Feasibility Study of a Pilot Testing Program for Emission Control Biogas Cleaning at a NYCDEP Water Pollution Control Plant

Final Report 08-20
April 2008

New York State
Energy Research and
Development Authority

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FEASIBILITY STUDY OF A PILOT TESTING PROGRAM FOR EMISSION CONTROL BIOGAS CLEANING AT A NYCDEP WATER POLLUTION CONTROL PLANT

Final Report

Prepared for the

NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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NYSERDA Report 08-20 | NYSERDA 9402 | April 2008

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Executive Summary

The New York City Department of Environmental Protection (NYCDEP) and Malcolm Pirnie prepared this report in response to the New York State Energy Research and Development Authority (NYSERDA) Program Opportunity Notice (PON) 946, Advanced Clean-up and Emission Control Technological for Biogas-fueled Distributed Generation Systems and Other Beneficial Uses. The purpose of this project was to establish the technical and economical feasibility of implementing a full-scale pilot testing program by the NYCDEP to demonstrate an anaerobic digester gas (DG) cleaning system and an emissions control technology

The NYCDEP owns and operates fourteen water pollution control plants (WPCPs) in the New York City metropolitan area. Each WPCP produces significant volumes of digester gas as a byproduct of the anaerobic digestion of wastewater biosolids (sludge). Currently, the digester gas produced is used on-site as a fuel for the plants' combustion processes, while the remaining gas is flared. Four of the WPCPs have internal combustion (IC) engines that provide energy for the plant operations, for a total of 27 compression-ignited IC engines.

These four WPCPs have Title V (6 NYCRR Part 201) air permits because the nitrogen oxide (NO_x) and volatile organic compound (VOC) emissions are greater than the major source thresholds. Under 6 NYCRR Part 227-2 Reasonably Available Control Technology for Oxides of Nitrogen (known as "NO_x RACT"), the IC engines are required to meet specific NO_x emission limits if the facility is a major source of NO_x.

The NYCDEP previously performed the technological feasibility analysis under RACT to assess NO_x emission reduction options for the current engine configurations and controls at the four WPCPs that use engines, and it identified the selective catalytic reduction (SCR) as the best NO_x control technology. Typically, SCR is used as a post-combustion control to reduce NO_x emissions from IC engines burning diesel oil and natural gas. However, the SCR control catalyst has not been proven to have long-term effectiveness for IC engines burning digester gas because impurities in the digester gas (e.g., sulfur, siloxanes, moisture, etc.) rapidly foul the catalyst, significantly reducing NO_x control performance.

Studies have shown that siloxanes in digester gas have been found to be the primary contaminant causing engine silica buildup and rapid deterioration in post-combustion devices, such as SCR. Therefore, some type of gas cleaning system was required to remove these impurities in the digester gas, which result in a more rapid deterioration of the SCR system than anticipated for an engine using natural gas. This project determined the feasibility of and developed a pilot study implementation at the Owls Head WPCP using an SCR system to reduce NO_x emissions. The pilot test also included a digester gas cleaning system to remove digester gas impurities that mask the catalyst.

Technologies to remove siloxanes from waste gas were evaluated including: carbon adsorption, refrigeration/condensation and PSA/TSA systems. Carbon adsorption appears to be the most feasible, cost-effective, and commercially tested technology available for siloxane removal on IC engines with post-combustion catalytic air pollution control equipment on the engine exhaust. Appendix E-1 contains drawings M-1 through M-4, which show a pilot-scale system consisting of one SCR catalyst on one engine (the engine closest to the eastern door of the Pump and Powerhouse) with one carbon adsorption digester gas cleaning system vessel (located in the basement under the equipment access hatch).

Activated carbon adsorption uses activated carbon, which is highly porous and has a large internal surface area and pore volume, to capture compounds while releasing energy. The adsorption of organic compounds is relatively non-selective. Typically, three vessels are installed, in order to divert the digester gas flow when lead media reaches saturation, i.e. when all active sites are used by the target compounds, in this case siloxane.

The refrigeration/condensation technology removes compounds by lowering the temperature (through refrigeration) or the gas pressure (through depressurization) to allow the compounds to condense to a liquid form, then settle out as droplets. In addition, the technology removes moisture, which helps increase the quality of the gas by increasing the caloric value.

The PSA/TSA system has vessels filled with a media that selectively adsorbs siloxanes. The process uses the fact that gasses are more readily adsorbed onto surfaces under pressure.

The activated carbon adsorption system is the most feasible and commercially tested technology available for siloxane removal. However, the economic viability of using carbon adsorption solely for digester gas cleaning at the Owls Head WPCP for a full-scale operation is still a question. Based upon the preliminary cost estimates presented herein, the cost of implementing an SCR catalyst on all three engines and a digester gas cleaning technology ranged from $675,000 (Alternative 1) to $809,000 per year for annualized total capital investment and annual O&M costs.

In addition, the installation of an SCR catalyst on the three engines at the Owls WPCP will only result in a 58% reduction in NO_x emissions from the engines. Using the lowest budgetary estimates provided by the vendor, the annualized cost for the SCR and digester gas cleaning systems is below the RACT economic standard in Air Guide-20. Under the Maximum Potential operating scenario, the cost per ton of NO_x controlled is $3,444, as compared to the RACT economic standard of $4,966 per ton of NO_x adjusted to February 2010 dollars.

Given the required control of approximately 58% NO_x reduction and the permitted hours of operations of 5,840 hours per year per unit, the cost per ton of NO_x reduced equaled $3,444 under the Maximum Potential operating scenario (i.e., 100% diesel fuel combustion, carbon only scenario). With the proposed 225 TPY NO_x limit, and under the "carbon only" scenario, the cost per ton of NO_x reduced was $4,941. However, under realistic operating conditions (digester gas and with fuel oil as a pilot), the cost per ton of NO_x reduced was $19,540 under the current permit, and $8,156 under the proposed 225 TPY NO_x limit. Both of these costs far exceed the upper limit provided under NO_x RACT guidance. This study demonstrated that the SCR control with a digester gas cleaning system is not RACT for the IC engines at Owls Head.

1. Project Overview and Objectives

1.1. Project Overview

The New York City Department of Environmental Protection (NYCDEP) and Malcolm Pirnie prepared this report in response to the New York State Energy Research and Development Authority (NYSERDA) Program Opportunity Notice (PON) 946, *Advanced Clean-up and Emission Control Technologies for Biogas-fueled Distributed Generation Systems and Other Beneficial Uses*. The purpose of this project was to determine the technical and economic feasibility of implementing a full-scale pilot-testing program of an emissions control system and anaerobic digester gas (DG) cleaning system to be installed on engines at NYCDEP water pollution control plants (WPCPs). Installation of the emission control technology is in response to newly promulgated air quality regulations. This report will include the following.

- Provide a background of the project.
- Describe the facilities and specific engines evaluated.
- Summarize the digester gas quality at the specific WPCPs.
- Provide an overview of digester gas cleaning and emission control technologies.
- Conduct a financial analysis of the potential pilot test technologies.
- Recommend the facility, engine, and technologies for the pilot test program.
- Address the potential implementation of the technology at other NYCDEP WPCPs.

1.2. Background

The NYCDEP owns and operates fourteen WPCPs in New York City. Each plant produces significant volumes of digester gas, a biogas produced as a byproduct of the anaerobic digestion of wastewater biosolids (sludge). Currently, the digester gas produced at the 14 NYCDEP plants is used on-site as a fuel for the plants' combustion processes, including onsite engine and boiler operations. The engines and boilers are used to power mechanical operations, such as blowers and pumps; to generate electricity for onsite use; and to provide steam and hot water to maintain the plant operations. The remaining digester gas is flared in waste gas burners.

Four of the plants have internal combustion (IC) engines that provide energy for the plant operations. These four WPCPs have a total of 27 compression-ignited IC engines. The engines are either dual-fuel or multiple-fuel engines that use digester gas as the primary fuel, diesel fuel as pilot, with natural gas and/or diesel fuel used as supplemental fuels. Seven of the 27 engines generate electricity, and 20 engines provide mechanical power to drive pumps and blowers. Table 1-1 provides a summary of the engines at the four WPCPs, including the number of units, their size, and the type of power output.

Table 1-1
Summary of Engines at the NYCDEP WPCPs

Location	Number of IC Engine Units	Size/Unit, BHP[1]	Power Output
Coney Island	4	2,246	Electrical
North River	5 5	940 1,700	Mechanical (blower) Mechanical (pump)
Owls Head	3	3,174	Electrical
Tallman Island	5 5	546 1,013	Mechanical (blower) Mechanical (pump)

Notes:
(1) BHP = brake horsepower

1.2.1. NO_x RACT

Each of the four plants listed in Table 1-1 have a Title V (6 NYCRR Part 201) air permit because their nitrogen oxide (NO_x) and volatile organic compound (VOC) emissions are greater than the major source thresholds. Under 6 NYCRR Part 227-2 Reasonably Available Control Technology for Oxides of Nitrogen (known as "NO_x RACT"), IC engines are required to meet specific NO_x emission limits if the facility is a major source of NO_x. The New York State Department of Environmental Conservation (NYSDEC) promulgated new NO_x RACT regulations for IC engines in January 2004. The new NO_x RACT regulations lowered the allowable NOx levels to 2.3 grams per brake-horsepower-hour (gm/bhp-hr) for compression-ignited engines and required major facilities to either meet the new limits by April 1, 2005 or demonstrate through a RACT analysis that the engines could not achieve the proposed limits. The NYSDEC has published guidance on the performance of a RACT analysis in *Air Guide 20: Air Guide for the Economic and Technical Analysis for Reasonably Available Control Technology* (NYSDEC, 1996). A RACT analysis evaluates both the projected effectiveness of the control technologies considered and the costs associated with the installation and operation for each technology. The cost is then compared to a standard cost established by NYSDEC as the upper economic limit of RACT. Reasonably available technologies that are economically and technically feasible with costs in the range of the standard cost are considered to meet RACT requirements. Technologically feasible controls with associated costs above the standard are not RACT and can be eliminated from consideration.

Prior to the promulgation of the new NO_x RACT regulations, the IC engines at the NYCDEP WPCPs met the then existing NO_x RACT limit of 9 gm/bhp-hr. However, the engines would not meet the new lower NO_x RACT limit of 2.3 gm/bhp-hr. Therefore, the NYCDEP was required to evaluate various NO_x control technologies as part of a RACT analysis for these engines. This RACT analysis identified the following as potential NO_x control technologies:

- combustion modification
- fuel switching, e.g., use of emulsified diesel fuel
- post-combustion control, such as selective catalytic reduction (SCR).

Combustion modification technologies were eliminated from the evaluation because these required significant research and development and had no current commercial application. The NYCDEP performed pilot testing of the use of emulsified diesel fuel and concluded that this technology did not provide significant emission reductions since diesel fuel typically is used as the pilot fuel. Therefore, SCR post-combustion emission control was the most promising technology for reducing NO_x emissions.

1.2.2. Digester Gas Cleaning

Typically, SCR is used as a post-combustion control to reduce NOx emissions from IC engines that burn diesel oil and natural gas. However, the control catalyst used in SCR systems does not have long-term effectiveness for IC engines that burn digester gas because impurities in the digester gas (e.g., sulfur, siloxanes, moisture, etc.) rapidly foul the catalyst, which significantly reduces NOx control performance.

The IC engines at the NYCDEP plants primarily use digester gas with diesel fuel for the pilot fuel. Natural gas generally is used as a supplemental fuel when the quantity of DG is insufficient. Studies have shown that siloxane in the DG is the primary contaminant, which causes silica buildup in the engines and rapid deterioration in post-combustion devices, such as SCR. The contaminant siloxane forms silica, which accumulates in the engine, masks the catalyst, and significantly reduces the effectiveness of the catalyst performance to a much greater degree than in an engine combusting natural gas. Therefore, in order to use SCR on the digester gas-fueled engines, some type of gas cleaning system will be required to remove the impurities in the digester gas, which cause a more rapid deterioration of the SCR system.

Before implementing this control technology system-wide, full-scale pilot-testing of the combined SCR/gas-cleaning technology would need to be performed. The present study was designed to evaluate the feasibility of such full-scale pilot testing both from technological and economic perspectives at selected NYCDEP WPCPs.

1.3. Project Objectives

The overall goal of the project for NYCDEP was to address compliance with NOx RACT requirements for the IC engines combusting digester gas at NYCDEP wastewater treatment plants that use SCR emissions control and digester gas cleaning technologies. The approach included the following steps.

- Pilot testing of an existing digester gas-fueled IC engine at a NYCDEP WPCP
  - Identify applicable plant and engine for pilot testing of SCR/digester gas cleaning system with respect to site constraints, operational considerations, etc.
  - Develop preliminary design and cost information for this system.
- Full-scale implementation
  - Identify design constraints of installing /operating an SCR/Digester gas cleaning system at the plant identified for the pilot test.
  - Develop preliminary design and cost information for full implementation of system.
  - Compare annualized cost of full implementation to the RACT standard cost to determine overall project feasibility to meet NOx RACT requirements.

1.4. Project Benefits

The results of the program will be critical to the future use of digester gas at the NYCDEP WPCPs and other similar treatment plants that are required to meet NOx RACT. If a successful NOx control system, such as the SCR with gas cleaning, could be identified as a reasonably available control technology, then the NYCDEP would be able to meet NOx RACT requirements while allowing their wastewater plants to use digester gas as a fuel in their IC engines rather than as a waste gas to be flared.

The program would also provide test data for the control of contaminants and emissions for other power generation equipment using biogas. This data would be useful not only for NYCDEP, but for NYSERDA and other facilities in New York State (NYS). If successful, the benefits of the program would include the following.

- Environment – The program would provide emissions control options for facilities that use biogas, such as digester gas, in their combustion equipment (e.g., engines, turbines, boilers), thereby reducing the amount of air emissions released to the atmosphere, and in particular, reductions in NOx emissions.
- Energy – The program would provide for greater beneficial use of biogas in NYS, thereby reducing the need to purchase fuel or power.
- Cost – The program would reduce costs for all NYS energy consumers by reducing the demand from large energy users such as the NYCDEP, thereby making more energy available to residential and other consumers.

2. Facility Description and Evaluation

2.1. Facility Descriptions

Of the four plants with IC engines combusting DG, the NYCDEP and Malcolm Pirnie determined that the Coney Island and Owls Head WPCPs in Brooklyn, were potential candidates for the pilot-testing program.

2.1.1. Coney Island WPCP

The Coney Island WPCP, located in the Coney Island section of Brooklyn, serves an area of more than 23 square miles with a population of over 596,000. The Coney Island plant treats primarily domestic wastewater with some industrial and commercial waste. The plant's rated capacity is 110 million gallons per day (MGD) under average conditions. The Coney Island plant is capable of primary treatment up to the peak capacity and full secondary treatment up to 165 MGD. Treatment processes consist of screening, raw sewage pumping, grit removal, primary settling, air-activated sludge (capable of operation in the step-aeration mode), final settling, and disinfection. Sludge treatment at the plant site consists of degritting of primary sludge, screening of waste sludge, gravity thickening, high-rate anaerobic digestion, and sludge storage.

The Coney Island WPCP uses four 6-cylinder, multi-fuel engines that drive electric generators to supply the plant with electricity for its operation. Each engine is rated at 2,246 horsepower, and each engine can operate on diesel fuel (No. 2 fuel oil), digester gas, or natural gas. One engine is usually sufficient for full facility operation, with a second engine used only on a rare occasions during high demand periods.

2.1.2. Owls Head WPCP

The Owls Head WPCP is located in the Sunset Park area in western Brooklyn and serves an area of more than 20 square miles with a population of over 758,000. The plant treats primarily domestic wastewater with some industrial and commercial wastes. The plant's rated capacity is 120 MGD under average conditions. The Owls Head WPCP is capable of primary treatment up to the peak capacity and full secondary treatment up to 165 MGD. Treatment processes consist of screening, raw sewage pumping, grit removal, primary settling, air-activated sludge (capable of operation in the step-aeration mode), final settling, and disinfection. Sludge treatment at the plant site consists of degritting of primary sludge, screening of waste sludge, gravity thickening, high-rate anaerobic digestion, and sludge storage.

The Owls Head WPCP uses three 8-cylinder, multi-fuel engines that drive electric generators to supply the plant with electricity for its operation. Each engine is rated at 3,174 horsepower, and each engine can operate on either digester gas or diesel fuel. The engines do not run on natural gas because it is currently not available at the Owls Head WPCP. One engine is generally sufficient for full facility operation with a second engine used only rarely during high demand periods. Table 2-1 provides a summary of operating parameters for the engines at the Coney Island and Owls Head WPCPs.

Table 2-1
Coney Island and Owls Head WPCPs Engine Operating Parameters[1]

Plant	Rated Capacity (MGD)[2]	Number of Engines	Engine Rated Capacity Power[3]		Exhaust Flow Rate (scfm)[4]	Exhaust Temp (F)	Fuel Type[5]	Maximum DG Used in Engines Annually (MMCF/year)
			BHP	kW				
Coney Island WPCP	110	4	2246	1600	3,033	Not Available	DG/FO/ NG	92 (2005)
Owls Head WPCP	120	3	3174	2250	4,743	1055	DG/FO	214 (2005)

Notes:
(1) Information obtained from New York State Department of Environmental Conservation (NYSDEC) Title V Facility Air Permit ID 2-6107-00004/00017 for Coney Island (see Appendix A-2) and Title V Facility Air Permit ID 2-6102-00005/00017 for Owls Head (see Appendix A-3)
(2) MGD – millions of gallons per day
(3) Engine rated capacity abbreviations mean the following:
BHP – brake horsepower
kW – kilowatt
(4) SCFM – standard cubic feet per minute
(5) Fuel type abbreviations are as follows:
DG – digester gas
FO – diesel No. 2 fuel oil
NG – natural gas

2.2. Digester Gas Production and Usage

Table 2-2 shows the digester gas produced and used annually in the engines at both the Coney Island and Owls Head WPCPs, along with the maximum monthly average digester gas used from 2004 through 2006. [The complete digester gas database, which shows the quantity of digester gas produced, used in both boilers and engines, or wasted from 2004 through 2006 for Coney Island and Owls Head WPCPs, is provided in Appendix A-1.]

Table 2-2
Annual DG Production and Engine Usage: Coney Island and Owls Head WPCPs

Year	Coney Island WPCP		Owls Head WPCP	
	DG Produced (MMCFY)[1]	DG Used in Engines (MMCFY)[1]	DG Produced (MMCFY)[1]	DG Used in Engines (MMCFY)[1]
2004	185	87	320	101
2005	194	92	270	214
2006	175	86	287	136
Maximum Monthly Average	385 CFM (May 2005)	260 CFM [2] (June 2006)	734 CFM (January 2004)	561 CFM [2] (March 2005)

Notes:
(1) MMCFY – million cubic feet per year
(2) CFM – cubic feet per minute

2.3. Facility Evaluation

Malcolm Pirnie and NYCDEP staff performed site visits at both Coney Island and Owls Head WPCPs. The purpose of these site visits was to obtain the following information:

- potential space constraints around the engines
- potential piping, valve and metering constraints
- location of gas mixing station
- exhaust backpressure
- digester gas pressure drop
- ability to isolate an engine for the pilot study

The information obtained during the site visits was used to develop an evaluation matrix to select the site and engine most appropriate for implementation of the pilot study. The evaluation matrix is presented in Table 2-3.

Table 2-3
Evaluation Matrix for Selection of Pilot Test Location

Evaluation Criteria	Coney Island WPCP	Owls Head WPCP
Space constraints	Significant space constraints around the engine; not enough room for standard sizes of SCR pilot testing equipment operation.	Space constraints around the engine do not allow enough room for standard sizes of SCR pilot testing equipment operation but customized design for testing was provided by one manufacturer in the available space.
Piping, valve, or metering constraints	No significant piping, valve or metering constraints.	No significant piping, valve or metering constraints. Plant produces enough digester gas to operate one engine at 100 % load on DG at a time.
Location of gas mixing station	The gas mixing station is upstream of gas compressors, therefore, gas cleaning system must clean both NG and DG for all engines.	Plant does not utilize natural gas, therefore, no gas mixing required. Diesel fuel and DG blending station is located at each engine.
Issues related to pressure drop for engine exhaust system and digester gas system	No issues with the digester gas cleaning system if implemented after the compressor.	No issues with the digester gas cleaning system if implemented after the compressor.
Ability to isolate and meter digester gas for one engine	Can isolate one engine but with greater difficulty than at Owls Head WPCP.	Normal operation has one engine firing DG with diesel pilot fuel. All gas metered is DG. Able to isolate and meter DG for one engine.

A comparison of the constraints at the two plants listed in Table 2-3 indicates that the Owls Head WPCP is a more appropriate location for the implementation of the pilot study. Although there are space constraints at Owls Head for the pilot study, there would be sufficient room for the system with the use of the custom design.

3. Digester Gas Analysis

Studies have shown that siloxanes in digester gas are the primary contaminants causing engine silica buildup and rapid deterioration in post-combustion devices, such as those proposed for this pilot testing project (i.e., SCR). Therefore, some type of gas cleaning system is needed to remove these impurities in the digester gas to prevent the rapid deterioration of the SCR catalyst. Determination of the digester gas composition, which consists of quantifying the concentration of contaminants in the digester gas and the digester gas quality (i.e., methane, carbon dioxide, higher heating value, density, etc.), is required to properly evaluate and size digester gas cleaning system technologies.

Therefore, a total of five digester gas sampling events were conducted over the course of five months (April to August 2006) with two and three digester gas sampling events at the Coney Island and Owls Head WPCPs, respectively. The extra sampling event at the Owls Head WPCP was performed because the NYCDEP decided that the Owls Head WPCP would be a more feasible location for the implementation of the pilot study. Digester gas quality is variable throughout the year and multiple tests allow for the system design through an observed range of results. Sampling was either conducted by Malcolm Pirnie and sent to Air Toxics Ltd. for analysis or conducted and analyzed by KeySpan Energy (KeySpan). The laboratories performed the following tests to determine the quality of the digester gas:

- siloxanes
- gas quality
- reduced sulfur compounds
- volatile organic compounds (VOCs)

The purpose of this section of the report is to summarize the digester gas composition at the WPCPs to properly size the digester gas cleaning equipment.

3.1. Gas Composition Tests

3.1.1. Siloxanes

Siloxanes in digester gas burned in IC engines can result in silicon dioxide deposition and/or silicate formation (a glass-like substance) at or near the point of combustion, such as on the catalyst elements, piston heads, or pre-combustion chamber check valves. Silicon dioxide deposition or silicate formation also masks the catalyst and reduces the effectiveness of the catalyst performance on post-combustion air pollution control equipment (i.e., SCR and catalytic oxidizer catalyst elements). The purpose of testing for siloxanes was to develop the range of siloxanes and siloxane concentrations observed in the digester gas and to determine the control method that provides the best removal efficiency and cost effectiveness given the known concentrations and quality of the digester gas. Some removal methods have proportional operating costs to siloxane concentrations while others have constant operating costs that are not dependent on concentration.

Siloxane sampling was performed by bubbling digester gas through a methanol impinger train after the flow meter, which monitors the digester gas. The siloxanes dissolve into the methanol. The impingers then were sent to the laboratory (Air Toxics, Ltd.) for analysis. The laboratory measured the quantity of siloxanes in micrograms (µg) using the modified DOW Method test method. The concentrations were then converted using the known quantity of digester gas that was bubbled through the impingers and the molecular weight of the individual siloxane compounds.

3.1.2. Gas Quality

The purpose of the gas quality test was to determine the chemical composition and physical properties (i.e., higher heating value (HHV), dewpoint and dry bulb temperatures, gas density, etc.) of the digester gas. The dewpoint and dry bulb temperatures are used to determine the digester gas relative humidity. The humidity is important because some media used in carbon adsorption gas cleaning systems require humidity in the range of 40%. A higher digester gas relative humidity would require different media to be used or additional chilling and reheat equipment to be installed.

Gas quality testing was performed by collecting a grab sample of the digester gas in a Tedlar® bag, which was then sent to the laboratory for analysis (Air Toxics, Ltd, or KeySpan). The analysis method was ASTM (American Society for Testing and Materials) D1945, which uses gas chromatography to determine chemical composition for C1 – C6 hydrocarbon molecules in addition to nitrogen, carbon dioxide, carbon monoxide, and oxygen.

3.1.3. Reduced Sulfur Compounds

The purpose of the reduced sulfur testing was to determine the quantity of sulfur compounds in the digester gas. Sulfur compounds can impact the gas cleaning efficiency (i.e., the sulfur compounds compete with siloxane compounds for available sites when using activated carbon for gas cleaning). In addition, the concentrations of certain compounds will affect the operating costs of the gas cleaning technologies.

The sampling of reduced sulfur compounds in the digester gas was performed by collecting a grab sample in a Tedlar® bag, which was then sent to the laboratory for analysis (Air Toxics, Ltd, or KeySpan). The analysis method was ASTM D5504, which uses gas chromatography and chemiluminescence to determine the quantities of sulfur compounds in the sample.

3.1.4. Volatile Organic Compounds Analysis

Knowing the composition of volatile organic compounds in the digester gas is important because VOCs with a similar molecular weight to siloxanes can also compete with siloxane compounds for available sites on the media when using activated carbon for gas cleaning. The concentration of certain compounds will also affect the operating costs of the gas cleaning technologies.

The VOC concentrations were determined by collecting a grab sample in a Tedlar® bag and sending the sample to the laboratory for analysis. United States Environmental Protection Agency (USEPA) Method TO-15 was used for this test. TO-15 uses gas chromatography and mass spectrometry (GC-MS) to determine the quantity of the sampled compounds.

3.2. Digester Gas Analysis Results

The results of the siloxane sampling are presented in Table 3-1. The total siloxane concentration ranged from 433 ppbv to 1681 ppbv over both plants. These values are within the range of report values for anaerobic digester gas produced at municipal wastewater treatment plants in the United States.

Table 3-2 presents the gas composition and quality of the digester gas at two plants. These results are also typical of the range of values found for anaerobic digester gas at municipal wastewater treatment plants in the United States.

The reduced sulfur compound data indicate that, with the exception of hydrogen sulfide, most of the reduced sulfur compound concentrations were below their respective reporting thresholds. The hydrogen sulfide data from this series of testing ranged from 85 ppmv to 480 ppmv. Based upon a larger historical database obtained from the various NYCDEP wastewater plants, hydrogen sulfide concentrations ranged from less than 0.1 ppmv to 167 ppmv. Therefore, the highest values from the current series of sampling events may not be considered representative of typical hydrogen sulfide concentrations at the NYCDEP WPCPs. Concentrations of dimethyl sulfide, isopropyl mercaptan, and tert-butyl mercaptan were not detected in any of the five sampling events. The results of the reduced sulfur sampling are presented in Appendix B-3.

The results of the VOC sampling are found in Appendix B-4. The VOC data were typical of historical sampling data taken at the other NYCDEP WPCPs.

Table 3-1

Individual and Total Siloxane Compound Concentrations at Coney Island and Owls Head WPCPs [1]

Siloxane Compound [2]	Concentration (ppbv)				
	Coney Island WPCP		Owls Head WPCP		
	12 April 06	1 June 06	12 April 06	1 June 06	22 August 06
D4	120	199	52	117	216
D5	416	798	148	290	1217
D6	ND (69) [3]	ND (70)	ND (71)	ND (66)	ND (76)
Hexa.	ND (95)	ND (95)	ND (96)	ND (92)	ND (102)
Octa.	ND (65)	ND (65)	ND (66)	ND (63)	ND (70)
Total [4]	**765**	**1,227**	**433**	**628**	**1,681**

Notes:
(1) Actual laboratory results from Air Toxics, Ltd. (in µg with conversion to ppbv) are located in Appendix B-1.
(2) The following siloxane compounds were analyzed:
D4 – Octamethylcyclotetrasiloxane
D5 – Decamethylcyclopentasiloxane
D6 - Dodecamethylcyclohexasiloxane
Hexa. – Hexamethyldisiloxane
Octa. – Octamethyltrisiloxane
(3) Values in parenthesis represent 50 percent of the detection limit.
(4) Totals include 50 percent of the detection limit values for compounds not detected.

Table 3-2
Gas Quality Comparison at Coney Island and Owls Head WPCPs [1]

Compound	Units	Coney Island WPCP		Owls Head WPCP		
		12 April 06[2]	31 May 06[3]	12 April 06[2]	31 May 06[3]	22 Aug 06
Methane	%	52	67.8	60	71.3	65
Nitrogen	%	10	0.83	2.4	0.58	0.93
Carbon Dioxide	%	33	31.4	36	28.1	34
Oxygen	%	3.2	N/A	0.86	N/A	0.24
Specific Gravity	unitless	0.93	0.86	0.91	0.83	0.88
Heating Value	BTU/scf	530	677	610	713	650
Water Content	lb H_2O/ MMCF	N/A	114.5	N/A	85.9	N/A
Dew Point at STP	^oF	N/A	65	N/A	63	N/A
Relative Humidity[4]	%	N/A	58%	N/A	53%	N/A

Notes:
(1) Actual laboratory results from Air Toxics, Ltd. and Key Span are located in Appendix B-2.
(2) Analysis performed by Air Toxics, Ltd, sample passed usual handling time of three days.
(3) Sampling and analysis performed by KeySpan.
(4) Relative humidity was estimated using a psychometric chart with dewpoint and gas temperatures measured by KeySpan.

4. Gas Cleaning and Emission Control Technologies

This section of the report summarizes the gas cleaning technologies, along with the selection of available and applicable gas cleaning and emission control technology manufacturers.

4.1. Digester Gas Cleaning Technologies

Since siloxane and other compounds (e.g., sulfur compounds such as hydrogen sulfide) are present in the digester gas at concentrations high enough to potentially foul the emission control equipment, a gas cleaning system will be needed to remove these impurities. An evaluation of the following gas cleaning technologies was performed based on their historical reliability, performance, ease of implementation, capital cost, and maintenance.

- Activated carbon adsorption
- Refrigeration
- Pressure swing adsorption/temperature swing adsorption (PSA/TSA) resin adsorption
- Iron sponge (hydrogen sulfide only)

4.1.1. Activated Carbon Adsorption

The mechanism for contaminant removal from a gas stream by activated carbon is adsorption, in which gas phase compounds are captured on an active site on the surface of the carbon. During adsorption, a gas molecule migrates from the bulk flow to the surface of the carbon where the physical attraction results in a release of energy. Activated carbon has a highly porous structure with a vast amount of internal surface area and pore volume. With such an extremely high surface to volume ratio, an immense surface area is available for adsorption. Carbon adsorption units are highly effective at removing a number of organic compounds. The adsorption of these organic compounds is relatively non-selective; that is, the adsorption is not strongly affected by solubility or by the chemical class of the compounds.

The application of the carbon adsorption gas cleaning control technology involves placing activated carbon media into one, two, or three vessels. Typically, three units are installed with two units operating in series mode. Each vessel contains multiple layers of activated carbon media, which are small (typically 2 to 4 mm nominal diameter) and spherical in shape. The media types and depths per layer are based on a gas analysis or pilot study to confirm system performance.

The digester gas or biogas typically flows through a one to two or one to three pipe septa manifold header into the lead vessel, and then through the media layers where the majority of the contaminants are absorbed. As the lead vessel media becomes saturated with contaminants, the lag vessel is used to "polish," or remove contaminants that have broken through from the lead vessel. This system allows for the lead vessel to be periodically monitored for breakthrough, and when breakthrough occurs, operators divert the flow so that the lag vessel now becomes the lead vessel thus eliminating any down time. If a third vessel is present, the flow from the lead vessel is diverted to the third vessel so that the third vessel becomes the lag unit.

Media breakthrough occurs when all of the active sites on the carbon media have been used by the target compounds, in this case, by the siloxanes. Once breakthrough occurs, the compounds then have the ability to reach the engine. Eventually, siloxanes that breakthrough the system cause the deposition of silicon dioxide or silicate formation (a glass-like substance, silica) at or near the point of combustion, such as on the catalyst elements, piston heads, or pre-combustion chamber check valves.

When breakthrough is achieved and outlet concentrations exceed specified values, the carbon can be removed and disposed of in a landfill, regenerated on-site, or removed and regenerated off-site. Landfill disposal of the media depends on the results of a *toxicity characterization leachate procedure* (TCLP) test. This test determines if the carbon media can be classified as non-hazardous, so it can be disposed of in a municipal solid waste landfill. Typically, TCLP test results for digester gas produced at municipal wastewater treatment plants indicate that the spent carbon can be classified as non-hazardous. A hazardous classification would require special disposition of the carbon.

Regeneration of spent carbon media used in gas cleaning applications typically is accomplished through heating the spent media using steam or hot combustion gases. When the spent carbon media is heated to a sufficient temperature, the contaminants re-enter the air phase, thereby freeing the active adsorption sites.

4.1.1.1. Historical Reliability

Carbon adsorption is currently used in numerous commercial applications for the removal of siloxanes from digester gas and biogas used in internal combustion (IC) engines with post-combustion air pollution control equipment. One vendor, Applied Filter Technology, has supplied over 70 facilities with carbon adsorption systems worldwide.

4.1.1.2. Performance

A significant amount of testing has been performed in recent years on the ability of activated carbon media to remove siloxanes from gas streams. This testing has consistently shown removal of siloxanes down to total siloxane concentrations of <100 parts-per-billion (ppb) at the carbon system outlets. Recently completed pilot testing in California showed a consistent siloxane removal from digester gas down to 100 ppb and below for over one year with media changeout approximately every two to three calendar months.

4.1.1.3. Ease of Implementation

As noted above, activated carbon systems have been used to remove siloxanes from digester and landfill gas at numerous locations throughout the world. The system can be skid-mounted for easy installation. At the Owls Head WPCP, a single gas cleaning vessel for pilot testing may be installed inside the engine building in the lower floor. For full-scale implementation with three vessels (i.e., lead, lag, stand-by), either a new structure may be required to house a full-scale carbon system, or the vessels may need to be insulated for outside installation.

4.1.1.4. Equipment Cost

An activated carbon system is one of the least expensive control options with an estimated equipment cost for the Owls Head WPCP of approximately $47,000 per vessel. The installed capital cost is discussed in Section 5.

4.1.1.5. Maintenance Level of Effort

The maintenance of an activated carbon adsorption system is relatively straightforward, if the digester gas does not require refrigeration/condensation for moisture removal. Activated carbon adsorption systems have no moving parts. The amount of carbon required for replacement is relatively low, and spent carbon generally can be disposed of as a nonhazardous waste, which eliminates the need for regeneration.

4.1.2. Refrigeration/Condensation

Refrigeration/condensation removes selected compounds by dropping the temperature or pressure of the gas and allowing the compound to condense to a liquid form so it can settle out as droplets. Condensing is achieved by either refrigeration or through depressurization of a pressurized system. The collected condensation with contaminants is pumped to the head of the wastewater treatment plant. Literature provided by the manufacturers of refrigeration/condensation equipment reports that reducing the digester gas temperatures to -10^{o}F to -20^{o}F reduces the siloxane concentration by 95% and reduces the solubility of hydrogen sulfide by 437 grams per cubic centimeter of digester gas[1]

[1] Total Contaminant Removal Systems For Removing Moisture, Siloxanes & Most other Contaminants in LFG, Digester, Bio Gases. Pioneer Air Systems and Engineering Inc. 2004, page 8. (See Appendix C-1).

Refrigeration uses multiple heat exchangers in series to decrease the temperature to below freezing. An additional benefit of the system is the removal of moisture that will help increase the quality of gas by increasing the caloric value.

4.1.2.1. Historical Reliability

Refrigeration/condensation systems have been used at several facilities, but this technology alone is not as extensively used as carbon adsorption with or without refrigeration/condensation. Actual removal of siloxanes has been shown to vary, and more time is required to guarantee consistency[2]

4.1.2.2. Performance

The reduction of gas temperature to sub-zero greatly increases the removal capacity of the system. Although the system may be capable of removing a wide array of contaminants, actual removals tend to vary.

4.1.2.3. Ease of Implementation

A refrigeration/condensation system can easily be installed. The systems can be skid mounted to allow for easy installation. An outdoor enclosure with heat and light can also be supplied.

4.1.2.4. Equipment Cost

Due to the high concentration of hydrogen sulfide and other contaminants found in the digester gas, the manufacturer (Pioneer Air Systems, Inc.) initially proposed using refrigeration technology with the addition of three stainless steel catalytic carbon adsorber vessels. However, the refrigeration system coupled with a carbon adsorption system is one of the most expensive options with an equipment cost for the Owls Head WPCP of approximately $375,000 base cost. The installed capital cost is discussed in Section 5.

4.1.2.5. Maintenance Level of Effort

There are a number of moving parts in a refrigeration/condensation system. The chilling units may require frequent repair. In addition, the freezing and thawing cycles need to be monitored on a regular basis.

4.1.3. PSA/TSA Resin Adsorption

The pressure swing adsorption/temperature swing adsorption (PSA/TSA) process takes advantage of the fact that under pressure, gases are more readily adsorbed onto surfaces. The PSA/TSA system uses two separate adsorbers, with one on-line and the other off-line for regeneration. The vessels are filled with a media that selectively adsorbs siloxanes. The process is capable of reducing siloxanes to levels less than 400 ppb. The units are set

[2] Guidance on gas treatment technologies for landfill gas engines. The Environmental Agency. 2004, page 47. (See Appendix C-2)

up to run through an automated regeneration cycle. The cycle involves the removal of a vessel from service followed by the introduction of heated air (~ 300^{o}F) to fully desorb the siloxanes from the media. The exhaust gas from the regeneration process typically is sent to a flare.

4.1.3.1. Historical Reliability

This technology is relatively new and is just in the testing phase at a few locations in the US and Canada. This technology was reported to have reduced siloxanes of less than 400 ppbv while carbon has been shown to have removal levels of less than 100 ppbv.

4.1.3.2. Performance

The system is capable of reducing siloxane concentrations to levels less than 400 ppb. The inlet concentrations at the Owls Head WPCP are only slightly higher. The implementation of a PSA/TSA system may not result in sufficient removals to provide any significant reduction in engine maintenance requirements. *Performance – Fair/Poor.*

4.1.3.3. Ease of Implementation

The PSA/TSA system can be skid mounted and would be relatively easy to place on-site.

4.1.3.4. Equipment Cost

Based on a literature search, the majority of the applications that used PSA/TSA adsorption systems were for cleaning biogas to achieve pipeline quality gas. This system also requires an adsorption step that consists of using either molecular sieves or activated carbon as an adsorbent. Since this system requires high pressure compression, gas chilling, and an adsorption step, the equipment costs are estimated to be the highest of the three gas cleaning options investigated. For this reason, actual equipment costs that identified the breakout of the equipment costs required to successfully reduce the siloxane concentrations in the digester gas at the Owls Head WPCP using this technology were not obtained.

4.1.3.5. Maintenance Level of Effort

The vessel switching and regeneration process introduces an increased level of maintenance that would be required to keep the unit running properly.

4.1.4. Iron Sponge (hydrogen sulfide only)

After review of the digester gas sampling results from this study, it was observed that the hydrogen sulfide concentrations were higher than originally anticipated. Based upon conversations with different vendors, it was determined that additional gas treatment technology might be required to reduce the hydrogen sulfide concentrations if they were in the range detected. Typical hydrogen sulfide reduction technologies are either wet or dry scrubbing. One commercially-available hydrogen sulfide dry scrubbing removal technology is called an "iron sponge" (wood chips impregnated with hydrated ferric oxide). The hydrogen sulfide reacts with the iron sponge to form iron sulfide.

In additional discussions with the NYCDEP regarding the high hydrogen sulfide concentrations measured during the current round of sampling at Coney Island and Owls Head WPCP, it determined that the current sampling results should not be the impetus for recommending additional gas cleaning to lower reduced sulfur concentrations. Based on 23 sampling events in the past 10 years at various NYCDEP plants, the average H_2S concentration in digester gas was generally less than 65ppm, with a maximum concentration of 167 ppm. Therefore, it was concluded that the hydrogen sulfide concentrations from the five sampling events at Owls Head and Coney Island WPCPs were not representative of the typical hydrogen sulfide concentrations found at the NYCDEP WPCPs.

4.1.4.1. Historical Reliability

This technology is commonly used in the industry to remove hydrogen sulfide from digester gas.

4.1.4.2. Performance

This system reports typical removal efficiencies of up to 99.98% reduction in hydrogen sulfide using this add-on technology. Appendix C-2 provides more detailed information on this technology.

4.1.4.3. Ease of Implementation

The iron sponge has been used to remove hydrogen sulfide from digester and landfill gas at numerous locations throughout the world. The system can be skid-mounted for easy installation. At the Owls Head WPCP, a two vessel system may be installed.

4.1.4.4. Equipment Cost

The equipment includes two vessels fabricated of ASTM A36 steel with coal-tar epoxied interiors and an in-vessel regenerative system. The cost estimate for this technology is found in Appendix C-9.

4.1.4.5. Maintenance Level of Effort

Based on the high level of hydrogen sulfide (~ 480ppm), the media would be regenerated and replaced on a annual basis.

4.1.5. Gas Cleaning Technology Selection

A summary of the gas cleaning technology ratings is presented in Table 4-1. Of the three technologies evaluated for removal of siloxanes in the digester gas, carbon absorption was determined to be the most technologically feasible and commercially-tested system for siloxane removal. With respect to economics, preliminary costs were estimated for activated carbon and refrigeration, the two most widely used gas cleaning technologies of the three evaluated. The preliminary costs estimated for the Owls Head WPCP found that the pilot testing system for refrigeration was more expensive in equipment cost than the activated carbon gas cleaning system. The iron sponge technology was considered as a supplement to the gas cleaning technologies under the alternatives since this technology only treats hydrogen sulfide emissions.

In order to allow for long-term application, a permanent gas cleaning system, including multiple vessels for continuous operation capabilities, and potentially, a chiller for moisture removal, was the objective for the pilot test program. The system should include either one or two pressure vessels containing activated carbon in addition to all associated piping and valves. Manufacturers of activated carbon adsorption gas cleaning technology systems provided cost quotes for full-scale gas cleaning systems for the pilot test. Table 4-2 shows the cost breakdowns from the two vendors that responded with quotes for the system equipment and annual replacement cost for the media (Applied Filter Technology (AFT) and SCS Energy (SCS)). The equipment selected by AFT was selected for the feasibility study based on the lower equipment cost and the vendor's history of successful implementation of gas cleaning technology for siloxane removal from digester gas to be used in internal combustion engines with post-combustion control equipment.

4.2. Emission Control Technology Review

A technology review was performed in July 2003 for the NYCDEP by Advanced Engine Technology Corporation (AETC) (see Appendix C-3). AETC reviewed the following solutions for NOx reduction:

- selective catalytic reduction (SCR)
- pre-treatment-vapor injection
- diesel pilot pre-combustion chambers (indirect injection)
- micro-pilot high pressure fuel injection (direct injection)
- conversion to spark ignited engines

The review concluded that, although it was possible to reduce NOx related to engine reformulation, the only commercially viable solution for NOx reduction is selective catalytic reduction (SCR). The other options are still in the research and development stages and may not be appropriate for a feasibility study at this time. Therefore, SCR was selected as the emissions control technology for this feasibility study.

With the selection of SCR as the appropriate emissions reduction technology, the maximum allowable engine exhaust backpressure and available engine exhaust backpressure is required in order to determine if SCR can be installed with no adverse affects on the engine operation at the Owls Head WPCP. Based on information from the manufacturer and additional information obtained for other engines owned by the NYCDEP, the maximum allowable backpressure is approximately 18 inches (in.) water column (wc) to 20 in. wc.

Vronay Engineering Services performed backpressure testing on May 25, 2007, on an engine at the Owls Head WPCP using diesel fuel and operating under varying loads. The engine was not able to achieve 100% load during the test program; therefore, the engine exhaust backpressure at 100% load was determined through curve fitting and extrapolation. The full report can be found in Appendix C-4.

SCR system vendors provided quotes for their control systems associated with the feasibility study. Table 4-3 lists vendor quotes for the SCR system equipment costs. MIRATECH offered the least expensive system. MIRATECH also performed a site visit before delivering the quote to develop a system to custom fit the available space. CSM Worldwide proposed a system in which the heat recovery boiler would be converted to be a part of the SCR system. However, due to the space constraints at Owls Head WPCP, this retrofit does not appear to be feasible. Therefore, the MIRATECH system was selected for the feasibility study.

The MIRATECH catalyst and housing has an estimated backpressure of 5 in. wc. This amount of backpressure appears to be available while operating on digester gas or dual fuel (DG and fuel oil) at 100% load, but is not available when using diesel fuel at 100% load. Therefore, if Owls Head WPCP must operate on diesel fuel, the maximum capacity should not exceed 91% (2050 kW) to remain below the maximum allowable engine exhaust backpressure.

4.3. Selection of Alternatives

Based on the review of the gas cleaning and emissions control technologies, the following four alternatives to clean siloxane and other compounds from the digester gas and reduce NOx emissions from IC engines to meet the new RACT regulations were selected for further evaluation.

- Alternative 1 – SCR Catalyst and Carbon Adsorption Gas Cleaning System
- Alternative 2 – SCR Catalyst and Refrigeration/Condensation with Catalytic Carbon Adsorption System
- Alternative 3 – SCR Catalyst, Carbon Adsorption, and Iron Sponge System
- Alternative 4 – AFT SCR Catalyst, Refrigeration/Chiller, and Carbon Adsorption System

The four alternatives will be evaluated on the basis of economics.

Table 4-1
Gas Cleaning Technology Ratings Summary

Technology	History of Operation	Performance	Ease of Implementation	Equipment Cost	Maintenance Level of Effort
Activated Carbon Adsorption	Good	Good	Good	Good	Good
Refrigeration/Condensation	Fair	Fair/Poor	Good	Fair/Poor	Fair/Poor
PSA/TSA Resin Adsorption	Poor	Fair/Poor	Good	Poor	Poor

Table 4-2
Pilot Scale Activated Carbon Adsorption Gas Cleaning System Vendor Cost Breakdown

Vendor	Equipment Cost ($)	Carbon Media Cost ($/yr)
AFT [1]	47,130	102,600
SCS ENERGY[2]	108,500	35,200

Notes:
(1) AFT cost estimate is for one stainless steel vessel measuring 66-inch diameter by 96-inch straight length on side with galvanized steel bolt on legs and three outlet piping manifold arrangement. The carbon media usage cost is based on 5700 pounds per vessel with a replacement frequency of 12 times per year. The full report can be found in Appendix C-5.
(2) SCS cost estimate is for two vessels measuring 66-inch diameter by 13 feet overall height. The carbon media usage cost is based on 13,000 pounds total with a replacement frequency of two times per year. SCS requires that the relative humidity of the gas be less than 60% and that the gas temperature not exceed 115^{o}F. To accomplish this, they recommend a chiller plus reheat heat exchanger, cooling tower plus electric heater, water scrubber plus electric heater or electric heater alone. The cost of the additional equipment is not included in this table. The full report can be found in Appendix C-6.

Table 4-3
Pilot Scale SCR Equipment Costs

Vendor	Equipment Cost ($)
MIRATECH [1]	124,200
CSM Worldwide [1]	175,000

Notes:
(1) The full MIRATECH and CSM Worldwide reports can be found in Appendices C-7 and C-8 respectively.

5. Economic Analysis

This section summarizes the economic analysis of the alternatives to remove siloxanes and other compounds from the digester gas and reduce NOx emissions from the IC engines at the NYCDEP Owls Head WPCP on a pilot-scale and full-scale basis. The pilot scale costs are based on a one-year operation. The full scale costs are based on a 10-year operation. The full scale economic analysis followed guidance provided in *Air Guide-20* RACT analysis guidelines and in the *USEPA Air Pollution Control Cost Manual* (USEPA, 2002).

Section 4 and Appendix C contain detailed information from vendors for the digester gas cleaning system and IC engine control options. This information was used to develop the total capital investment, total annual operation and maintenance (O&M) costs, and the total cost for a one-year pilot test program. Appendix D-1 provides a detailed summary investment of these costs to implement selected digester gas cleaning system alternatives identified in Section 4 at the Owls Head WPCP.

Total capital investment includes the total direct capital costs and total indirect installation costs. The total direct capital costs include the following items: equipment; installation; mechanical; structural; electrical; site/architectural; instrumentation; and costs to comply with general conditions, contractor overhead, profit, staging, and sales tax.

Total indirect capital costs for the options include the following: one-time demonstration performance test costs, permitting, and engineering and administration. The total cost for the demonstration performance test was assumed to be $14,000 for each alternative.

Total annual O&M costs include the following: annual additional electrical cost, annualized equipment and media replacement costs, periodic equipment performance testing, and miscellaneous and project allowance costs.

For each alternative the following assumptions apply:

- The total direct capital cost is time dated for August 2007.
- The total direct capital cost includes a 10% factor for complying with NYCDEP general conditions.
- The total direct capital cost includes a 21% factor for contractor overhead, profit, and staging.

- Sales tax in New York City is 8.375%. The total direct capital cost assumes that sales tax only applies to equipment that makes up less than 75% of the total direct capital costs. Therefore, the total direct capital cost includes a 6% factor for sales tax.
- The total capital investment includes a 15% contingency factor on the total direct capital and total indirect installation costs.
- The total capital investment includes a 25% engineering and administration factor on the total direct capital cost for the design, bidding assistance, design services during construction, and construction administration services.
- The total annual O&M costs include a 10% project allowance factor of the subtotal annual O&M cost.
- The construction costs were escalated to the mid-point of construction by February 2010 assuming an increase of 4% per year for 2.5 years.

The economic analysis to implement alternatives to meet the new NOx RACT regulations for IC engines at the Owls Head WPCP on a pilot-scale and full-scale basis are presented below.

5.1. Gas Cleaning/Emission Control Alternatives

As discussed in Section 4, the following are four alternatives to clean siloxane and other compounds from the digester gas and reduce NOx emissions from IC engines to meet the new RACT regulations:

- Alternative 1 – SCR Catalyst and Carbon Adsorption Gas Cleaning System
- Alternative 2 – SCR Catalyst and Refrigeration/Condensation with Catalytic Carbon Adsorption System
- Alternative 3 – SCR Catalyst, Carbon Adsorption, and Iron Sponge System
- Alternative 4 – AFT SCR Catalyst, Refrigeration/Chiller, and Carbon Adsorption System

Table 5-1 summarizes the annualized costs for these alternative combinations for the pilot test. The cost assumptions for each alternative combination are discussed below.

5.1.1. Alternative 1 – SCR Catalyst and Carbon Adsorption Gas Cleaning System

Under this alternative combination, the engine will be modified at the Owls Head WPCP to include the SCR system, and an activated carbon adsorption/digester gas cleaning system will be installed. The total capital investment and total annual O&M costs related to the SCR catalyst with activated carbon adsorption digester gas cleaning are presented below. Refer to Appendix D-2 for more details.

- The total capital investment included one complete SCR system for one engine operation and one digester gas cleaning system vessel for the pilot test.

- Installation costs included site work for installation of the urea storage tank, engine exhaust ductwork and insulation, and associated piping, supports, valves, electrical, and controls.
- The total annual O&M costs included the replacement of the SCR catalyst once a year. No carbon media changeout was assumed, since under the maximum tons reduced scenario of operating on 100% diesel fuel, no gas cleaning would be required.
- The total annual O&M costs also include electrical usage for the instrumentation and urea supply pump, urea usage, and project allowance of 10%.

5.1.2. Alternative 2 – SCR Catalyst and Refrigeration/Condensation with Catalytic Carbon Adsorption System

Under this alternative combination, the engine will be modified at the Owls Head WPCP to include the SCR system, and the refrigeration/condensation with catalytic carbon adsorption system equipment will be installed. The total capital investment and total annual O&M costs related to the SCR catalyst with refrigeration and catalytic carbon adsorption system are presented below. Refer to Appendix D-3 for more details.

- The total capital investment included one complete SCR system for one engine operation and one Pioneer Air Systems (Pioneer) refrigeration gas cleaning system with two stainless steel catalytic carbon adsorption vessels for the pilot test.
- Installation costs included site work for installation of the urea storage tank, gas cleaning system, engine exhaust ductwork, and insulation and associated piping, supports, valves, electrical, and controls.
- The total annual O&M costs included the replacement of the SCR catalyst once a year and outside O&M costs for the gas cleaning system, including parts, labor, and travel. No carbon media changeout was assumed, since under the maximum tons reduced scenario of operating on 100% diesel fuel, no gas cleaning would be required.
- The total annual O&M costs also included electrical usage for the instrumentation, urea supply pump, and refrigeration unit; urea usage; and project allowance of 10%.

5.1.3. Alternative 3 – SCR Catalyst, Carbon Adsorption and Iron Sponge System

Under this alternative combination, the engine will be modified at the Owls Head WPCP to include the SCR system, an activated carbon adsorption/digester gas cleaning system, and an iron sponge. The total capital investment and total annual O&M cost related to the SCR catalyst with activated carbon adsorption digester gas cleaning and iron sponge are presented below. Refer to Appendix D-4 for more details.

- The total capital investment included one complete SCR system for one engine operation, one digester gas cleaning system vessel for the pilot test, and one iron sponge system.

- Installation costs included site work for installation of the urea storage tank, iron sponge, engine exhaust ductwork and insulation, and associated piping, supports, valves, electrical, and controls.
- The total annual O&M costs included the replacement of the SCR catalyst once a year and the changeout of the iron sponge once a year. No carbon media changeout was assumed, since under the maximum tons reduced scenario of operating on 100% diesel fuel, no gas cleaning would be required.
- The total annual O&M costs also included electrical usage for the instrumentation, urea supply pump, and iron sponge regenerative blower; urea usage; and project allowance of 10%.

5.1.4. Alternative 4 – AFT SCR Catalyst, Refrigeration/Chiller and Carbon Adsorption System

Under this alternative combination, the engine will be modified at the Owls Head WPCP to include the SCR system, an activated carbon adsorption digester gas cleaning system, and a refrigeration system. The total capital investment and total annual O&M cost related to the SCR catalyst with activated carbon adsorption digester gas cleaning and refrigeration are presented below. Refer to Appendix D-5 for more details.

- The total capital investment included the AFT SAGPack gas conditioning system that consists of a coalescer, blower, heat exchanger, chiller, controller, instrumentation, two SAG 72V carbon adsorption vessels, piping, and air wedge cart loading/unloading unit.
- Installation costs included site work for installation of the urea storage tank, engine exhaust ductwork and insulation, refrigerant chiller, and associated piping, supports, valves, electrical, and controls.
- The total annual O&M costs included the replacement of the SCR catalyst once a year. No carbon media changeout was assumed, since under the maximum tons reduced scenario of operating on 100% diesel fuel, no gas cleaning would be required.
- The total annual O&M costs also included electrical usage for the instrumentation, urea supply pump, and refrigerant chiller; urea usage; and project allowance of 10%.

5.2. Evaluation of NOx RACT Compliance for Full Scale Implementation Alternatives

An economic analysis of the full-scale SCR system and four alternative digester gas cleaning system technologies was performed to determine the Reasonable Available Control Technology (RACT). The analysis followed *Air Guide 20* RACT analysis guidelines and the *USEPA Air Pollution Control Cost Manual*.

Quotes for the SCR equipment were requested from three experienced vendors. *Air Guide 20* requires that the lowest of at least three budgetary bids be used for the economic evaluation. Two vendors provided budgetary estimates for SCR systems to control NOx emissions from the engines. The other vendor (Johnson Matthey) declined to provide a quote because of the space constraints for the SCR equipment at Owls Head WPCP. Therefore, two budgetary bids were available for this analysis. The budgetary estimates are summarized in Table 5-2, and found in Appendix C-7 and C-8. Refer to Appendices D-7 to D-10 for full-scale construction cost estimate details.

Quotes for the full-scale implementation of the four alternative digester gas cleaning systems also were obtained. The budgetary estimates are summarized in Table 5-3 and also can be found in Appendices C-1, C-5, C-9, and C-10.

As summarized in Table 5-4 and shown in Appendix D-6, the lowest annualized total capital investment (TCI) and total annual O&M costs for procuring, installing, and operating an SCR system with digester gas cleaning for the engines at the Owls Head WPCP was approximately $675,000 per year (Alternative 1) using *Air Guide 20* guidelines. The maximum tons of NOx reduced was calculated using the difference of the existing Title V permit limit of operating 5,840 hours per year per unit on diesel fuel with an NOx emission factor of 5.5 grams per brake horsepower-hour and emissions when the IC engines meets the NOx RACT limit of 2.3 grams per brake horsepower-hour. Given the approximately 58% NOx reduction required and the permitted hours of operations of 5,840 hours per year per unit, this results in a cost of $3,444 per ton of NOx controlled.

Using the lowest budgetary estimates provided by the vendor and not accounting for the site constraints, the annualized cost for the SCR and digester gas cleaning systems are below the *Air Guide-20* RACT standard cost of $3,000 per ton of NOx in 1994 dollars (or $4,599 per ton of NOx adjusted to July 2007 dollars) based on the Engineering News Record (ENR) for the New York City Metropolitan Area (NYCMA). In order to compare these costs to the aforementioned costs for implementing the technologies, the RACT standard cost was further escalated by 3.21% per year for 2.5 years to $4,966 per ton of NOx reduced adjusted to February 2010 dollars. The 3.21% per year escalation represents the historic ENR escalation rates from 1994 through July 2007.

This approach used for the NOx RACT evaluations of the Alternatives was conservative because the uncontrolled emissions assumed diesel operations and the cost included a digester gas cleaning system. Therefore, further refinement to the NOx tons reduced under Alternative 1 was performed for the NOx RACT analysis.

5.3. Full-Scale Implementation– Alternative 1

Since Alternative 1 has the lowest total annualized TCI and annual O&M cost of the four alternatives presented, it represented the "worst case" for the economic analysis for the remaining alternatives, as Table 5-5 presents the full-scale cost estimates for the various

Alternative 1 scenarios. Estimates based upon actual engine usage for 2004, 2005, and 2006 also are presented in Table 5-5. Details of this evaluation are presented in Appendix D-11.

Under the existing Title V permit, assuming the use of 100% fuel oil in the engines (which requires no gas cleaning) would appear to make Alternative 1 (SCR Catalyst and Carbon Adsorption Gas Cleaning System) a feasible system both technically and economically. NOx emissions before control equal approximately 377 TPY; after control, emissions equal approximately 141 TPY, which indicates a reduction of 196 TPY. Total cost per ton of NOx reduced ($3,444) is below the *Air Guide 20* standard cost of $4,966. However, the engines do not operate on 100% diesel fuel; they operate on a mixture of digester gas and fuel oil. Under this realistic operating scenario, the reduction in NOx emissions is 53 TPY after the controls are implemented, with an estimated cost of $13,632 per ton of NOx reduced, which is three times the NOx RACT standard cost. Therefore, although Alternative 1 is technologically feasible, it does not meet NOx RACT based upon the economic analysis.

On January 2, 2008, the NYCDEP provided comments on the draft Renewal 1 to the Title V Air Permit for the Owls Head WPCP submitted by NYSDEC. At this time, NYCDEP incorporated a modification to cap NOx emissions at 225 tons per year, down from the previous level of 337 tons of NOx per year (uncontrolled). The economic analysis was performed for this new NOx emissions cap. Again, assuming 100% diesel fuel combustion, Alternative 1 initially appears to meet the RACT criteria; i.e., estimating 131 TPY of NOx reduced, the cost per ton almost equals the standard cost. However, the engines do not use 100% fuel oil; they use a mixture of digester gas and diesel fuel oil. Under realistic operating conditions and including the proposed emissions cap, the cost per ton of NOx reduced is almost double ($8,156) the standard cost according to *Air Guide 20*. Therefore, while Alternative 1 may be technologically feasible, it does not meet NOx RACT based upon the economic analysis under the proposed emission cap of 225 TPY of NOx.

In addition, the total NOx emissions of the past three years are 124 TPY (2004), 90 TPY (2005), and 108 TPY (2006). Actual tons reduced were calculated from a difference of actual emissions (uncontrolled) and calculated controlled emissions using 2.3 g/bhp-hr and actual fuel usage. Therefore, the total actual tons reduced are 64 TPY (2004), 35 TPY (2005), and 52 TPY (2006).

5.4. Summary

Based on equipment vendor information, total capital investment, total annual O&M cost, and the total cost were developed for a one-year pilot test program to evaluate alternative

SCR emissions control and digester gas cleaning systems on IC engines combusting digester gas. The tests were to be conducted at the Owls Head WPCP. The control and gas cleaning systems are being considered for the engines in order to meet the new NOx RACT emission limits promulgated by NYSDEC. In addition, costs also were estimated for the full-scale implementation of these systems. Table 5-1 summarizes the cost information for the four alternatives for the Owls Head WPCP for a one-year pilot study program, and Table 5-4 summarizes the information for the full-scale study.

The alternatives were screened based upon total annualized TCI and annual O&M costs, and it was determined that Alternative 1 could represent a worst case for the economic analysis. The economic analysis indicated that while Alternative 1 was technologically feasible, it did not meet NOx RACT economic requirements; i.e., the total cost per ton of NOx reduced far exceeded the upper limit cost defined by NYSDEC in *Air Guide 20.* Therefore, the analysis demonstrated that the use of an SCR with digester gas cleaning does not meet NOx RACT requirements under current and proposed NOx permit limits.

Table 5-1
Preliminary Pilot Scale Cost Estimate for the Owls Head WPCP

Cost Category	Alternative 1 Carbon Only and SCR System [1, 2]	Alternative 2 Carbon, Refrigeration and SCR System [1, 2]	Alternative 3 Iron Sponge, Carbon and SCR System [1,2]	Alternative 4 AFT Skid Mounted Package [1, 2]
Total Direct Capital Costs	$812,000	$1,452,000	$1,052,000	$1,495,000
Total Indirect Installation Costs	$217,000	$377,000	$277,000	$388,000
Total Capital Investment (TCI)	$1,183,000	$2,103,000	$1,528,000	$2,165,000
Escalated TCI to Mid-point [3]	$1,305,000	$2,320,000	$1,685,000	$2,388,000
Total Annual O&M Cost	$223,000	$208,000	$155,000	$151,000
Total Cost for One Year Pilot Test Program	$1,528,000	$2,528,000	$1,840,000	$2,539,000

Notes:
(1) Assumed one SCR system for one engine for the pilot test.
(2) Assumed one digester gas cleaning vessel required (Alternatives 1 and 3) and two digester gas cleaning vessels required (Alternatives 2 and 4) for the pilot test.
(3) Construction cost estimates were escalated to the mid-point of construction by February 2010 assuming an increase of 4% per year for 2.5 years.

Table 5-2
SCR Equipment Costs [1]

SCR Vendor	Equipment Cost
MIRATECH SCR Corporation	$139,200
CSM Worldwide	$190,000

Notes:
(1) Equipment costs include urea tank cost of $15,000.

Table 5-3
Full-Scale Digester Gas Cleaning System Equipment Costs at Owls Head WPCP

Digester Gas Cleaning Alternative	Gas Cleaning Vendor	Equipment Cost
Carbon Adsorption	Applied Filter Technology (AFT)[1]	$141,390
Refrigeration with Carbon Adsorption	Pioneer Air Systems Inc. (Pioneer) [2]	$407,500
Carbon Adsorption and Iron Sponge	AFT and Marcab[3]	$254,190
AFT Skid Mounted Package: Carbon Adsorption and Refrigeration	AFT[4]	$412,300

Notes:
(1) AFT cost estimate is for three stainless steel vessels measuring 66 in. diameter by 96 in. straight length on side with galvanized steel bolt on legs and three outlet piping manifold arrangement. The full report can be found in Appendix C-5.
(2) Pioneer Air Systems Inc. cost estimate includes a net price of $375,000 plus additional costs for the Class 1 Group D Division 1 option for $25,000 and the Blower Motor Variable Frequency Drive for $7,500. The full report can be found in Appendix C-1.
(3) Marcab cost estimate is for two vessels fabricated of ¼ in. ASTM A36 steel with coal-tar epoxied interiors measuring 12 in. diameter with an overall height of approximately 10ft., with each unit containing 588 ft^3 t of Iron Sponge. The full report can be found in Appendix C-9. The estimate for the alternative includes the AFT carbon adsorption system (refer to Note 1).
(4) The AFT Skid Mounted Package includes a coalescer, blower, exchanger, chiller, controller, instrumentation, SAG 72V carbon adsorption vessels, piping and air wedge cart loading/unloading unit. The full report can be found in Appendix C-10.

Table 5-4
Preliminary Full-Scale Cost Estimate for SCR Control at Owls Head WPCP

Cost Category	Alternative 1 Carbon Only and SCR System [1, 2]	Alternative 2 Refrigeration and SCR System [1,2]	Alternative 3 Iron Sponge, Carbon and SCR System [1,2]	Alternative 4 Carbon, Refrigeration, and SCR System [1,2]
Total Direct Capital Costs	$2,304,000	$2,690,000	$2,536,000	$2,719,000
Total Indirect Installation Costs	$590,000	$687,000	$648,000	$694,000
Total Capital Investment (TCI)	$3,328,000	$3,884,000	$3,662,000	$3,925,000
Escalated TCI to Mid-point [3]	$3,671,000	$4,284,000	$4,039,000	$4,329,000
Total Annual O&M Cost [4]	$201,000	$256,000	$227,000	$217,000
Total Annualized TCI and Annual O&M Cost	$675,000	$809,000	$748,000	$776,000
NOx Tons Reduced [5] (Maximum Potential)	196	196	196	196
Total Cost of Control per Ton of NOx Reduced	$3,444	$4,128	$3,816	$3,959
RACT (*Air Guide-20*) Standard Cost [6]	$4,966	$4,966	$4,966	$4,966

Notes:
(1) Assumed one SCR system per engine.
(2) Assumed three digester gas cleaning vessels required for Alternatives 1 and 3 and two vessels for Alternatives 2 and 4.
(3) Construction cost estimates were escalated to the mid-point of construction by February 2010 assuming an increase of 4% per year for 2.5 years.
(4) The total annual O&M cost includes the labor and materials for maintaining the SCR system; external labor and materials for the iron sponge media, chemical and catalyst replacement material. This cost does not include labor and/or oversight by the NYCDEP staff for installing new media, chemical or catalyst replacement.
(5) Maximum potential tons of NOx reduced assumed two of three engines operating full time using diesel fuel, uncontrolled emission factor of 5.5 g/BHP-hr, and controlled emission factor of 2.3 g/BHP-hr.
(6) Cost adjusted to July 2007 dollars.

Table 5-5
Preliminary Full Scale Cost Estimate for the Owls Head WPCP– Alternative 1 Scenarios [1]

Cost Category		1 - Diesel FO Title V limit	1a - 90% DG, 10% FO Title V limit	1b - Diesel FO 225 TPY limit	1c - 70% DG, 30% FO 225 TPY limit	1d - Actual Annual 2004	1e - Actual Annual 2005	1f - Actual Annual 2006
Total Direct Capital Costs		$2,304,000	$2,304,000	$2,304,000	$2,304,000	$2,304,000	$2,304,000	$2,304,000
Total Indirect Installation Costs		$590,000	$590,000	$590,000	$590,000	$590,000	$590,000	$590,000
Total Capital Investment (TCI)		$3,328,000	$3,328,000	$3,328,000	$3,328,000	$3,328,000	$3,328,000	$3,328,000
Escalated TCI to Mid-point		$3,671,000	$3,671,000	$3,671,000	$3,671,000	$3,671,000	$3,671,000	$3,671,000
Total Annual O&M Cost		$201,000	$244,000	$172,000	$214,000	$187,000	$178,000	$183,000
Total Annualized TCI and Annual O&M Cost		$675,000	$718,000	$646,000	$688,000	$661,000	$652,000	$657,000
Estimated Emissions TPY	**Before Control**	337	194	225	225	124	90	108
	After Control	141	141	94	141	60	55	56
Tons Reduced		196	53	131	84	64	35	52
Total Cost per Ton Reduced		$3,444	$13,632	$4,941	$8,156	$10,396	$18,400	$12,562
RACT (*Air Guide 20*) Standard Cost		$4,966	$4,966	$4,966	$4,966	$4,966	$4,966	$4,966

Notes:
(1) Alternative 1: Title V Permit Condition - 2 units operating using diesel fuel, no carbon media replacement and no siloxane testing
Alternative 1a: Title V Permit Condition - 2 units operating using digester gas with diesel pilot, 2 carbon media replacements and 4 siloxane testings
Alternative 1b: Proposed 225 tpy NOx limit using diesel, no carbon media replacement and no siloxane testing
Alternative 1c: Proposed 225 tpy NOx limit using digester gas with diesel pilot, 2 carbon media replacements and 4 siloxane testings
Alternative 1d: Annual 2004 engine usage, 2 carbon media replacements and 4 siloxane testings
Alternative 1e: Annual 2005 engine usage, 2 carbon media replacements and 4 siloxane testings
Alternative 1f: Annual 2006 engine usage, 2 carbon media replacements and 4 siloxane testings

6. Conclusions and Recommendations

The overall goal of the project for NYCDEP was to address compliance with NOx RACT requirements for the IC engines combusting digester gas at NYCDEP wastewater treatment plants using SCR emissions control and digester gas cleaning technologies. The approach included evaluations for the following programs:

- Pilot testing of an emissions control and digester gas cleaning system at an existing digester gas-fueled IC engine at a NYCDEP WPCP
- Full-scale implementation of an emissions control and digester gas cleaning system.

Current digester gas usage quantity, composition, and sources at the NYCDEP Owls Head and Coney Island WPCPs were reviewed. It was determined that the Owls Head WPCP is a more feasible location for the implementation of a pilot study for NOx emissions-control equipment using SCR catalyst and a digester gas cleaning system. The main reason for choosing Owls Head WPCP over the Coney Island WPCP were the space constraints at Coney Island and the difficulty in isolating the digester gas feed for only one engine. Based on the gas composition analyses, it was determined that the digester gas at both plants had siloxane concentrations present at levels that could be detrimental to the performance of the SCR equipment. Therefore, digester gas cleaning equipment would be required as part of the pilot test.

Technologies to remove siloxanes from waste gas were evaluated and included: carbon adsorption, refrigeration/condensation, and PSA/TSA systems. Carbon adsorption appeared to be the most feasible, cost-effective, and commercially tested technology available for siloxane removal on IC engines with post-combustion catalytic air pollution control equipment on the engine exhaust.

Under NOx RACT, the analysis must include economic as well as technical evaluation. Based upon the preliminary costs estimated presented in this report, the cost of implementing an SCR catalyst on all three engines, along with a digester gas cleaning system, ranged from $675,000 (Alternative 1) to $809,000 per year for annualized total capital investment and annual O&M costs. In addition, the installation of an SCR catalyst on the three engines at the Owls WPCP will only result in a 58% reduction in NOx emissions from the engines. Using the lowest budgetary estimates provided by the vendor, the annualized cost for the SCR and digester gas cleaning systems is below the RACT economic standard in *Air Guide 20*. The RACT economic standard is $3,000 per ton of NOx in 1994 dollars or $4,599 per ton of NOx adjusted to July 2007 dollars, based on the Engineering News Record (ENR) for the New York City Metropolitan Area. In order to compare these costs to the aforementioned costs for implementing the technologies, the RACT economic standard was further escalated by 3.21% per year for 2.5 years to $4,966 per ton of NOx adjusted to February 2010 dollars. The 3.21% per year escalation represents the historic ENR escalation from 1994 through July 2007.

Given the total NOx emissions of 124 TPY, 90 TPY, and 108 TPY for 2004, 2005, and 2006 respectively, the total actual tons reduced were 64 TPY, 35 TPY, and 52 TPY, and were calculated from a difference of actual emissions (uncontrolled) and calculated controlled emissions using 2.3 g/BHP-hr and actual fuel usage. For a range of 35 TPY to 64 TPY, this equals a cost of $10,396 to $18,400 per ton of NOx controlled (Alternative 1).

Given the required control of approximately 58% NOx reduction and the permitted hours of operations of 5,840 hours per year per unit, the cost per ton of NOx reduced equaled $3,444 under the Maximum Potential operating scenario (i.e., 100% diesel fuel combustion, carbon only scenario). With the proposed 225 TPY NOx limit, and under the "carbon only" scenario, the cost per ton of NOx reduced was $4,941. However, under realistic operating conditions (digester gas and with fuel oil as a pilot), the cost per ton of NOx reduced was $13,632 under the current permit, and $8,156 under the proposed 225 TPY NOx limit. Both of these costs far exceed the upper limit provided under NOx RACT guidance. This study demonstrated that the SCR control with a digester gas cleaning system is not RACT for the IC engines at Owls Head.

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