] Puget Sound Clean Air Agency, *Facts About Ultra-Low Sulfur Diesel Fuel, Diesel Solutions: Cleaner Air For Tomorrow, Today*; INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[31] *Ibid.*
[32] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[33] Diesel Technology Forum, *Clean Air, Better Performance*, 2003.

According to the Diesel Technology Forum, emissions benefits include reductions of total PM by 20% to 50% and CO and HC by 60% to 90%.[34] (Oxidation catalysts do not reduce NO_X emissions.) However, the USEPA states that DOC reduces emissions by a smaller amount. They contend that DOC reduces emissions of PM by at least 20%, CO by 40% and HC by 50%.[35]

Oxidation catalysts interact with the exhaust stream by oxidizing pollutants into water vapor and gases such as CO_2 and SO_2. Most oxidation catalysts are stainless steel canisters with a honeycomb-like structure inside, called a substrate. Precious metals, such as platinum and palladium, coat the interior surface of the substrate, helping to produce a chemical reaction that oxidizes the pollutants found in the exhaust stream. Oxidation catalysts can be used with regular diesel fuel, but the effectiveness may be increased with the use of ULSD fuel (15 ppm sulfur).

Costs for these devices range from $465 to $1,750, and may take from one to three hours to install. Like a catalytic converter on a car, once a DOC is installed it rarely requires maintenance. They last from 7 to 15 years and usually have a 100,000 to 150,000 mile warranty.

Figure 2.1.3-1
Diesel Oxidation Catalyst

[34] *Ibid.*
[35] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, *Questions and Answers on Using Diesel Oxidation Catalysts in Heavy-Duty Trucks and Buses*, June 2003.

2.1.4 Diesel Particulate Filters

Diesel particulate filters (DPFs), when used with ULSD, can reduce PM emissions by 50% to 90%, and HC and CO emissions by as much as 90%. However, like oxidation catalysts, these devices do not reduce NO_X emissions. Particulate filters cost roughly $7,500.[36]

DSNY filters cost $6,000 each. Testing by DSNY and West Virginia University of DPFs on heavy-duty sanitation vehicles has shown that particulate filters have the ability to reduce PM emissions by 81% to 97%. These tests compared diesel sanitation trucks that were equipped with DPFs against vehicles that were not equipped with the same filters.[37]

Particulate filters consist of a filter placed in the exhaust stream to collect particulate emissions as the pollutants pass through the filter. One main problem with these devices is that the filters become clogged over time and trap less and less particulate. Current research is focused on developing methods to dispose of this particulate by oxidizing it within the filter (filter regeneration). Like DOCs, particulate filters can be used with retrofitted engines. Tests are ongoing that are assessing the use of DOCs and DPFs in waste collection trucks. These after-treatment options are not yet widely available for waste collection trucks. DSNY is taking the lead in testing these technologies.

Figure 2.1.4-1
Particulate Filter

[36] Diesel Technology Forum, *Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines*, 2003.
[37] West Virginia University, Transportable Heavy Vehicle Emissions Testing Laboratory, *DPF Demonstration Program: Final Data Report,* November 2002.

2.1.5 Exhaust Gas Recirculation

Using exhaust gas recirculation can reduce NO_X emissions. It lowers NO_X by reducing the oxygen content in the combustion chamber. A share of the engine exhaust is recycled back to the engine air intake. The exhaust gas is then mixed into the fresh air that enters the combustion chamber. Because the exhaust gas is oxygen-depleted, this gas then reduces the oxygen content within the combustion chamber, resulting in a lower temperature burn and lower NO_X emission levels.

Due to the formation of sulfuric acid from the sulfur present in the fuel and lubricating oil, exhaust gas recirculation tends to reduce engine durability. However, with the new, lower-sulfur diesel fuels, production of sulfuric acid will be minimized. Exhaust gas recirculation can reduce NO_X emissions by as much as 40%, and can be used with engines that are being retrofitted.

Solid waste vehicles and buses in the United States are currently experimenting with exhaust gas recirculation. This engine modification system costs between $13,000 and $15,000.[38]

2.1.6 Selective Catalytic Reduction Devices

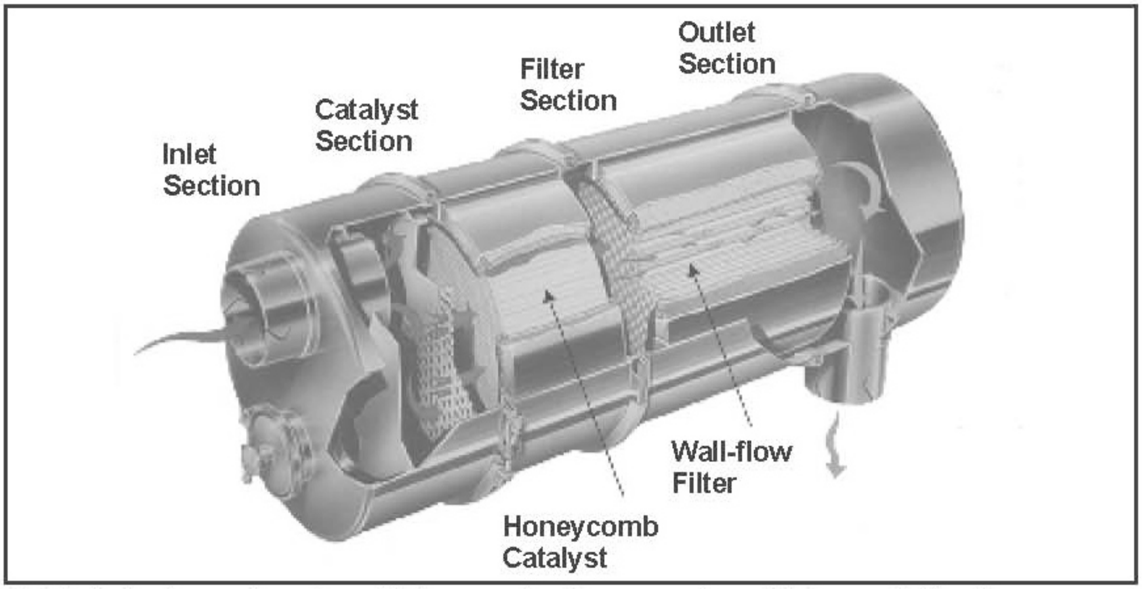
Selective catalytic reduction (SCR) has been used for over 15 years to reduce NO_X emissions from stationary sources. In the United States, SCR has been used in electrical utility boilers that burn coal and natural gas and in combustion turbines burning natural gas. SCR is now being developed in retrofit projects on mobile sources, including trucks and marine vessels. Emission reductions include NO_X by 75% to 90%, HC reductions up to 80% and PM reductions of 20% to 30%.

SCR operates like an oxidation catalyst by using chemical reactions that change pollution compounds. In addition to the catalytic activity, a reducing agent – usually ammonia or urea – is added to the exhaust stream. The reducing agent converts NO_X to nitrogen and oxygen. The exhaust gas and the reducing agent pass over the catalyst-coated substrate, where NO_X, PM and HC are converted to nontoxic emissions, such as molecular nitrogen and water. SCR devices cost between $10,000 and $50,000 per vehicle.[39]

---

[38] *Ibid.*
[39] *Ibid.*

Figure 2.1.6-1
Cutaway View of a Catalytic Converter



2.1.7 NO_X Catalysts

Currently, NO_X catalysts are being experimented with in the United States on retrofitted vehicles. Two NOx catalyst technologies are currently being developed that can reduce NO_X emissions up to 70%.

The first technology is called "lean NO_X catalyst." It works in the same manner as SCR by adding a reducing agent to the exhaust stream in order to speed up catalytic conversion. Diesel fuel is injected into the exhaust gas to add HC, which acts as a reducing agent. The NO_X gas is then converted into nitrogen and water vapor.

The second technology is called "NO_X absorber." This technology operates in two stages. The NO_X is converted and absorbed into a chemical storage site within the system. When the absorber becomes saturated, it is regenerated by adding extra diesel fuel to the exhaust stream. The added fuel causes the NO_X to transform into nitrogen and oxygen that is then released from the system. These devices are still under development and unit costs are unavailable.[40]

[40] *Ibid.*

2.1.8 New Engine Technology

In certain circumstances the replacement of older diesel engines and equipment may represent for the operator and fleet manager the most sensible and cost-effective emissions improvement options. When old vehicles are replaced, fleet managers can substitute their oldest and worst emissions performers with new technology present in new diesel engines. PM emissions from new on-highway diesel engines have been reduced by 83% and emissions of NO_X by 63% since 1983. New engines will continue to get cleaner as tougher emission standards take effect in 2004 and 2007; by 2007, new engines will provide 98% reductions in both PM and NO_X over 1988 engines. These reductions can be attributed to improvements in fuel delivery, the design of combustion chambers and turbo-charging. For example, current engines provide for a more complete burn by enabling the fuel to be injected at high pressures, and the timing of the fuel injection can be varied to allow for different emissions goals when vehicles operate under various vehicle-operating conditions.[41]

2.1.9 Implementation Issues

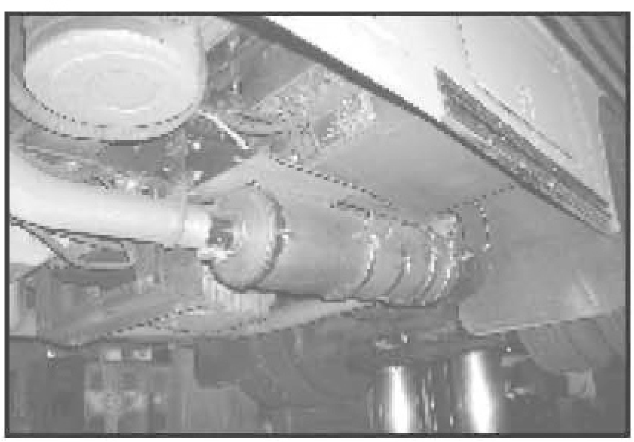
Many of the clean fuel enhancement technologies discussed above have certain requirements, such as ULSD, specific maintenance and monitoring requirements. In order to guarantee successful emission reductions, fleet managers must consult with engine manufacturers and technology vendors to address implementation issues. If engine retrofitting is desired, the selection of appropriate engines and corresponding appropriate after-treatment technologies must take place. Some engines make better retrofit candidates than others; some engines and vehicles may be inappropriate for upgraded investment. This section will briefly address some implementation issues regarding ULSD, engine enhancement technologies and exhaust after-treatment devices.

[41] *Ibid.*

Proper installation of after-treatment devices is an issue of prime importance. Many such devices replace the original exhaust muffler but are larger and heavier than the original. For certain truck models, specific engineering may be required for proper installation and filter support, and customized installation hardware may be required. Clearance between the filter and the cab may also be an issue. It should be noted that improper servicing or sizing of the filters would generally not be covered by the filter warranty or engine maker.[42]

When ULSD is required with an after-treatment device, it is important to make sure that only ULSD is used with that particular device. The most effective way to avoid misfueling vehicles that require ULSD is to convert the entire fleet and fueling facility to USLD. If this cannot be done or is not feasible, lockable fuel caps and segregated fuel storage tanks should be used. If fleet vehicles are not centrally fueled and there might be a risk of fueling with higher sulfur diesel off site, detailed planning should be undertaken. Educating fuelers and drivers of this issue is of prime importance. Other important implementation issues include understanding the duty-cycle that the filter will be exposed to, determining the service intervals, and filter maintenance procedures. Service intervals are typically determined by looking at the service environment, engine duty cycle and engine oil consumption.[43]

Figure 2.1.9-1
School Bus Retrofitted with a Particulate Trap



[42] *Ibid.*
[43] Puget Sound Clean Air Agency, *Facts About Ultra-Low Sulfur Diesel Fuel, Diesel Solutions: Cleaner Air For Tomorrow, Today*; INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

2.1.10 Clean Diesel Case Studies

2.1.10.1 New York City - Department of Sanitation[44]

DSNY currently has 600 of its 2,040 garbage trucks using low-sulfur diesel fuel, which contains sulfur up to 30 ppm by weight. DSNY is currently testing the effectiveness of a particulate trap used in combination with this fuel. (A study from the California Air Resources Board found the use of ULSD [sulfur content of 15 ppm] with a particulate trap has cleaner emissions than CNG.) If it proves worthwhile, they will outfit all trucks with particulate traps. So far, DSNY is quite pleased with the emission results of low-sulfur diesel fuel and particulate traps; they've been a leader in experimenting with use for heavy-duty refuse vehicles. By the end of this year DSNY is scheduled to complete construction on a heavy-duty vehicle emissions testing facility that will allow them to test diesel and alternative fuel exhaust emissions.

2.1.10.2 City of Los Angeles - Bureau of Sanitation[45]

In response to the Clean Fuel Policy adopted by the Los Angeles City Council in June of 2000, the Bureau of Sanitation has implemented an Alternative Fuel Program. The Bureau is committed to retrofitting the existing diesel-only sanitation trucks in its fleet with clean diesel technology, such as particulate traps and low-sulfur diesel. The fleet consists of 660 diesel fuel and dual fuel heavy-duty vehicles, including side loaders, front loaders, rear loaders, transfers and rolloffs.

Use of ultra-low-sulfur fuel began in November 2001 and particulate trap utilization started in July of 2002. All of the Bureau's vehicles that have particulate filters (except for two) use Englehard DPX DPFs. These particular traps are passive systems that use a catalyst (a combination of platinum and a base metal oxide) that is found in the porous walls of the filter. The catalyst helps to oxidize the collected PM by lowering the exhaust temperature.

---

[44] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[45] Based on e-mail correspondence with Alex H. Helou, Director, City of Los Angles, Sanitation Bureau, August and September, 2003.

The cost for each DPF (including the device and its installation) is between $6,300 and $6,500. The Bureau did not have any particulate filter maintenance or operating cost data. Vendors originally stated that the filters would not have to be serviced unless signaled by the back-pressure monitoring system lights. However, they have recently started to suggest that the traps be serviced once a year or every 12,000 miles.

Prior to implementation, Los Angeles conducted testing for a year in order to determine the effectiveness of particulate traps. A study conducted by the City of Los Angeles and the National Renewable Energy Laboratory found that PM emissions were reduced by 90% in the diesel-only refuse collection vehicles equipped with DPFs and operated on ULSD, compared to diesel-only refuse collection vehicles that were not equipped with particulate traps and were operated using regular California Air Resources Control Board diesel. The study stated that vehicles retrofitted with DPFs had lower levels of HC and CO emissions. The pollution reductions of refuse vehicles currently in operation have met the Bureau's expectations and have been found to be similar to tests and studies completed prior to implementation.

2.2 Natural Gas

Natural gas is a mixture of HC, with methane gas (CH_4) as the primary component. The gas is an abundant domestic resource that can be extracted from underground reserves or produced as a by-product of landfill operations. After extraction, natural gas requires only a purification (from sulfur compounds) and separation (from heavier hydrocarbons) process before being ready for use, thereby avoiding the expensive refining process needed for petroleum fuels. Natural gas is used extensively in the home heating market and a vast natural gas pipeline delivery system of 1.3 million miles is in place in the continental United States.[46]

2.2.1 Fuel Characteristics

Natural gas can be used as an alternative fuel source to power vehicles in either a gaseous or liquid state. In the gas form, natural gas is compressed to 3,000 pounds per square inch to 3,600 pounds per square inch and is stored on the vehicle in high-pressure tanks. The compressed form of the gas, referred to as CNG, is transferred to the vehicle at the fueling

[46] Helen Cothran, ed., *Energy Alternatives,* November 2002.

station. To create liquefied natural gas (LNG), natural gas is cooled to minus 260 degrees Fahrenheit. The liquefaction process occurs either at the refueling site or off site and delivered by truck.[47]

There are different processes for the combustion of natural gas in an engine, including stoichimetric, lean-burn and dual-fuel diesel. Stoichimetric is a spark-ignited internal combustion that uses equal parts of fuel and air. Lean-burn is also spark-ignited but uses more air to minimize NO_X emissions. Dual-fuel diesel natural gas engines run on both diesel and natural gas. They utilize a compression ignition system (such a system is required for diesel ignition) in which a small amount of diesel is used to ignite the natural gas. At low speeds or when idling, dual-fuel engines run on diesel, but at higher speeds the amount of natural gas used can increase to 80% to 85% of the fuel being consumed by the vehicle. The majority of CNG vehicles use the lean-burn technology, due to the NO_X reduction benefits.[48]

CNG and LNG refuse trucks are in waste collection truck fleets in municipalities throughout the United States, including the City. DSNY began using CNG trucks in their refuse hauler fleet in 1989, with 16 such trucks. They were the first municipal sanitation agency in the United States to begin testing natural gas refuse vehicles.[49] Currently DSNY has 26 CNG garbage trucks in their refuse hauler fleet and nine CNG street sweepers. They also have about 350 CNG light-duty vehicles that have dual fueling capabilities (gasoline or CNG).

2.2.2 CNG vs. LNG

When compared, CNG and LNG each have advantages and disadvantages. The advantage of LNG over CNG is that it offers a greater range for the vehicle; in the liquid state more natural gas can be stored. The liquefied state also allows for faster fueling of LNG vehicles. CNG fueling can take a few minutes or several hours, depending on the type of fueling system. The quick-fill fueling system uses a high-pressure tank compressor to fill the vehicle's tank within a few minutes. The slow-fill fueling system does not require the high-pressure compressor system, but can take six to eight hours to fill the tank of a CNG vehicle.[50]

[47] Energy Information Administration, *Developments in U.S. Alternative Fuel Markets,* 1999.
[48] The World Bank, *Breathing Clean: Considering the Switch to Natural Gas Buses*, 2001.
[49] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[50] *Ibid.*

The advantages of CNG over LNG are mostly safety related. If LNG is accidentally spilled, it will pool on the ground, creating a potential fire hazard if an ignition source is nearby. CNG is lighter than air and if spilled will rise, lessening the chance of ignition. Odorants can also be added to CNG, which will help in the detection of a spill. In addition, methane detectors are often utilized with CNG for added safety protection. (Methane is the largest component of natural gas.) LNG is odorless and odorants cannot be added in order to facilitate easy detection - leak detection is based solely on a methane detection system.[51]

There is currently a moratorium in the City on the establishment of LNG fueling facilities.[52] CNG is the only natural gas option available in the short and near term for the private and public refuse haulers due to this moratorium. Therefore, LNG will not be discussed further in this report.

2.2.3 Safety

Like petroleum fuels, CNG is stable but flammable. The danger of CNG is from leakage coming from the tanks or during the fueling process. However, unlike other fuels, CNG is a gas under pressure and requires a different facility and personnel-training procedures than conventional fuels.[53]

There are several essential elements that need to be in place in order to have a safe CNG facility. Facilities need high ceilings with ventilation systems to dissipate any escaped natural gas that will rise and collect in the ceiling of a facility; methane gas sensors are also usually installed to detect gas build-up. CNG buses and tanks should not be stored near strong ignition sources that could ignite leaked gas. (Possible ignition sources include open-flame gas heaters or spark-producing electrical equipment.) Finally, personnel training on the unique properties of CNG fuel and proper procedures to follow is necessary to ensure a safe CNG operation.[54]

---

[51] *Ibid.*
[52] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[53] U.S. Department of Energy, *Running Refuse Haulers on Compressed Natural Gas*, November 1997.
[54] *Ibid.*

2.2.4 Costs

The cost of acquiring CNG vehicles and the infrastructure needed is one of the main drawbacks for fleet operators seeking to use CNG as an alternative fuel. The incremental cost of a CNG refuse truck ranges from $38,000 to $70,000 over a standard diesel refuse hauler. However, this price differential may decrease in the future as the prices of diesel engines increase in response to stricter USEPA diesel engine requirements that will be in place in 2007.[55]

In addition to requiring a more expensive truck, CNG requires a capital investment in fueling infrastructure. The cost of a CNG infrastructure can range between $500,000 and $1,250,000. These costs cover the compressor needed for the natural gas and ventilation and alarm systems.[56]

Another cost to consider for CNG garbage trucks is the cost of fuel. In the City the cost of a natural gas gallon equivalent is more than the cost of a gallon of conventional diesel fuel.[57] In addition, the natural gas market is subject to price volatility that is more extreme than for the price of oil. The demand for natural gas has increased in past years and the production has not been able to keep up. Increasing the supply of natural gas faces many obstacles; increased drilling for natural gas in North America raises environmental concerns, and access to foreign supplies is hampered by an insufficient number of tankers and terminals in the U.S. that are needed to import natural gas.[58]

---

[55] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[56] *Ibid.*
[57] *Ibid.*
[58] Simon Romero, Short Supply of Natural Gas Raises Economic Worries, New York Times, June 17, 2003.

2.2.5 Fuel Emissions

The principal benefit of CNG over conventional diesel fuel is the reduction of tailpipe emissions. Experiences of CNG operators and several studies on the subject have documented the reduction of pollutant emissions of CNG over standard diesel. One such study completed by the Northeast Advanced Vehicle Consortium found that CNG engines had 50% to 60% lower NO_X emissions than conventional diesel. It also showed that PM emissions were 80% to 90% lower for CNG engines than for diesel engines.[59]

These reductions in NO_X and PM are corroborated by a report completed by INFORM, an independent environmental research group. After surveying several refuse haulers using CNG, INFORM reports that PM emissions were reduced anywhere from 67% to 94%, and NO_X emissions were reduced 32% to 73%. Additionally, INFORM results show CNG refuse fleets reporting non-methane HC emissions reductions of 69% to 83%.[60]

One drawback of CNG emissions is related to the release of greenhouse gases, particularly CO_2 and CH_4. Intuitively, CNG should have lower carbon emissions, since it is comprised mainly of CH_4 (which has a high hydrogen to carbon ratio). Theoretically, this should translate into low CO_2 emissions relative to diesel fuel (which has a lower hydrogen to carbon ratio). However, according to the aforementioned report completed by the Northeast Advanced Vehicle Consortium, the extra weight and throttle loss of CNG vehicles relative to conventional diesel vehicles results in a lower fuel economy for CNG trucks and cancels out the potential CO_2 emission benefits of CNG. Moreover, CNG vehicles release unburned fuel in the form of CH_4, which is classified as a greenhouse gas. The factors lead to CNG actually emitting more greenhouse gases than conventional diesel fuel vehicles.[61]

---

[59] Northeast Advanced Vehicle Consortium, *Hybrid-Electric Drive Heavy Duty Vehicle Testing Project*, February 2000.
[60] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[61] Northeast Advanced Consortium, *Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project*, February 2000.

2.2.6 Incentives and Disincentives

The main incentive for choosing natural gas as an alternative fuel for heavy-duty refuse trucks is the emissions benefits. Studies of heavy-duty engines running on CNG and diesel have shown that engines fueled with CNG emit significantly less PM (80% to 90% less) and NO_X (50% to 60% less) emissions than diesel engines. However, CNG engines emit higher total HC than diesel engines, which is mostly due to higher CH_4 release.[62]

Another benefit of using a CNG engine is the reduction of engine noise. CNG engines are significantly quieter than diesel engines. Some studies have reported a 50% to 98% reduction in noise with CNG trucks, depending on the position of sanitation personnel relative to the engine. Much of the engine noise reduction is gained during idling and slow speeds.[63]

CNG use as an alternative fuel is seen as a bridge to the eventual use of hydrogen as a fuel for vehicles. Though still far off, hydrogen fuel cell technology is advancing and one day its use as a fuel could be as prevalent as diesel and gasoline are today. Natural gas is a source of hydrogen for fuel cells and investing in CNG facilities now will ease future transitions to hydrogen fuel cells as a vehicle fueling source.[64] (Fuel Cells will be discussed later in this report.)

One of the major disincentives to creating a CNG refuse truck fleet is the cost related to purchasing the trucks and the infrastructure needed for a CNG facility. Trash haulers, either private companies or public agencies, have limited budgets and are concerned about their financial bottom line. A CNG trash hauler can cost up to $70,000 more than a conventional diesel truck. In addition, the cost of a CNG facility with fueling, proper ventilation and leakage alarms can cost $500,000 to $1,250,000 to construct.[65]

---

[62] *Ibid.*
[63] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[64] *Ibid.*
[65] *Ibid.*

Another disadvantage of CNG is that most of the natural gas used in CNG engines comes from reserves in North America. Demand for natural gas has increased in the past few years and the supply has not been able to keep pace. This has caused extreme price fluctuations. Attempts to increase supply by drilling for additional natural gas reserves has met resistance from environmental groups and the importation of natural gas (in a liquid form) requires an investment in proper docking facilities and a transport infrastructure necessary to handle natural gas.[66]

In addition to the cost implications of CNG, there are logistical issues that could be disincentives to using CNG with refuse haulers. CNG vehicles have limited range and the expense of constructing fueling stations prohibits a network of fueling stations from being constructed. This does not offer operators much flexibility to use CNG trucks on various routes, as distance from the fueling station must always be considered. The CNG refuse trucks are also heavier and longer than conventional diesel garbage trucks, leading to the CNG trucks having lower fuel efficiency than diesel engines and making it harder for CNG trucks to maneuver through narrow city streets.[67]

Finally, there are some environmental drawbacks from the emissions associated with CNG combustion. CNG engines have been found to emit noticeable levels of CH_4 and CO_2, both of which are greenhouse gases. The emission of formaldehydes is also a concern with CNG emissions.[68]

2.2.7 CNG Case Studies

2.2.7.1 New York City Department of Sanitation[69]

DSNY has been a leader in using CNG engines in its collection fleet. They began their CNG program in 1989 with 16 CNG garbage trucks. The CNG program has grown to include 26 CNG garbage trucks in the DSNY hauler fleet and nine CNG street sweepers that are considered part of their heavy-duty fleet. DSNY also has about 350 CNG light-duty vehicles that have dual fueling capabilities (gasoline or CNG).

---

[66] Simon Romero, Short Supply of Natural Gas Raises Economic Worries, New York Times, June 17, 2003.
[67] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[68] *Ibid.*
[69] *Ibid.*

The major problem with DSNY's CNG truck program is the lack of fueling infrastructure. Currently, DSNY's CNG trucks refuel at Keyspan and Con Edison CNG fueling facilities, which have capacity issues. These facilities have a hard time supporting both the DSNY fleet and their own CNG fleet. The result is that DSNY CNG trucks have fueling times that are significantly longer than their diesel counterparts.

DSNY is planning to build a CNG facility in Woodside, Queens. This will help address the fueling-time issue, but there are other factors related to CNG that are still a concern. One is that the centralized nature of the new CNG facility would run counter to DSNY's somewhat decentralized operations. Having one central CNG facility doesn't let DSNY have the flexibility of fueling at different facilities. This is troubling because CNG trucks have limited range, which is one of the main complaints of the operators using CNG trucks. Diesel trucks are refueled every two to three days -- CNG trucks need to be refueled every day. Construction of additional CNG fueling facilities is difficult as there is community opposition; the facilities are perceived as unsafe and require a great deal of real estate to accommodate the large garbage trucks.

Some of the range issues DSNY has encountered with CNG could be solved if LNG could be used. Since LNG is in liquid form, a truck can hold more fuel, thereby increasing the range of the truck. (Increasing the range of CNG is important as CNG trucks cannot be used for waste export out of the City because of this limitation.) However, there is a moratorium on LNG in the City and there are no current initiatives to lift it.

Another issue related to CNG is that DSNY maintenance and fueling facilities need to be upgraded. Escaping gas is a major concern; air monitors and circulation devices need to be installed and training of DSNY personnel has to occur. A CNG truck is two feet longer than a standard garbage truck. This creates a storage problem, as well as problems navigating the truck through narrow streets. The CNG vehicle is also a heavier vehicle and has less refuse capacity. In addition, the CNG trucks experience a degradation of engine performance as the pressure in the tank decreases.

The price difference of CNG and standard refuse trucks is more than $70,000. CNG trucks cost $212,000 versus $133,000 for standard diesel refuse trucks. Also, CNG costs more per gallon equivalent than diesel. DSNY pays just under $1.00 per gallon for diesel and over

$1.00 per gallon equivalent for CNG (price can vary due to natural gas market conditions). Since CNG has a lower density per gallon compared to diesel, CNG trucks are also not as fuel efficient as diesel trucks, which further increases the cost differential between the two fuels.

2.2.7.2 New York City Transit Gleason Depot CNG Facility[70]

The Jackie Gleason Depot has roughly 250 CNG buses and in the future will hold an additional 250 CNG buses. Located in Sunset Park, Brooklyn, the depot functions as a storage, fueling and maintenance facility (except major overhauls) for CNG buses. The CNG program first started in 1994.

Several drawbacks have been noted with CNG use at the facility. CNG has longer fueling times than conventional buses and higher operational costs (the depot was unable to quantify the higher costs). The CNG buses weigh more, due to the added weight of the tanks, and use 20% to 30% more fuel than diesel buses. However, it was noted that highway driving uses less fuel.

Safety is also a big concern with CNG used at the depot. There is emergency ventilation throughout the facility, emergency doors and alarms, and methane detectors, and special measures are taken to seal electrical equipment and wires, adding to the cost of using CNG. Plus, a one- to two-day CNG training seminar is necessary for drivers and maintenance workers. CNG is not necessarily more dangerous, but it requires different precautions than those for diesel fuel.

In order to have the CNG facility at the depot, a new fueling infrastructure was built and an outside contractor hired to maintain and monitor fueling and CNG on-site infrastructure. A CNG vehicle costs roughly $70,000 more than a diesel bus (a diesel bus is approximately $270,000) and the facility upgrades were a huge cost. In addition, CNG buses have lower reliability and more maintenance requirements than diesel buses, requiring more spark plugs and increased replacement of ignition components.

[70] Based on meeting with Gordon Coor, Superintendent Research and Development, MTA-NYCT, July 2003.

Although the depot does not have exact emissions data, CNG were noted as having higher greenhouse gas emissions than diesel buses. There is an increase in CO_2 and CH_4. However, CNG PM and NO_X emissions are lower than conventional diesel emissions.

2.3 CNG vs. Clean Diesel (Cost Comparison)

In order to compare compressed natural gas refuse vehicles with vehicles operating on clean diesel technology, the costs associated with both options need to be analyzed. These costs include capital costs, such as vehicle and infrastructure costs. (Infrastructure costs include vehicle storage, maintenance and refueling facilities.) Operating costs (fuel and maintenance) will also need to be evaluated, as well as economic incentives such as government grant programs used to purchase AFVs.

2.3.1 Capital Costs

Major new capital outlays are required before the conversion of a diesel garbage truck fleet to one that operates with natural gas can take place. Capital costs needed may include the purchase of more expensive natural gas refuse vehicles, the modification of existing storage and maintenance facilities, the construction of new storage and maintenance facilities, and the provision of refueling infrastructure.

2.3.1.1 Vehicle Costs

Natural gas garbage trucks are more expensive than conventional, diesel refuse vehicles. Natural gas garbage trucks have more expensive engine and fuel storage systems; manufacturers charge more for CNG vehicles in order to cover the costs of development, certification and warranty service; and the smaller number of CNG vehicle orders contribute to their higher prices.[71]

[71] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

DSNY reports that the price difference between CNG refuse vehicles and standard refuse trucks is more than $70,000. DSNY states that CNG trucks cost $212,000 vs. $133,000 for standard diesel refuse trucks -- 60% more. The DSNY cost differential is much higher when compared to other required costs. Waste Management, for example, cites an average cost of $234,000 for a new natural gas truck vs. $200,000 for comparable diesel models -- 17% more. The public interest group INFORM attests that natural gas refuse trucks cost an additional $40,000 over the median $170,000 price of a conventional diesel refuse truck -- a 24% cost differential. None of these sources specified if the diesel trucks utilized after-treatment technology or engine modification technology to reduce emissions. It is assumed that the cost figures reported do not include such clean diesel technologies. See Table 2.3.1.1-1 for a comparison of these figures.

Table 2.3.1.1-1
Vehicle Comparison (CNG vs. Conventional Diesel)

Source	CNG	Diesel	Incremental Cost of CNG
DSNY	$212,000	$133,000	$79,000 (60%+)
INFORM	$210,000	$170,000	$40,000 (24%+)
Waste Management	$234,000	$200,000	$34,000 (17%+)

The vehicle costs differences for CNG and diesel refuse vehicles are similar to those found with transit bus vehicle costs. The Natural Resource Defense Council indicates the CNG buses cost 20% to 30% more than diesel buses. Moreover, a U.S. General Accounting Office study, "Mass Transit: Use of Alternative Fuels in Transit Buses," states the transit operators who operate CNG buses pay approximately 15% to 25% more on average for full-sized CNG buses than for similar diesel buses. CNG buses cost between $290,000 and $318,000, while typical standard diesel buses cost between $250,000 and $275,000.[72]

In order to accurately compare vehicles that use clean diesel technology with CNG vehicles, the costs of exhaust after-treatment and engine modification technology need to be taken into account. (See Tables 2.3.1.1-2, 2.3.1.1-3 and 2.3.1.1-4.) Based on data gathered from a Diesel

[72] Natural Resources Defense Council, *The Role of Clean-Fuel Buses in New York City's Transit Future*, September 4, 1997; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

Technology Forum report published in May of 2003 entitled "Cleaner Air, Better Performance: Strategies for Upgrading and Modernizing Diesel Engines," unit cost figures for the different clean diesel technologies will be applied to the three different baseline diesel truck cost figures listed in Table 2.3.1.1-1.

NO_X catalysts were not included in the clean diesel and CNG vehicle cost comparison because the technology is still under development and unit costs were not available. In addition, each clean diesel technology is applied by itself to the baseline conventional diesel costs and not in conjunction with other clean diesel technologies. In actuality, a combination of clean diesel technologies may be utilized, further reducing the CNG vehicle cost/conventional diesel vehicle cost differential.

Table 2.3.1.1-2
DSNY Vehicle Cost Comparison (CNG vs. Clean Diesel)

Clean Diesel Technology	CNG Cost	Clean Diesel Cost	Incremental Cost of CNG
Oxidation Catalyst	$212,000	$134,108	$77,892 (58%+)
Particulate Filters	$212,000	$140,500	$71,500 (51%+)
Exhaust Gas Recirculation	$212,000	$147,000	$65,000 (44%)
Selective Catalytic Reduction	$212,000	$163,000	$49,000 (30%)

Table 2.3.1.1-3
INFORM Vehicle Cost Comparison (CNG vs. Clean Diesel)

Clean Diesel Technology	CNG Cost	Clean Diesel Cost	Incremental Cost of CNG
Oxidation Catalyst	$210,000	$171,108	$38,892 (23%+)
Particulate Filters	$210,000	$177,500	$32,500 (18%+)
Exhaust Gas Recirculation	$210,000	$184,000	$26,000 (14%+)
Selective Catalytic Reduction	$210,000	$200,000	$10,000 (5%+)

Table 2.3.1.1-4
Waste Management Vehicle Cost Comparison (CNG vs. Clean Diesel)

Clean Diesel Technology	CNG	Clean Diesel Cost	Incremental Cost of CNG
Oxidation Catalyst	$234,000	$201,108	$32,892 (16%+)
Particulate Filters	$234,000	$207,500	$26,500 (13%+)
Exhaust Gas Recirculation	$234,000	$214,000	$20,000 (9%+)
Selective Catalytic Reduction	$234,000	$230,000	$4,000 (2%+)

It should be noted that the price differential between CNG and diesel vehicles will likely decrease in the future. Stricter USEPA diesel emission requirements are going to take effect in 2007, essentially requiring that diesel engines be equipped with oxidation catalysts and DPFs, thereby increasing a diesel vehicle's overall capital cost. Some economists indicate that demand for CNG vehicles will increase, causing production of these vehicles to rise. The higher demand and likely higher production levels of CNG vehicles will drive down the production costs per vehicle and the overall price per vehicle.[73]

Due to the large capital costs, fleet operators may not want to purchase new CNG trucks. Instead, they may consider retrofitting older diesel engines into CNG vehicles, a process called repowering. During this process, the entire engine and fuel system is replaced. Repowers that convert a diesel vehicle into a CNG vehicle range from $30,000 per truck to $100,000 per truck. This option has lower capital costs than purchasing new CNG or clean diesel vehicles and may be utilized by fleet managers who want avoid the high capital costs of replacing entire vehicles.[74]

2.3.1.2 Infrastructure Costs

The operation of CNG refuse vehicles usually requires building a new refueling infrastructure or the existing fueling facilities undergoing extensive and costly modification. This capital investment is not necessary in order operate clean fuel technology vehicles, as it is assumed that refuse fleet operators already have diesel-bus refueling facilities in place. Clean fuel technology

[73] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[74] *Ibid.*

refuse vehicles operate using ULSD fuel, and this fuel can be used with existing diesel fueling facilities with no modifications or capital costs required. Therefore the fixed capital costs for CNG refueling facilities are incremental to diesel facility fixed capital costs. This assumption may favor clean fuel technology in any cost comparison. Nevertheless, it is realistic given the current widespread use of diesel fleets within the refuse hauling industry. This same assumption also applies to maintenance facilities.[75]

The equipment needed to operate a CNG fueling facility includes gas supply equipment, compressors, control valves, piping, gas conditioners, dispensers and safety equipment. The cost to construct a CNG fast fueling station for refuse fleets generally ranges from $500,000 to $1,250,000.

Due to these high fueling facility costs, many CNG operators choose to share these capital costs by partnering with public or private entities. Local utilities, transit agencies, private refuse companies, delivery truck operators, taxicab companies and municipal governments are all entities that could share in the cost of developing CNG fueling infrastructure. Further, if an existing natural gas refueling facility is already built and it could be shared with a municipal refuse operator or among private waste haulers, significant reductions in infrastructure costs could result. Currently more than 50 U.S. cities are equipped with the infrastructure to refuel natural gas fleets.[76]

Additional infrastructure costs associated with CNG conversion include truck storage and maintenance facility improvements. Operators that switch to CNG must modify indoor storage facilities and maintenance facilities to include proper ventilation and leak detection monitoring systems. Although new CNG maintenance and storage facilities do not cost significantly more than new conventional or clean diesel facilities, retrofitting an existing diesel facility for use with CNG vehicles can be expensive.

---

[75] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.
[76] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999; INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; U.S. Department of Agriculture, Life-*Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.

Data for CNG refuse vehicles storage and maintenance facilities were not available. However, comparable data was found for CNG transit buses. Typical cost for one maintenance garage is $600,000. Tacoma, Washington's Pierce Transit Authority spent $645,000 to modify their diesel maintenance facility. Larger transit systems such as the Greater Cleveland Regional Transit Authority and Los Angeles County Metropolitan Authority have spent $750,000 and $1,000,000 respectively.[77] (See Table 2.3.1.2-1.)

Table 2.3.1.2-1
Cost of Natural Gas Garbage Trucks and Refueling Infrastructure

Location	Operator	Incremental Cost of New Truck	Cost of Fuel Infrastructure
Irvine, CA	Waste Management	$40,000	$600,000
Moreno Valley, CA	Waste Management	$35,000	$600,000
New York City	Department of Sanitation	$70,000	$1,250,000
Yucca Valley, CA	Waste Management of the Desert	$100,000*	$500,000
Palm Desert, CA	Waste Management	$45,000	$550,000

*Cost of natural gas truck repower

CNG vehicles have significantly higher capital (vehicle and infrastructure) costs than clean diesel vehicles. Comparing diesel/biodiesel vs. CNG, total infrastructure costs per bus (per vehicle) are $1,461 for diesel and biodiesel compared with $10,000 per bus for CNG.[78] (Biodiesel will be discussed in detail in Section 3.1.)

2.3.2 Operating Costs

2.3.2.1 Fuel Costs

Fuel cost is one variable that determines total operating costs. Total fuel cost per vehicle is based on the price per gallon of the fuel and the fuel efficiency of the CNG vehicles in operation. Since CNG vehicles are heavier than conventional diesel counterparts, they are 20% to 40% less fuel-efficient than diesel vehicles.

[77] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1995.
[78] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.

CNG fuel costs vary depending on what part of the country operators are located in. The overall market for natural gas is more volatile than for diesel fuel. During the past few years the demand for natural gas has increased, but production levels have not been able to keep up. This is a major issue influencing price. Currently, due to environmental concerns, there are barriers to new natural gas drilling in North America. Moreover, access to foreign supplies is currently hampered due to a lack of sufficient tankers and terminals capable of importing the needed quantities of natural gas. The transport of enough natural gas in liquid form to meet future demand will necessitate additional investment in tanker and new terminal facilities nationwide.

Other factors that influence CNG price include the cost to compress the natural gas and the nature or extent of any special contracts refuse haulers have with the local gas company or local gas distributors. Some operators can see fuel cost savings by signing contracts with local gas distributors at decreased prices.

In the City, the cost of CNG (dollars per gallon diesel-equivalent) is more than the cost of a gallon of conventional diesel fuel. (See Table 2.3.2.1-1.) DSNY currently pays just under $1.00 per gallon for diesel and over $1.00 per gallon equivalent for CNG (price may vary due to natural gas market conditions). In comparison, ULSD represents a minimal cost increase over regular diesel fuel -- $0.05 to $0.10 cents per gallon more. The USEPA estimates that ULSD will be $0.045 to $0.05 cents more per gallon in 2006 when more stringent sulfur regulations are in place.[79]

Table 2.3.2.1-1
Regional Fuel Prices (2002)

Region	CNG ($ per gallon diesel-equivalent)	Diesel ($ per gallon)	Biodiesel* ($ per gallon)
New England	1.59	1.29	1.77
Central Atlantic	1.52	1.27	1.80
Lower Atlantic	1.05	1.13	1.06
Midwest	1.21	1.13	1.27
Gulf Coast	1.20	1.12	1.40
Rocky Mountain	1.11	1.13	1.29
West Coast	1.31	1.23	1.40

* B20 - 20% biodiesel & 80% conventional diesel; will be discussed more fully in Section 3.1.
Source: INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*.

[79] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

2.3.2.2 Maintenance Costs

Maintenance costs include engine and fuel system repairs and parts replacement. Overall maintenance CNG costs are higher than for conventional diesel engines. Factors that contribute to this include increased fuel system inspection, more expensive parts and higher tune-up costs. Data gathered from operators of CNG refuse vehicles and operators of CNG transit buses indicate that maintenance for CNG vehicles is 10% to 20% higher than for conventional diesel vehicles.[80]

Another factor that can contribute to higher maintenance costs for CNG and natural gas vehicles is that when a fleet is largely composed of diesel trucks, the natural gas trucks in the fleet require separate maintenance, storage and fueling facilities (with separate safety protocols). This tends to increase CNG maintenance costs. Conversion of an entire fleet to natural gas with equipment, labor and facilities dedicated to just one fuel type will lower CNG maintenance costs.

Over time, engine improvements have increased the maintenance intervals required for new natural gas trucks relative to earlier models, thus reducing maintenance costs. Manufacturers of natural gas engines contend that extending the maintenance interval between oil changes would provide savings of thousands of dollars over a garbage truck's lifetime. In addition, the after-treatment and emission control technologies present on clean fuel vehicles that will need to meet USEPA 2007 emission standards are likely to raise the maintenance and operating costs of diesel-fueled trucks, thus reducing the maintenance cost differential between clean diesel vehicles and CNG trucks.[81]

Data based on the U.S. Department of Agriculture report entitled "Life-Cycle Costs of Alternative Fuels" indicates that CNG vehicles are approximately 1.7 times more expensive than diesel vehicles. This paper used a 5% discount rate to calculate the present value per bus mile for the total cost of a transit fleet over the 30-year life-cycle of a refueling infrastructure. Diesel buses had the lowest cost at $0.247 cents per mile. The cost of CNG ranged from $0.375 to $0.42 cents per mile. Although this report did not compare CNG vehicles with clean fuel

---

[80] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999; INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[81] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

technology vehicles, the minimal fuel cost increases (due to the use of more expensive ULSD) and higher maintenance costs (due to the use of emission control devices) in clean diesel vehicles will likely not offset the higher CNG cost per mile presented in this report. Total costs evaluated in this report include infrastructure costs, and operating costs such as fuel and maintenance. (Vehicle capital costs were not included.) The author cites that the difference in infrastructure costs between diesel and CNG is the main reason for the lower diesel per mile cost.[82]

2.3.3 Programs and Incentives

Tax incentives and grant programs that give economic and financial preference to companies and agencies that operate natural gas vehicles can make CNG vehicles more economically feasible for waste haulers. Grant money is available from both state and federal sources to help fleets defray the higher capital costs associated with CNG vehicles. These grant programs are not available with diesel and clean diesel vehicles.

The NYCDOT, in conjunction with NYSERDA, authorizes the use of federal CMAQ funding available in order to reduce the out-of-pocket costs associated with the purchase of AFVs. Called the Private Fleet Program, the funds can be used to offset the incremental costs of vehicle acquisition. Up to 70% of the incremental costs of new or converted medium- and heavy-duty CNG vehicles are eligible for funding. New York City Clean Air Communities also has funds available for the implementation of clean air transportation programs in the City -- vehicle and infrastructure costs are eligible.[83]

Most large transit fleets that operate natural gas buses utilize federal funding to offset the higher vehicle costs of these vehicles. For example, Long Island Bus has used federal funds such as CMAQ for its purchase of natural gas buses in Nassau County, and the NYCDOT has also used federal funds for its natural gas purchases.

---

[82] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.
[83] U.S. Department of Transportation, Federal Highway Administration, The Congestion Mitigation and Air Quality Improvement Program, http://www.fhwa.dot.gov/environement/cmaq/funding.htm.

Federal and state tax incentives are also available to help lower the capital costs of CNG vehicles. The federal tax code allows businesses that purchase AFVs or build an alternative fuel refueling facility to take tax deductions. The deductions are allowed for the incremental cost of the AFV or facility compared to the diesel counterpart. In addition, New York State offers a tax credit of up to $10,000 for the purchase of a heavy-duty AFV.[84]

[84] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

3.0 OTHER CLEAN FUEL TECHNOLOGIES AVAILABLE

3.1 Biodiesel

Biodiesel fuel is a fuel produced from biological sources such as vegetable oils and animal fats. It is biodegradable, nontoxic and nonvolatile. The main benefits of biodiesel include lower exhaust emissions and production from renewable energy sources. The major negative is cost. According to the DOE, biodiesel costs roughly \$0.30 to \$0.40 cents more per gallon than pure petroleum diesel. However, unlike other alternative fuels, biodiesel does not require expensive equipment modifications to vehicles, fueling infrastructure or storage tanks. Another drawback of biodiesel is that in spite of its reduced CO, HC and PM relative to conventional diesel, it emits more NO_X than diesel. NO_X is a precursor to smog and an issue for major cities in non-attainment areas.[85]

3.1.1 Fuel Characteristics

In order to create biodiesel fuel, an oil source is mixed with an alcohol. (A chemical catalyst is used to speed up the process.) The most common alcohol used is methanol, although ethanol is also sometimes used. After the alcohol is mixed with the oil -- typically soybean oil -- a methyl ester (methanol) or an ethyl ester (ethanol) is produced. Both can be used as fuel for diesel engines. The most common biodiesel fuel is the 80/20 blend (80% petroleum diesel/20% biodiesel) called B20. Blending usually reduces the cost of biodiesel and extends the fuel's storage life. Industry experts recommend that biodiesel be used within six months of purchase. In addition, the use of biodiesel poses a problem during the winter months, as the fuel will begin to gel during cold weather.[86]

---

[85] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[86] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

3.1.2 Use and Development

Biodiesel was first developed in South Africa before World War II in order to power heavy-duty vehicles. Currently in Europe there is a much larger base of experience and use with biodiesel than in the United States, and in most European countries, there is a total or near-total exemption from fuel taxes on this fuel. In 1992 the National Biodiesel Board started its efforts to commercialize and promote the use of biodiesel fuel in the United States. This trade group places emphasis on the use of soybean oil methyl ester blended with petroleum-based diesel at various percentages. Blends, specifically the B20 blend, display the best combination of cost efficiency and engine emissions benefits, according to the National Biodiesel Board. B20 is widely used as the biodiesel blend among heavy-duty diesel engine operators in the United States.[87]

There is a sufficient supply of biodiesel currently available in the United States. And, there are currently three billion gallons of excess vegetable oil on the market that can be used to make biodiesel. Most biodiesel fuels are made from soybean, rapeseed or canola oil, which are secondary products of the manufacturing process that makes animal protein supplements and animal feed for livestock. Nutritional awareness has led to the increased use of lighter and unsaturated vegetable oils and is lowering demand in the United States for saturated oils and fats. This development is increasing the availability of animal fats and certain vegetable oils for conversion into biodiesel fuel.

3.1.3 Costs

No major modifications are necessary to maintenance garages and fueling facilities when using biodiesel fuel. There is no increased capital cost associated with biodiesel above the capital cost associated with the use of diesel fuel (pure petroleum diesel). According to the National Biodiesel Board, the B20 blend will generally cost $0.15 to $0.30 cents per gallon more than diesel fuel. The DOE's figures have biodiesel (B20) costing approximately $0.30 to $0.40 cents more per gallon than diesel fuel.[88] No explanation could be found to describe the discrepancy in costs between the DOE and the Biodiesel Board.

---

[87] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

[88] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.

3.1.4 Fuel Emissions

The National Biodiesel Board asserts that, compared to conventional diesel fuel, B100 (pure biodiesel, with no petroleum diesel fuel added) can reduce total unburned HC by 67%, CO by 48% and PM by 47%. In addition, the Board states that B100 will increase NO_X emissions by 10%.[89] The May 2003 edition of BioCycle Energy magazine confirms this by stating that B100 fuel can reduce unburned HC that contribute to smog and O_3 formation by 68% and CO by 44% over conventional diesel fuel.[90]

The data on B20 is more relevant because it is more widespread in use and is used more frequently with heavy-duty vehicles such as refuse trucks. The National Biodiesel Board states that average B20 emissions compared to conventional diesel can reduce total unburned HC by 20%, CO by 12%, and PM by 12%.[91] The NO_X increase is 2%. The increase in NO_X emissions from biodiesel is largely due to the organic portion of the fuel, which, when burned in the engine, releases more NO_X than conventional diesel.

The data reported by public agencies (see Section 3.1.6 Biodiesel Case Studies) that utilize B20 generally corroborates the National Biodiesel Board's data and findings regarding B20 emissions. For example, Arlington County, Virginia reports that using B20 in diesel-powered vehicles has reduced HC emissions for the entire fleet by 30%, CO levels by 20% and PM emissions by 22%. However, emissions of NO_X have increased by 2%. Also, the City of Tacoma, Washington has seen a 20% reduction in CO and PM emissions, with a slight increase in NO_X emissions.

---

[89] National Biodiesel Board, http://www.biodiesel.org/pdf_files/emissions.PDF.
[90] Biosolids and Biodiesel Team Up for Sustainable Economics, *BioCycle Energy*, May 2003.
[91] National Biodiesel Board, http://www.biodiesel.org/pdf_files/emissions.PDF.

3.1.5 Incentives and Disincentives

An important incentive for biodiesel use is that operators can use conventional diesel fueling equipment, as biodiesel fuel has mechanical and ignition properties that are comparable to conventional diesel fuel. Since biodiesel is less volatile than diesel fuel, there are no modifications regarding safety procedures. And, using biodiesel in pure or blended form does not require engine or storage modifications as with other alternative fuels, such as compressed natural gas. In short, the capital costs associated with diesel and biodiesel are the same.[92]

In addition, biodiesel compared with conventional petroleum diesel has similar heavy-duty diesel engine performance. There is no difference in terms of power, acceleration or fuel consumption between the two types of fuel. However, some engine manufacturers do not guarantee their warranties on biodiesel blends greater than B20. One benefit of biodiesel over petroleum-based diesel is that it provides better lubricity -- it acts as an engine cleaner and can lubricate the engine more thoroughly, which can contribute to longer engine life.[93]

The major disincentive to using biodiesel is cost; as previously mentioned, biodiesel is more costly than regular diesel fuel. Minor disincentives include the potential for fire hazards, biodiesel's cold weather properties and its properties as a solvent. A physical characteristic of biodiesel is the possibility of spontaneous combustion, as some vegetable oils and methyl ester oxidize in the air. This is not considered a serious issue and can be simply resolved by using closed metal cans for storage. There are no fire hazards during transport. Due to its low volatility during a leak or spill, biodiesel is less likely to ignite than diesel. In addition, there are no specific fire hazards during storage or unloading from storage.[94]

There is a greater probability for biodiesel to gel in colder temperatures than conventional diesel. An additive may be needed to prevent this. Other solutions include using a pour point depressant and storing the vehicles near or in a building. Usually, this cold-weather property of biodiesel is not a problem. B20 blends have been used in Iowa and the upper Wisconsin areas without issues.

---

[92] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[93] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[94] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

Because of the excellent solvent properties of biodiesel, the use of fuel filters may increase when first using this fuel. Petroleum diesel can leave deposits in fuel tanks, fuel lines and delivery systems over time. Biodiesel dissolves these deposits and may initially clog filters, necessitating the increased replacement of such filters.[95]

3.1.6 Biodiesel Case Studies

3.1.6.1 New York City Department of Sanitation[96]

DSNY has explored the use of biodiesel as a fuel source for their diesel refuse truck fleet, including meeting with representatives of World Energy, a group that promotes biodiesel. DSNY has identified some barriers that would have to be overcome before considering its use. Beginning in 2004, Mack engines will power all DSNY garbage trucks. Mack voids warranties if a biodiesel blend of more than 5% biodiesel (B5) is used; however, the environmental benefits from using biodiesel can only be derived from blend that is at least 20% biodiesel (B20). DSNY is also concerned by the increase in NO_X emissions associated with biodiesel compared to conventional diesel fuels, which makes it less than ideal for USEPA non-attainment areas, such as the City. (NO_X contributes to the creation of smog.) Another issue identified by DSNY with the use of biodiesel as a fuel source is that it has limited shelf life and could not be used with seasonal DSNY heavy-duty equipment.

3.1.6.2 Arlington County, Virginia[97]

In September of 2002 Arlington County, located just south of Washington D.C., switched to using biodiesel (B20) for use with refuse vehicles. The county also decided to use biodiesel with other vehicles such as fire trucks, school buses and street sweepers that operate using diesel engines. Arlington County's refuse fleet includes 39 cubic-yard side loaders, 31 cubic-yard rear loaders, 25 cubic-yard rear loaders and 3 to 4 small side loaders.

---

[95] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001; Rick Markley, Friendly Fuel, *Construction and Mining Trucks;* Tom Moore, Looking for Alternatives, *Fleet Owner*, June 1998.
[96] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[97] Based on phone conversation with Frederic I. Hiller, Chief of Equipment Division, Office of Support Services, Arlington County, Virginia, July 30, 2003.

The main reason the county made the switch was for the reduction in emissions that the use of biodiesel provides. Arlington County is in a non-attainment area for O_3, and HC emissions are an important contributor to O_3 production; the use of biodiesel can reduce these emissions. The reduction in fossil fuel use and the reduction in dependence on foreign oil were other important considerations cited by Arlington County.

The speed it took to implement biodiesel as a fuel for Arlington County's fleet was extremely important in making the decision to use biodiesel. Unlike other alternative fuel options, once the decision was made to switch to biodiesel, it was implemented very quickly. There was no need to modify storage, maintenance or fueling facilities.

Another important factor was cost. Arlington County compared the costs of utilizing CNG and biodiesel, and found there is a large cost difference. The fueling, safety, maintenance and vehicle costs associated with CNG technology are much larger than those for biodiesel. Biodiesel was selected because it is a low-cost alternative.

It should be noted, however, that despite lower biodiesel costs when compared to CNG, Arlington County has seen an increase in fuel costs with the use of biodiesel over what it pays for diesel fuel. It costs the county $1.23 per gallon for biodiesel vs. $0.97 per gallon for diesel fuel.

Arlington County provides extra money for the use of alternative fuel in its vehicle fleet. Hybrid, ethanol and biodiesel vehicles are all currently used. The county sees itself as being proactive in terms of support and funding for the use of alternative fuels. No public sector grants, incentives or mandates were identified as influencing the decision to use biodiesel.

There have been no supply issues. The county contracts out for its fueling needs despite utilizing county-owned fueling facilities. Nationally, engine manufacturers generally honor all warranties with blends of B20 or lower (although Mack does void warranties if blends higher than B5 are used), and there have been no problems regarding warranties for the Ford and Cummings diesel engines Arlington County uses. Overall, there has been no degradation in performance with the use of biodiesel in the county's refuse vehicles. Range and fuel economy are reported to be equal when the county compared both biodiesel and conventional diesel.

As expected, Arlington County has seen overall emissions reductions, with a slight increase in NO_X emissions. Also, two minor maintenance issues have arisen with the use of biodiesel: gelling in cold weather and the excellent solvent and detergent-like qualities of biodiesel. To address the cold weather properties of biodiesel, an additive is used to prevent the fuel from gelling up. In addition, because biodiesel is a good solvent, the vehicle fuel tanks were cleaned when the switch to biodiesel was made, and fuel filters at the fueling pumps were used to remove the deposits left from the use of conventional diesel. Nonetheless, the county reported it has increased its use of primary fuel filters because of biodiesel's solvent-like qualities.

3.1.6.3 Tacoma, Washington[98]

The city of Tacoma, Washington switched to B20 in November of 2001 for use with all of its 85 refuse vehicles. The vehicles include rear, side and front loaders. The city's use of biodiesel has seen a reduction in emissions without compromising the performance of the vehicles or an increase in the city's budget.

In November of 2001, Tacoma contracted out with Kent, Washington-based Petro Card to provide B20 biodiesel and mobile fueling. Mobile fueling is the process in which the contractor delivers the fuel to the city's refuse vehicle storage site in a tanker truck each evening, and is responsible for refueling the refuse trucks. In the contract, Tacoma committed to using 200,000 gallons of fuel per year. Because of such a large commitment, the biodiesel only costs Tacoma $0.20 cents more per gallon than regular diesel. The city states that this increase in fuel costs is completely offset by the savings in wages, fuel and time that results with the use of Petro Card's on-site fueling service. (Previously, drivers of the refuse vehicles would have to drive and fuel their trucks off-site each day.)

Biodiesel has not compromised the performance of the refuse trucks, nor has there been any additional maintenance needed. Maintenance crews originally thought they might have to change the fuel filters more frequently, but they've found this unnecessary. And, there was no special training for operators or mechanics. Additionally, Tacoma has seen a 20% reduction in CO and PM emissions, and a slight increase in NO_X emissions.

---

[98] Based on phone conversation with Steve Hennessey, Fleet Division Manager, City of Tacoma, Washington, July 30, 2003.

The city made its decision to use biodiesel without any incentives such as grants or regulatory mandates. They also did not look into other alternative fuels regarding its refuse fleet; the costs of natural gas were prohibitive and the natural gas infrastructure was deemed not to be available. Tacoma is currently looking into increasing the number of trucks that use biodiesel.

For its use of biodiesel with all of the city's refuse fleet and reduction in refuse truck emissions, in May 2002 the U.S. DOE inducted Tacoma into the Clean Cities Hall of Fame and awarded them its National Partner Award.

3.2 Fuel Cells

A fuel cell generates electricity from the chemical reaction of combining hydrogen and oxygen into water, without the need for combustion as an intermediate step. Fuel cells can either be directly fueled by hydrogen stored on board the vehicle, or by reformers that generate hydrogen from sources such as natural gas or methanol.

The combination of very high energy efficiency and low emissions makes the concept of fuel cells extremely attractive as an alternative fuel source.[99] However, they are currently only in the development stage for heavy-duty vehicles and buses.[100] They are not expected to be a viable option for at least ten years.[101]

To determine the total net environmental benefit of fuel cells, the energy expended and pollutants released from the process to liberate the hydrogen needed for fuel cells should be considered. If, for example, the burning of coal is involved in the process of making hydrogen, the emissions associated with coal would potentially need to be included in the determination of emissions from the total fuel cell process.[102]

---

[99] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[100] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[101] *Ibid.*
[102] Matthew L. Wald, *Turning to Hydrogen for Energy is Harder than it Seems*, International Herald Tribune, November 13, 2003.

3.2.1 Fuel Characteristics

Hydrogen is the most abundant element in the universe. It has the highest energy per unit of weight of any chemical fuel and is non-polluting when used to generate power. However, in order to be used as a primary fuel with fuel cells, hydrogen needs to be transformed from water, fossil fuels, biomass or other materials that are rich in hydrogen. Natural gas, petroleum, coal, ethanol, methanol and landfill waste are all potential sources.[103]

Fuel cells are actually not alternative fuels, but fuel conversion systems. They can be conceptualized as being batteries that operate with hydrogen and oxygen. Water and electricity are the by-products of the hydrogen reacting with the oxygen. Chemical energy is transformed into electrical energy with little or no noise or pollution, and energy conversion efficiencies of approximately 80% are theoretically possible -- burning fuels in heat engines produce efficiencies around 40%.[104]

3.2.2 Use and Development

Currently, there are no fuel cells that power heavy-duty vehicles being produced – use of hydrogen in vehicles is primarily limited to experimental and prototype vehicles. In the future, with increased research and development, hydrogen as a transportation fuel will likely occur.

3.2.3 Costs

Since there are no heavy-duty vehicles powered by fuel cells in production, firm cost data is hard to ascertain or estimate. With any new technology, unit costs will fall as production rates and manufacturing experience increase. One fuel cell engine manufacturer, Ballard, has estimated that, with large commercial production, transit buses using fuel cells could be priced competitively with CNG buses.[105]

---

[103] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[104] National Conference of State Legislatures *Ground Transportation for the 21st Century*, August, 1999.
[105] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

In addition to vehicle costs, the actual costs of the hydrogen or other fuels in which the hydrogen is generated need to be taken into account. Hydrogen can be stored on board or generated from other fuels by an on-board reformer. Reformers can be used with methanol or natural gas; it may also be possible to use diesel or gasoline. Utilizing reformers increases the cost and complexity of the fuel cell system. Vehicles that do not use reformers are fueled using hydrogen directly. The hydrogen is stored as a liquid, vaporized to a gas, and dispensed into on-board storage tanks on the vehicles. Depending on whether a vehicle uses an on-board reformer or hydrogen directly, the fueling facilities for fuel cell vehicles will differ considerably.[106]

3.2.4 Fuel Emissions

Fuel cells effectively emit zero emissions with the use of hydrogen.[107]

3.2.5 Incentives and Disincentives

The primary benefit and incentive for utilization of fuel cells is zero emissions. Other advantages include high operating efficiency, quick start-up, and operation over a wide range of temperatures. Currently, fuel cells are in the very early stages of development for heavy-duty vehicles. There are currently issues and problems with hydrogen fueling that have to be addressed and resolved. These include high costs, poorly developed hydrogen fuel supply infrastructure, very large storage volume, and safety concerns associated with compressed hydrogen, especially when stored on a vehicle -- compressed hydrogen systems have a tendency to leak and present fire safety hazards.[108]

If hydrogen fuel is produced off board the vehicle, electrical power is required. However, there are transmission costs associated with off-board production and the use of electrical power, as well as production inefficiencies (compared to on-board production).

---

[106] National Conference of State Legislatures *Ground Transportation for the 21st Century*, August, 1999.
[107] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, General, 1999.
[108] *Ibid.*

There are tradeoffs between on-board and off-board hydrogen production. With on-board production, the technology used to produce the hydrogen is complex, whereas with off-board production, the technology is simple but to generate the hydrogen there are transmission costs and larger electrical production inefficiencies.

3.3 Battery Electric

Vehicles that operate on electricity alone utilize batteries to store the electricity, which then transfer the power to an electric motor. These vehicles do not produce any emissions. However, the production of the electricity used to power these vehicles does produce remote-source emissions, which are emissions from power plants.[109]

The widespread use of battery electric in refuse vehicles requires the advancement of battery electric propulsion systems, which are needed for the battery electric engines to be able to deliver the power that garbage trucks require.[110]

3.3.1 Fuel Characteristics

Electricity is an alternative source of propulsion. The majority of the electricity used in battery electric vehicles comes from the nation's electric power distribution infrastructure, with batteries used as the electricity storage medium. Battery electric vehicles have characteristics, such as low energy density and weight, which usually limit vehicle performance and driving range. Electric vehicles are recharged overnight, with typical battery recharging time taking six to eight hours.[111]

Battery electric vehicles are operationally much simpler than vehicles powered by internal combustion engines (which can have hundreds of moving parts). The three main mechanisms that power a battery electric vehicle are the battery pack, the inverter and rotor, and the regenerative braking system. Regenerative braking allows the vehicle to reclaim a portion of the

---

[109] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*
[110] *Ibid.*
[111] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

energy that is usually lost in conventional friction braking (which is used in diesel vehicles). Battery electric vehicles, as well as HEVs (discussed in Section 3.7), use both braking systems. The braking systems are controlled electronically in order to maximize stopping ability and make the dual system transparent to the driver.[112]

3.3.2 Use and Development

At the turn of the 20th century, electric vehicles outnumbered gasoline vehicles, with approximately 50,000 electric vehicles operating in the United States. Use decreased when less-expensive methods of producing gasoline were introduced and the electric starter replaced the crank in gasoline vehicles. The current research focus for electric propulsion vehicles is in the area of battery development, with the goal of developing batteries that have low initial cost, high specific energy and high power density. Further advancement of battery electric propulsion systems is needed before the power that garbage trucks need is delivered.[113]

3.3.3 Costs

The vehicle costs of battery electric vehicles are significantly higher than those of diesel vehicles of comparable size. (Because no cost data was available for heavy-duty vehicles, transit bus comparisons will be made.) When a lead-acid battery pack is used, a battery electric shuttle bus is slightly more than twice as costly as a comparable diesel model. For larger transit buses, the cost differential is approximately 33% higher for battery electric vehicles than comparable diesel models. A nickel cadmium battery option will add roughly $40,000 to $50,000 dollars to the cost of a battery electric bus. However, nickel cadmium batteries yield greater range per battery charge and provide an increased battery life of three to seven years more than a typical lead-acid battery.[114]

---

[112] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August, 1999.
[113] *Ibid.*
[114] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

The operating costs that are used to compare diesel vehicles with battery electric are energy costs and maintenance costs (which includes replacement of the battery packs and the individual battery units used in the pack). The energy costs per mile are similar for diesel vehicles and battery electric. General maintenance for battery electric vehicles includes checking the condition of the motor, brakes, batteries and electrical connections, battery pack integrity and battery pack mounting.[115] Battery packs may need to be replaced every 25,000 miles and individual units every 10,000 miles. No data could be found comparing the maintenance costs for battery electric and diesel vehicles.

3.3.4 Fuel Emissions

Battery electric vehicles did not produce any emissions, smoke or exhaust odor.[116]

3.3.5 Incentives and Disincentives

The main benefit and incentive for using battery electric systems is emissions reductions. Battery electric vehicles have no tailpipe emissions, low noise levels and effortless cold starts.[117] The main disincentives associated with battery electric vehicles include the reduced range and performance and the substantially higher purchase price. Also, batteries tend to diminish in power output in cold weather.

The main safety issue with battery electric is the exposure of personnel to electrical hazards when using the recharging system and when connecting vehicles to the recharging system. However, this is not a major concern as safeguards can be put in place to ensure personnel are protected from direct exposure to electrical hazards. In addition, there are no specific health or environmental hazards associated with the transmission and use of electricity at a fleet facility.[118]

---

[115] U.S. Department of Energy*, Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001; National Conference of State Legislatures *Ground Transportation for the 21st Century*, August, 1999.
[116] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[117] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[118] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

3.4 Propane

Propane, also known as liquefied petroleum gas, is the most commonly used alternative fuel in the U.S., with an estimated 350,000 propane vehicles currently in operation.[119] However, it is not widely used in the private or public refuse hauling sector. The main obstacle associated with the use of propane with refuse fleets is that major garbage truck manufacturers do not make or offer models that burn propane; the development of heavy-duty propane engines is needed for propane to expand in use as an alternative fuel in the refuse hauling vehicle sector.[120]

3.4.1 Fuel Characteristics

Propane is a by-product of both natural gas processing and petroleum refining. At room temperature, propane is a gas, and liquifies at relatively low pressures (about 200 pounds per square inch [psi]). Liquefied petroleum is a liquid mixture containing 90% propane and 2.5% butane (and other higher hydrocarbons), as well as ethane and propylene. Special tanks are utilized to force propane to remain under pressure and in a liquid state. Propane is stored on board vehicles as a liquid. Before being burned in engines, propane is easily converted to a gas before combustion takes place.[121]

3.4.2 Use and Development

Propane was first experimented with as a motor fuel as early as 1910. During the 1950s, it became more widespread and popular. Currently, most of the propane produced in North America is generated from natural gas processing.

---

119 INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August, 1999.
120 INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
121 U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.

Propane can be purchased in two ways: wholesale from distribution centers, which may be the best option for fleet managers and operators that have their own refueling stations; or at public-access stations, where low and discounted prices may be available for large purchases.[122]

Propane has the largest use among all alternative fuel types in the United States. Nevertheless, vehicles that utilize propane experienced the slowest growth during the 1990s. Propane vehicles are most prevalent in the South, where large numbers are operated in Texas and Oklahoma, two large oil-producing states.[123]

The propane industry has been criticized for not promoting and generating interest for its use as an alternative transportation fuel. Comparisons have been made with the natural gas industry, which actively promotes the use of its fuel for vehicle use. The propane industry is dominated by small-scale suppliers who primarily serve residential consumers. Possible reasons for little promotion include the lack of internal cohesion within the industry, concern among propane customers that the increase in propane use as a vehicle fuel will cause an increase in price, and fear that the many small propane suppliers would see their businesses suffer if propane was used as a vehicle fuel in large transportation fleets.[124]

The major problem associated with using propane as an alternative fuel in refuse vehicles is that propane engine technology has not been used in large engines that can power and are suitable for refuse vehicles. Major garbage truck manufacturers currently do not offer models capable of burning propane.[125] However, propane does have extensive use in vehicles such as school buses, small transit buses, light- and medium-duty vehicles and heavy-duty trucks and buses.

Another problem associated with propane is the special handling it requires. For propane use, new facilities need to be constructed or old facilities redesigned. Various design specifications for a propane maintenance facility include explosion-proof wiring and flammable gas detectors. In addition, propane storage and dispensing areas must be located at a certain minimum distance from buildings, adjacent property, underground tanks and adjacent streets due to flammability concerns.

---

[122] Energy Information Administration, *Developments in U.S. Alternative Fuel Markets,* 1999.
[123] *Ibid.*
[124] *Ibid.*
[125] *Ibid.*

3.4.3 Costs

It is presently hard to determine the incremental cost of a propane garbage truck with a comparable diesel refuse vehicle due to a lack of data and a lack of propane-powered refuse vehicles being produced. With transit vehicles, the incremental vehicle cost of a propane bus over a standard diesel bus was $35,000 to $45,000 in 1998.[126]

As noted in Section 3.4.2, the use of propane brings increased capital costs associated with the design of propane maintenance, storage and fueling facilities. It is assumed that most sanitation fleets are currently already utilizing diesel refuse vehicles and diesel refueling and maintenance facilities. For propane use, new facilities need to be constructed or old facilities redesigned, resulting in additional, higher capital costs.

The increased operating costs (higher than comparable diesel operating costs) associated with propane use are attributed to two main factors: high propane fuel cost and lower fuel efficiency. More propane is needed than an equivalent amount of diesel, which contributes to higher operating costs.

Since the early 1990s, propane prices have been increasing relative to gasoline and diesel fuel. It is difficult to quantify the price of propane because its purchase price depends on a number of factors, including the quantity being purchased, the location of purchase in the United States, the particular state's tax on propane and the season the fuel was purchased. It should be noted that experience with propane vehicles indicates that although initial capital costs are high, significant savings in lower maintenance costs may outweigh the short-term, higher capital costs. This is due to the fact that propane engines are reported to last two to three times longer than gasoline or diesel engines.

---

[126] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

3.4.3 Fuel Emissions

Propane buses have lower emissions than diesel engines, but not as low as natural gas or methanol engines. Low levels of NO_X and PM emissions are a characteristic of propane combustion.[127]

3.4.4 Incentives and Disincentives

The main benefit or incentive realized with the use of propane is the emissions benefits. Disincentives include the lack of suitable heavy-duty engines and increased capital costs. Further, there are safety concerns associated with use of propane, including the potential fire hazards associated with its transport, and storage concerns when the fuel is stored as a pressurized liquid. Finally, propane supply is limited by the supply of liquid and gaseous fossil fuels from which propane is produced.[128]

3.5 Ethanol

Ethanol, despite having similar physical and combustion properties to diesel fuel, is not a satisfactory alternative fuel for use with medium- and heavy-duty vehicles, as previous ethanol experience has resulted in high rates of engine failure and low rates of engine reliability. Ethanol is generally not used for heavy-duty vehicles such as refuse trucks; there are few if any OEMs producing ethanol garbage trucks and few if any ethanol-powered refuse vehicles currently in operation.[129]

3.5.1 Fuel Characteristics

Ethanol is produced by the fermentation of plant sugars derived from corn or sugar cane. When used for commercial or industrial applications, ethanol is denatured -- denaturing the fuel involves the addition of a small amount of a toxic substance (typically gasoline) in order for producers to avoid the federal alcoholic beverage tax.

---

[127] *Ibid.*

[128] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August, 1999; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

[129] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air.*

Ethanol, when used as an alternative fuel, is most commonly used as a blend of 85% ethanol and 15% gasoline (E85), or a blend composed of 95% ethanol and 5% gasoline (E95). These are the only ethanol forms that are considered to be alternative fuels, and are mainly used with light-duty vehicles. However, the most common application of ethanol is as a blend with gasoline that contains 10% ethanol and 90% gasoline. This fuel, known as gasohol or E10, is not considered an alternative fuel.

Ethanol can be blended with gasoline at lower concentrations to produce oxygenated gasoline. Ethanol is also a chemical component of ethyl tertiary butyl ether (ETBE), a type of oxygenate. Oxygenated gasoline (containing ethanol or ETBE) is also not considered an alternative fuel, but is mandated in certain CO non-attainment areas to reduce exhaust CO emissions.[130]

3.5.2 Use and Development

Alcohols were used as fuel in several of the earliest vehicles ever designed. In fact, Henry Ford's very first car used an alcohol-based fuel. During the oil crisis of the 1970s, ethanol use increased.

Since the largest supply of corn is grown in the Midwest, most ethanol production facilities in the United States are located there. It follows that use of ethanol (E85 and E95) has also been mostly limited to this section of the country. There are roughly only 50 E85 refueling sites currently operating in the United States.[131] The lack of an adequate refueling infrastructure is a barrier that impedes more widespread use of ethanol.

There are no ethanol garbage trucks in operation and no ethanol refuse vehicles available from OEMs. In addition, experience with ethanol transit buses in the mid- and late-1990s has shown that ethanol engines failed at a much higher rate than methanol-fueled engines, and their operational life was only half that. The use of ethanol is more successful with light-duty

---

[130] U.S. Department if Energy, T*aking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[131] Energy Information Administration, *Developments in U.S. Alternative Fuel Markets*, U.S. Department of Energy, 1999.

vehicles. DSNY uses approximately 350 light-duty vehicles that run on E85 in the non-collection operations. These vehicles are well suited for DSNY's non-collection operational needs and the agency is in the process of developing seven ethanol filling stations.[132]

3.5.3 Costs

Data suggests that ethanol-powered vehicles are characterized by higher operating and capital costs than diesel-powered vehicles. A 1999 DOE study states that the maintenance costs associated with ethanol-powered vehicles were significantly higher than for those vehicles with diesel engines.[133] Ethanol also suffers a fuel economy penalty compared to vehicles using diesel fuel, which may result in higher operating costs. More ethanol is needed than an equivalent amount of diesel fuel used in diesel-powered engines.

Capital costs are also likely to be greater if heavy-duty ethanol vehicles were used and produced. These costs include a higher purchase price for vehicles and modifications to maintenance and fueling facilities. For example, in the late 1990s, if a 200-bus transit fleet is considered, modifications to one maintenance garage would be between $300,000 and $400,000. In addition, the incremental cost for a standard ethanol bus, if available, is higher than the purchase of an equivalent diesel bus. An ethanol bus would likely cost $25,000 to $35,000 more than an equivalent diesel bus.[134]

3.5.4 Fuel Emissions

The main emissions advantage of ethanol and ethanol blends is that the oxygen content present in the ethanol lowers emissions of CO. When combusted, alcohol fuels do not produce any soot or PM and their emissions are less reactive in the atmosphere, thus producing smaller amounts of O_3, the harmful component of smog. However, ethanol usually produces slightly higher NO_X emissions.[135]

[132] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[133] Energy Information Administration, *Developments in U.S. Alternative Fuel Markets*, U.S. Department of Energy, 1999.
[134] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[135] *Ibid.*

3.5.5 Incentives and Disincentives

The primary benefit of using ethanol and alcohol fuels is lower emissions of CO. However, emissions of NO_X and HC can increase somewhat with ethanol use.[136]

The main disincentive is that heavy-duty engine manufacturers do not currently produce alcohol fueled engines. Two main reasons for this are the high rate of engine failure and low engine reliability.

3.6 Methanol

Methyl alcohol, or methanol, is a liquid fuel that, like ethanol, displays similar physical and combustion properties to diesel fuel. Basic engine and fuel system technologies can be used both with methanol and diesel fuel. However, similar to ethanol, methanol use has shown high engine unreliability. There appears to be no heavy-duty engine manufacturer currently producing methanol engines for refuse vehicles.[137]

3.6.1 Fuel Characteristics

Methanol is produced in a variety of ways. The most common method is via the reformation of natural gas, but it can also be produced from coal and municipal waste. Methanol is primarily produced in the Gulf Coast states.

When used as an alternative transportation fuel, methanol is typically blended with gasoline -- 85% methanol and 15% gasoline (M85) -- or left unblended, which is pure methanol (M100). Methanol is also being tested as a source of hydrogen to power fuel cells for use in vehicles.[138] In addition to use as an alternative fuel, methanol is used as a solvent and in a variety of ways in many industrial manufacturing processes.

---

[136] Living Without Oil, *U.S. News & World Report*, February 17, 2003.
[137] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[138] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.

3.6.2 Use and Development

Because of poor engine reliability and high engine failure, there is currently very little effort to develop heavy-duty methanol engines.[139]

Currently, methanol is principally used in light-duty flexible fuel vehicles that operate on methanol, gasoline, or a combination of the two. Seventy-five percent (75%) of all methanol vehicles in the United States are operated in California; only around 15 methanol refueling sties are located outside of California.[140]

3.6.3 Costs

Methanol has a similar capital cost structure to ethanol, with higher capital costs than diesel-powered vehicles. These higher costs include higher purchase prices for vehicles and modifications to maintenance and fueling facilities. The modifications consist of alcohol-compatible fuel tanks, new fuel dispensers and special safety equipment. Because they have a higher fuel consumption rate than diesel-powered engines, methanol vehicles need more on-board fuel than diesel vehicles and require additional fuel storage capacity. For example, methanol buses require on average 2.5 times as much fuel as diesel buses. A United States Department of Agriculture (USDA) 1995 study titled "Life-Cycle Costs of Alternative Fuels" found that for urban buses, total infrastructure cost per bus is $10,000 for methanol vs. only $1,646 for diesel- and biodiesel-powered buses.[141]

Operating costs associated with methanol are higher than those for diesel. Fuel costs are substantially higher because of higher methanol fuel prices and lower fuel economy mileage. Higher maintenance costs are present as well because of the need for frequent engine rebuilds.[142]

---

[139] U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001; U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[140] Energy Information Administration, *Developments in U.S. Alternative Fuel Markets,* 1999.
[141] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.
[142] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

The 1995 USDA study referenced above indicates that annual refueling costs are $21,102 per methanol-fueled bus -- twice the amount of the cost for diesel buses. The higher refueling labor costs are due to the 2.5-times higher fuel consumption rate present in methanol buses over those fueled with diesel, requiring 4.5 times more labor for refueling purposes. This study also indicates that methanol buses have higher maintenance costs than diesel buses, including engine rebuilds ($9,500 per engine for methanol vs. $6,500 for diesel) and general maintenance and repair. Overall, the maintenance cost per month per bus for diesel is $4.34, compared with the $31.84 for methanol buses.[143]

3.6.4 Fuel Emissions

Methanol combustion produces negligible amounts of PM and low levels of NO_X. Since methanol emissions are less reactive in the atmosphere than diesel fuel, smaller amounts of O_3 are produced.

3.6.5 Incentives and Disincentives

.

The main benefit of using methanol is a reduction in PM, NO_X and O_3 emissions.

Major disincentives of using methanol are the lack of heavy-duty engine production, high rate of engine failure and poor engine durability. The poor durability is due to mechanical wear and accumulation of combustion deposits in the injector tips, which cause fuel injectors to leak. In addition, methanol vehicles experience lower fuel economy compared to diesel vehicles, likely due to the additional fuel storage weight carried by methanol buses. There are also higher operating and capital costs associated with methanol, and special safety concerns -- it can cause toxic effects through skin contact, ingestion or inhalation. Special training programs are needed for those personnel who work with methanol. Finally, due to its inhalation toxicity, methanol is regulated as a hazardous air pollutant (HAP) under 1990 CAA Amendments.[144]

---

[143] U.S. Department of Agriculture, *Life-Cycle Costs of Alternative Fuels: Is Biodiesel Cost Competitive For Urban Buses*, 1995.
[144] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August 1999.

3.7 Hybrid Electric Vehicles

Hybrid electric vehicles (HEVs) are powered by two energy sources: an energy conversion unit such as an internal combustion engine or fuel cell, and an energy storage device such as a battery. Fuels used in HEVs to power the energy conversion unit include gasoline, diesel, methanol, CNG and hydrogen. The main benefits of HEV use are reduction in emissions and increased fuel economy and efficiency. Nevertheless, there is currently a lack of commercially manufactured hybrid engines that can be used with heavy-duty vehicles such as refuse trucks.[145]

3.7.1 Fuel Characteristics

HEVs can be configured in a parallel or series design. In a parallel design, the HEV is powered by the power generation unit (such as an internal combustion engine) and the electric motor, either at the same time or separately. In a series design, the power generation unit is used to generate electricity, which recharges the HEV's battery pack and powers the vehicle with use of an electric motor. Both designs enable the battery pack and internal combustion engine to be smaller than those found in a battery electric vehicle or diesel engine.[146]

In a parallel design, the power generation unit and electric propulsion system are connected directly to the vehicle's mechanical drive train. The primary engine is typically used for highway driving, while the electric motor provides added power during hill climbs, acceleration and other periods of high demand.

In a series design, the primary engine (internal combustion engine) or power generation unit is connected to a generator that produces electricity. The electricity charges the batteries that are then used as a power source for the electric motor that drives the vehicle. Series configuration is thought to be more suited for city and stop-and-go driving. However, the need for a larger battery pack (relative to parallel design) associated with series design increases the costs of these vehicles.[147]

[145] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air*. U.S. Department of Energy, *Taking an Alternative Route: A Guide for Fleet Operators and Individual Owners Using Alternative Fuels in Cars and Trucks*, April 2001.
[146] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August 1999.
[147] *Ibid.*

3.7.2 Use and Development

Currently, HEVs are not in widespread use in the refuse vehicle sector. However, refuse vehicles operate under conditions that would make the development of hybrid refuse vehicles feasible and practical; refuse vehicles demonstrate intense stop-and-go driving cycles, a characteristic well-suited for hybrid electric technology.

DSNY is exploring the future use of HEVs in their refuse collection fleet. However, before the widespread commercialization of hybrid heavy-duty refuse vehicles takes place, the cost of batteries will have to be addressed with new engineering and technology. DSNY, in their non-collection operations, is currently using some HEVs.[148]

Hybrid electric technology is being developed and experimented with for use with transit buses, as most major bus manufacturers are currently producing or involved with hybrid-electric demonstration projects.[149]

3.7.3 Costs

Heavy-duty HEVs are still in the developmental stage, so it is difficult to project and estimate the capital and operating costs. With transit buses, HEVs are currently more expensive than regular diesel vehicles. For example, in 1997 New York City Transit (NYCT) purchased diesel hybrid electric buses at an average price per bus of $465,000, compared to the cost of a comparable diesel bus at $290,000.[150] It is anticipated that commercialized diesel hybrid electric buses will eventually have prices similarly to CNG motor buses.[151]

---

[148] Based on meeting with Spiro Kattan, Supervisor of Mechanics, Bureau of Motor Equipment, DSNY, July 9, 2003.
[149] INFORM, Inc., *Greening Garbage Trucks: New Technologies for Cleaner Air;* U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.
[150] Jason Penshorn, Lessons Learned from NYCT's Hybrid-Electric Fleet, *Mass Transit,* July/August 2003.
[151] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

The maintenance facilities used for HEVs require new equipment. Space for storing and replacing propulsion batteries will be needed, and, as hybrids usually require less transmission and brake maintenance, the number of service bays and maintenance spares may need to be decreased. It should be noted that diesel HEVs do not require new fueling infrastructure and fueling facilities.[152]

NYCT has seen higher maintenance costs and lower reliability and availability with its diesel hybrid electric buses. The new technology and the learning curve of the mechanics are the likely causes of the lower reliability of the buses. Over time, as mechanics become more experienced with these new vehicles, they will likely approach the reliability of diesel vehicles. Subsequently, the operating costs for HEVs will be lower than diesel vehicles and reliability and durability will likely not be an issue after the initial implementation. Furthermore, the reduction in fuel consumption and the extended repair intervals used to service the brakes (lower wear rates) will likely result in a reduction in operating costs.[153]

3.7.4 Emissions

There appears to be significant emission reductions with the use of HEVs. HEVs use diesel fuel more efficiently than conventional vehicles, resulting in reduced emissions.[154]

NYCT is currently utilizing diesel hybrid electric buses. A report sponsored by the U.S. Defense Department's Defense Advanced Research Projects Agency titled "Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project" (2000) found that PM emissions from diesel hybrid electric NYCT buses are generally found to be 50% to 70% lower than conventional diesel-fueled vehicles. (Note that when tested these hybrid vehicles used low-sulfur diesel fuel as well as after-treatment technologies such as particulate filters.) Several systems are responsible for these PM reductions, such as the after-treatment technologies and the ability of these vehicles to utilize regenerative braking.

---

[152] *Ibid.*
[153] Jason Penshorn, Lessons Learned from NYCT's Hybrid-Electric Fleet, *Mass Transit,* July/August 2003.
[154] U.S. General Accounting Office, *Mass Transit: Use of Alternative Fuels in Transit Buses*, 1999.

NO_X emissions from NYCT diesel hybrid electric buses are 30% to 40% less than from conventional diesel buses. Engine operation and performance is a prime reason for this difference. Even when the regenerative braking system is turned off during emissions testing, the hybrid vehicles still exhibit 20% to 30% lower NO_X emissions than conventional diesel buses.

Diesel hybrid electric buses also have lower emission levels of CO_2 and CO than diesel buses. Reductions of CO_2 emissions are 10% to 40% lower than conventional diesel bus engines, and CO is 70% lower.[155]

3.7.5 Incentives and Disincentives

The combination of improved fuel economy and emissions reductions is an extremely attractive combination of benefits. Diesel hybrid buses operated by NYCT demonstrate 10% higher fuel economy over conventional diesel buses.[156] The components of a hybrid vehicle that result in improved fuel performance include regenerative braking, an efficient electric-drive system, and on-board energy storage (battery pack).[157] The concept behind regenerative braking is that the forward inertial energy of the vehicle is captured and stored on board the vehicle for later use. When the driver brakes, the motor becomes a generator and uses the kinetic energy of the vehicle to generate electricity that can be stored in the battery and used at a later time. With friction braking, energy is wasted when the energy of the motion of the vehicle is turned to heat as the brakes are applied.

The main disincentive associated with hybrid electric technology is the current lack of commercially manufactured hybrid engines that can be utilized with heavy-duty trucks such as refuse vehicles. The development of heavy-duty hybrid electric propulsion systems has to advance before hybrid technology is used and available with refuse vehicles. In addition, the high cost of batteries used with heavy-duty HEVs will have to be addressed before the

---

[155] Northeast Advanced Vehicle Consortium, *Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project*, 2000.
[156] Jason Penshorn, Lessons Learned from NYCT's Hybrid-Electric Fleet, *Mass Transit*, July/August 2003.
[157] National Conference of State Legislatures, *Ground Transportation for the 21st Century*, August 1999.

large-scale production by major refuse vehicle manufacturers takes place. Other disincentives include high capital costs and necessary modifications to maintenance and storage facilities. In addition, higher maintenance costs and lower reliability (due to the new technology and learning curve of mechanics) are disincentives associated with initial use of these vehicles.

4.0 SUMMARY OF FINDINGS AND OPTIONS

4.1 Need to Promote Clean Fuels

Two main factors currently drive the switch to alternative fuels with refuse vehicles and heavy-duty diesel vehicles.

- Environmental concerns related to heavy-duty diesel truck utilization in the City.
- New stricter government emission standards for heavy-duty vehicles.

4.2 Types of Clean Fuels

4.2.1 Clean Diesel

- Can cut certain emissions by 90%.
- Ultra-low-sulfur diesel fuel needs to be utilized in conjunction with after-treatment devices in order to maximize the emissions reductions.
- Diesel oxidation catalysts and particulate filters are two promising after-treatment technologies.
- By 2007, new heavy-duty diesel engines, in conjunction with clean diesel after-treatment technologies, will provide up to 98% reductions (from 1998 model year engines) in PM and NO_X emissions.

4.2.2 Natural Gas

- Drilled from underground supplies in the U.S.
- Two forms -- CNG and LNG.
- The City has a moratorium on establishing LNG facilities.
- More expensive to purchase, maintain and operate than diesel.
- On average cost about 25% more per vehicle.
- Retrofitting diesel vehicle for natural gas use can cost $30,000 to $100,000.
- Incentives from public sector can help offset costs.
- Cleaner and quieter than diesel.
- Loss of torque and power compared to diesel engines.
- CNG can be a transitional fuel used as a hydrogen source for fuel cells.

4.2.3 Biodiesel

- More expensive than regular diesel.
- Does not require mechanical modifications or conversions.
- Works best in diesel engines as B20 (80% petroleum diesel).
- B100 eliminates sulfur emissions and cuts PM by approximately 50%, but NOX emissions increase when biodiesel is used.

4.2.4 Fuel Cells

- Not a viable option for heavy-duty vehicles for at least 10-15 years.
- High energy-efficiency and zero emissions.
- Infrastructure of hydrogen fueling stations needs to be built.

4.2.5 Battery Electric

- Despite advances in power production, battery electric vehicles cannot currently provide the power or torque needed for heavy-duty vehicles such as refuse vehicles.
- Battery needs a long time to recharge and vehicles that use battery power have a limited range.
- Vehicles have zero tailpipe emissions.

4.2.6 Propane

- The most commonly used alternative fuel in the U.S.
- Major garbage truck manufacturers currently do not offer models capable of burning propane.
- Low levels of NO_X and PM emissions are a characteristic of propane combustion.

4.2.7 Ethanol

- High operating and capital costs.
- High rate of engine failure and low engine durability.
- Lack of heavy-duty engine production.
- Like methanol, emission reductions in CO and PM, but higher NO_X emissions than diesel engines.

4.2.8 Methanol

- M85 is primarily an alternative fuel used in light-duty vehicles.
- High operating and capital costs.
- High rate of engine failure and low engine durability.
- Lack of heavy-duty engine production.

4.2.9 Hybrid Electric

- Vehicles are powered by two energy sources: an energy conversion unit such as an internal combustion engine and an energy storage device such as a battery.
- Lack of commercial hybrid engines and propulsion systems that can be used with refuse trucks.
- Combination of improved fuel economy and emissions benefits makes these vehicles an attractive future option.

4.3 Options

4.3.1 New York City Department of Sanitation

- Continue to utilize and experiment with ULSD and clean diesel technology with use in existing vehicles with the goal being that all diesel vehicles currently in operation should utilize clean diesel technology in order to meet the USEPA 2004 and 2007 emissions standards applicable to new diesel vehicle engines.
- Continue to make clean diesel technology the preferred vehicle standard for new heavy-duty refuse vehicle purchases.
- Continue to test and compare alternative fuel exhaust emissions in order to evaluate hybrid electric refuse vehicles.
- Continue to pursue its CNG heavy-duty program, so that DSNY will be able to take advantage of potential advancements in CNG technology and fuel cell technology.
- Continue to develop partnerships with fuel suppliers, OEMs and infrastructure providers in order to help reduce the cost of clean fuel implementation.
- For light-duty vehicles, continue with ethanol purchase and plans for ethanol fueling facilities.
- Utilize government grants and economic incentives to offset the higher costs associated with natural gas, hybrid electric and ethanol vehicles.

4.3.2 Private Waste Haulers

- Retrofit old diesel vehicles with clean diesel technology.
- Begin using ULSD ahead of June 2006 mandate.
- Deploy and purchase clean diesel vehicles now in order to avoid future expenses that will be needed to meet new strict USEPA emission standards.
- Utilize government grants and economic incentives to help offset the incremental capital costs associated with natural gas refuse vehicles.
- In conjunction with infrastructure supplier and engine manufacturers, explore the future option of CNG heavy-duty refuse vehicles