Greenhouse Gas Reduction Benefits of the Ammonia Recovery Process to Operation of a Generic Water Pollution Control Plant

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EXECUTIVE SUMMARY

Water pollution control plants (WPCP) are large consumers of energy and are currently of concern as substantial generators of greenhouse gas (GHG) emissions. The ThermoEnergy Corporation has patented a technology, called the Ammonia Recovery Process (ARP) for the removal of ammonia from the concentrated waste streams (centrates) of WPCP that can substantially decrease these emissions.

This report identifies categories of GHG emission sources from WPCP operations and quantifies these emissions from conventional biological nutrient removal processes with and without the application of ARP. The largest source of GHG at the WPCP is associated with the biological activity. Nitrogen reduction achieved with the introduction of the ARP significantly reduces emissions of carbon dioxide and nitrous oxide, the two most important GHG from this process. The result of the analyses of the GHG emissions from prototypical processes indicate GHG emissions at the WPCP would be reduced by approximately seven to nine percent with the utilization of the ARP.

1. INTRODUCTION

The ThermoEnergy Corporation has patented a technology called the Ammonia Recovery Process (ARP) for the removal of ammonia from the concentrated waste streams (centrates) of WPCP. A recent study conducted by HydroQual, Inc. demonstrated the economic and environmental benefits of ARP relative to conventional biological nutrient removal (BNR) processes for the reduction of ammonia, but did not address ARP's carbon footprint impact. This report estimates the relative amounts of GHG emissions associated with BNR and this new technology.

Generic simulation models were developed in the HydroQual study for the BNR process as it would operate in both single- and two-sludge water pollution control plant designs. An updated simulation for this GHG analysis was conducted using a revised version of the BioWin model (Version 3.0) for both plant designs with and without the ARP technology.

2. GREENHOUSE GASES AND CLIMATE CHANGE

Greenhouse gases are atmospheric gases that absorb and emit infrared radiation and trap the heat in the lower atmospheric layer. This "greenhouse effect" occurs naturally, but is believed to be enhanced by human activity. Emissions of several important GHGs have increased since large-scale industrialization began, mostly due to the proliferation of fossil fuel use and to changes in land use and agriculture. While naturally occurring GHGs are essential to life on Earth, anthropogenic causes, if not checked in time, are projected to bring about climate change (global warming) with subsequent disastrous effects on human life and civilization.

Many gases exhibit greenhouse properties. Some of them occur in nature (water vapor, carbon dioxide, nitrous oxide, methane and ozone), while others are anthropogenic. "Halocarbons", which is a collective term for fluorinated gases, chlorine and bromine-containing organic compounds are created and emitted solely through human activity, but are not generally associated with water pollution control plants.

The principal anthropogenic GHGs relevant to this study are:

- **Carbon Dioxide (CO_2)**. Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and as a result of other chemical reactions. Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle or when it reacts with minerals or dissolves in the ocean.
- **Methane (CH_4)**. Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and from the decay of organic waste in municipal solid waste landfills or at water pollution plants.
- **Nitrous Oxide (N_2O)**. Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

Greenhouse gases differ in their ability to trap heat. To compare emissions of different GHGs, inventory compilers use a weighting factor called a Global Warming Potential (GWP). The heat-trapping ability of 1 metric ton of CO_2 is taken as a standard, and emissions of other gases are rated relative to it. The impact of emissions of other gases is described by their GWP and expressed in CO_2 equivalents (CO_2Eq). The GWPs used in this analysis are shown in Table 1.

TABLE 1: GLOBAL WARMING POTENTIALS

GAS	GWP
CO_2	1
CH_4	21
N_2O	310

Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005 (April 2007) http://www.epa.gov/climatechange/emissions/downloads06/07ES.pdf.

3. REPRESENTATIVE WPCPS AND PROCESSES CONSIDERED

Sources of GHG emissions associated with ammonia reduction at WPCPs are described in the following sections. Accurately estimated emission rates are dependent on the realistic assumptions regarding process variables used at these plants. Contemporary facilities are multi-stage biochemical facilities, with complex interaction of the stages. Consideration of the feedback of intermediate streams and the behavior of clarifiers and dewatering devices requires that simulations account for these phenomena.

The BioWin model is the most widely used software for simulating WPCP activities. All simulations were conducted for a steady-state operation at 20 degrees Centigrade and used BioWin version 3.0. Two types of water pollution plants were considered:

- *Single-sludge* plants, such as those used by the New York City Department of Environmental Protection, in which modification of secondary treatment is employed for nutrient reduction; and
- *Two-sludge plants,* such as the Washington, DC Water and Sewer Authority's Blue Plains Plant, in which a separate treatment train is used for nutrient reduction.

The ARP is a physical-chemical ammonia-nitrogen removal process for the treatment of centrate that reduces the power and chemical requirements of BNR and does not directly generate GHGs. This treatment can be effectively applied to either the single-sludge or the two-sludge plants.

Analyses were conducted for each plant type, assuming generic 100-million-gallon-per-day facilities. Operating parameters and effluent quality were developed for the BNR process with and without ARP. Parameters were specified in the BioWin model for each operation, and identical effluent characteristics were used for each process. Parameters used in the modeling for each case are presented in Appendix 1, Exhibit 1 (for the single-sludge plant) and Exhibit 2 (for the two-sludge plant).

The BioWin 3.0 model for each category of WPCP was modified to include ARP as shown in Exhibits 1 and 2. Centrate flow to the head of the plant was eliminated in the ARP cases and the ARP-treated centrate was introduced at the start of the BNR process. The chemical and oxygen inputs to the BNR process were adjusted to keep effluent characteristics constant. Oxygen demand was taken as a surrogate for power requirement since the major energy benefit of ARP is the decrease in the power demand for aeration. A conservative estimate of caustic demand for ARP based on full conversion of centrate bicarbonate to carbonate was employed. Input and output for ARP in these models are displayed in Appendix 1, Exhibit 3. The results of the BioWin 3.0 simulations are summarized in Appendix 1, Exhibits 4.1 and 4.2. These results were used for GHG estimates relating to BNR and anaerobic digestion processes.

4. GHG EMISSION INVENTORY APPROACH

The approach used to estimate GHG emissions from the WPCP differs from the approach used in the International Panel for Climate Change (IPCC) Guidelines, which are used in the Inventory of US GHGs and Sinks. The IPCC Guidelines were developed to estimate GHG emissions for an entire country and, therefore, do not consider detailed operations of an individual plant. Instead, they refer to surrogate categories, such as number of people served by the plant, to estimate emissions. In addition, because the IPCC Guidelines are intended for assessment of GHG emissions resulting from all economic sectors of a country, in order to avoid double counting, WPCP emissions are limited to direct wastewater treatment operations. Emissions resulting from, for example, production and delivery of chemicals required for these operations are accounted for in another sector (e.g., chemical production and transportation).

The goal of this analysis is to estimate GHG emissions from the representative WPCPs with and without the ARP. This requires the assessment of all affected direct and indirect operations at each plant, including deliveries in and out of the plant, changes in chemical production, fertilizer production, etc. However, because of uncertainties, emissions were estimated only for the first level of affected indirect processes; no assessment was made for energy production for indirect uses, distribution of fertilizers, or such other secondary sources. Land application of biosolids (sludge) has very large uncertainties for estimated GHG emissions and therefore emissions from land applications were also not included in the inventory. This is a conservative assumption because it underestimates reductions of GHG with the ARP technology as less sludge would be produced with the ARP.

5. GHG EMISSION CALCULATION METHODS

Emissions of GHG are the result of direct actions at the WPCP and indirect impacts such as transport of biosolids or the use of energy for caustic production. Descriptions of each emission source and calculation approach are provided in this section and the details are presented in Appendix 2.

5.1 Emissions from BNR Process

5.1.1 Aeration for Nitrification and Bacterial Respiration

The oxidation process in the BNR for both types of water pollution control plants requires a constant supply of fresh oxygen. The oxygen demand is smaller with ARP than with the conventional process since BNR is required to remove less nitrogen due to centrate treatment with ARP. Use of electricity to power the compressor for aeration necessitates GHG generation. The type of compressor that would be used at the generic plant was selected, at the request of PB, by Tuthill Compressors, a UK-based firm that specializes in manufacturing aeration compressors for WPCPs, based on the estimated airflow resistance for the process. The GHG emissions due to operation of the compressors were based on the New York State average CO_2 emission factor for electricity: 0.389 ton per megawatt-hour (Department of Energy: Updated State- and Regional-Level GHG Emission Factors for Electricity, 2002).

The reduction in aeration with the ARP technology is due to reduced oxygen demand as follows:

- Removal of the oxygen demand to nitrify the ammonia in the BNR process; and
- Reduction in oxygen demand for the respiration of bacteria performing BNR.

The results presented in Table 2 indicate that GHG emissions from the energy required for aeration would be smaller with the ARP for both plant types.

TABLE 2: GHG EMISSIONS FROM POWER CONSUMED BY AERATION

WPCP Plant Type	Alternative	Oxygen Demand (tons/year)	Electricity Demand (MWH/year)	CO_2 (tons/year)
Single-Sludge	BNR	22,338	2,065	803
	With ARP	20,849	1,895	737
Two-Sludge	BNR	23,083	2,124	826
	With ARP	20,849	1,895	737

5.1.2 CO_2 Generated by Biological Activity – Bacterial Respiration

Bacteria in aeration tanks consume organic material from the wastewater and release carbon dioxide. The amount of carbon dioxide produced in this process is proportional to the amount of oxygen used for bacteria respiration. Table 3 shows that lower nitrogen input to the BNR with ARP treatment of centrate results in less biological activity, lower oxygen requirements, and lower CO_2 production.

TABLE 3: GHG EMISSIONS FROM BACTERIA RESPIRATION

WPCP Plant Type	Alternative	Total Oxygen (tons/year)	Oxygen Used for Bacteria Respiration (tons/year)	CO_2 (tons/year)
Single-Sludge	BNR	22,338	17,542	24,120
	With ARP	20,849	16,569	22,783
Two-Sludge	BNR	23,083	18,317	25,186
	With ARP	20,849	17,117	23,536

5.1.3 N_2O Generated by Biological Activity – Nitrification and Denitrification

The biological action specific to BNR is the oxidation of ammonia (nitrification) and the subsequent reduction of the oxidized forms of ammonia to nitrogen gas (denitrification). There are various BNR methods that carry out these processes under differing conditions and with different species of bacteria, and the amounts of nitrous oxide produced vary depending on the specific BNR technique employed.

The mechanisms of nitrous oxide production are currently being studied and methods for quantifying emissions of this GHG are not finalized. The emission factor used in this report (0.01 kg N_2O/kg N input) takes nitrous oxide emissions as proportional to the nitrogen load to the BNR, which is consistent with the approach recommended in the IPCC Guidelines and the DOE Technical Guidelines on Voluntarily Reporting GHG (2007).

While the quantities of nitrous oxide emitted are small relative to the CO_2 emissions, the global warming potential of nitrous oxide, which is shown in Table 1, is 310 times that of CO_2 and the impact of these emissions, therefore, can be significant.

TABLE 4: GHG EMISSIONS FROM NITRIFICATION AND DENITRIFICATION

WPCP Plant Type	Alternative	Total N_2 Load (kg/day)	BNR N_2O (kg/day)	BNR N_2O (tons/yr)
Single-Sludge	BNR	9,237	92	34
	With ARP	8,328	83	30
Two-Sludge	BNR	10,217	102	37
	With ARP	8,439	84	31

5.2 Emissions from Production of Caustic and Methanol

The chemicals required for the BNR and ARP processes are a source of GHG emissions. Since ARP consumes less caustic per unit of ammonia removed than BNR, and does not require methanol, there are less GHG emissions generated with ARP.

The energy and consequent GHG savings for the production of methanol are much easier to calculate than the production of caustic. While the simulation provides values for caustic use, the energy calculations are complicated by the fact that caustic and chlorine are produced as co-products. This report estimates energy for each co-product based on allocating equal portions of the energy input to each unit of weight produced. Caustic and chlorine are produced in fixed proportions, removing subjectivity from the calculation.

GHG estimates for caustic production are based on the energy required to produce chlorine (Energy Use and Energy Intensity of the US Chemical Industry, Berkley National Lab, 2000). For each ton of chlorine produced, 1.1 tons of caustic is also produced. Energy requirements for methanol production were obtained from the same report. The New York State average CO_2 emission factor for electricity of 0.389 T/MWH (Department of Energy: Updated State-and Regional-Level GHG Emission Factors for Electricity, 2002) was used throughout this analysis. Methane emitted as a result of methanol production was obtained from the DOE Technical Guidelines on Voluntarily Reporting GHG (2007).

In Table 5, the results indicate that total GHG emissions would be higher with the BNR process for both the single-sludge and two-sludge control plants.

TABLE 5: GHG EMISSIONS FROM PRODUCTION OF CAUSTIC AND METHANOL

WPCP Plant Type	Alternative	Dry Caustic Required (tons/year)	Methanol Required (tons/year)	CO_2 (tons/year)	CH_4 (tons/year)
Single-Sludge	BNR	36,500	3,473	1,150	6.9
	With ARP	32,704	2,460	1,004	4.9
Two-Sludge	BNR	43,800	8,249	1,548	16.5
	With ARP	33,726	6,657	1,204	13.3

5.3 Emissions from Fertilizer Production

ARP captures ammonia as ammonium sulfate, a common form of fertilizer. By producing the fertilizer with captured ammonia, ARP does not require the energy needed for ammonia synthesis. Ammonia production generates 1.26 tons of CO_2 per ton of ammonia according to the USEPA Compilation of Air Pollutant Emission Factors (AP-42). The energy demand and GHG emissions from production of the ammonia destroyed by BNR is considered BNR-only to account for the destruction of the ammonia resource during BNR.

TABLE 6: GHG EMISSIONS FROM FERTILIZER PRODUCTION

WPCP Plant Type	Alternative	Ammonia Produced (tons/year)	CO_2 (tons/year)
Single-Sludge	BNR	559	704
	With ARP	0	0
Two-Sludge	BNR	706	890
	With ARP	0	0

5.4 Emissions from Deliveries to and from the WPCP

Chemicals used in the BNR and ARP processes are conveyed by truck to the WPCPs. Ammonium sulfate, a fertilizer generated in the ARP, is delivered to the fertilizer manufacturer. Biosolids (sludge) that result from the wastewater treatment are transported from the WPCP and used for soil enrichment. All deliveries are performed by heavy-duty diesel trucks/tanker-trucks that generate GHG while burning diesel fuel. The amounts of GHG generated are estimated based on vehicle miles traveled (VMT) and energy required per vehicle mile of truck travel. This approach is described in the Department of Energy (DOE) Technical Guidelines on Voluntarily Reporting GHG (2007) and in the Government Accountability Office (GAO) report: Energy Audits Are Keys to Strategy for Reducing GHG (2007). It was assumed that chemical and fertilizer deliveries are made within a 250-mile radius and that the biosolids are transported 1,000 miles.

The CO_2 emissions from deliveries are presented in Table 7. As indicated in the table, CO_2 emissions from trucks are much higher than CH_4 and N_2O emissions, which were insignificant in all cases. In addition, trucking GHGs were higher using ARP for both plant types because of the additional fertilizer deliveries associated with ARP.

TABLE 7: GHG EMISSIONS FROM DELIVERIES

WPCP Plant Type	Alternative	VMT	CO_2 (tons/year)	CH_4 (tons/year)	N_2O (tons/year)
Single Sludge	BNR	173,505	261	0.00088	0.00521
	With ARP	204,796	308	0.00104	0.00614
Two-Sludge	BNR	289,336	435	0.0015	0.0087
	With ARP	352,198	530	0.0018	0.0106

5.5 GHG Emissions from Anaerobic Digestion

Digester gas is typically used either to generate energy or flared in a well-run WPCP. The full combustion of methane was assumed for all cases studied. The digester gas produced by anaerobic digestion is roughly proportional to the sludge production, but is sensitive to sludge properties as well.

5.5.1 Emissions from Anaerobic Digestion

Sludge produced during wastewater treatment is typically concentrated and subjected to anaerobic digestion for stabilization. In the anaerobic digesters, anaerobic bacteria consume organic material and produce carbon dioxide and methane. The digester gas generated in this process is generally 71 to 73 percent CH_4, and the remainder is CO_2. Table 8 shows the amounts of each GHG generated under each plant type and process considered in this analysis. The amount of carbon dioxide generated in the anaerobic digester was higher with ARP for the single-sludge plant and lower for the two-sludge design, while methane production was lower in both cases. While ARP always causes lower sludge production, changes in the sludge chemistry can cause slightly different digester gas composition with the consequences shown in the table.

TABLE 8: GHG GENERATED IN ANAEROBIC DIGESTER

WPCP Plant Type	Alternative	Digester Gas ($10^3 m^3$/year)	CH_4 (tons/year)	CO_2 (tons/year)
Single-Sludge	BNR	6,992	3,216	3,355
	With ARP	6,997	3,134	3,589
Two-Sludge	BNR	9,737	4,418	4,842
	With ARP	9,628	4,368	4,788

5.5.2 Emissions from Methane Combustion

Methane gas generated in the digester is burned and produces CO_2 emissions as presented in Table 9. Since the use of ARP reduces methane production in both cases, it also reduces the CO_2 produced by combustion of methane.

TABLE 9: GHG EMISSIONS FROM METHANE COMBUSTION

WPCP Plant Type	Alternative	CO_2 (tons/year)
Single Sludge	BNR	8,844
	With ARP	8,619
Two-Sludge	BNR	12,148
	With ARP	12,012

6. RESULTS

Projected GHG emissions were estimated for four cases:

- Single-sludge WPCP with and without ARP
- Two-sludge WPCP with and without ARP

Estimated GHG emission rates from the prototypical WPCP processes considered for this study are provided in the preceding sections. The global warming potential for methane and nitrous oxide, which are shown in Table 1, were used to estimate CO_2 equivalents under each scenario considered. The CO_2 equivalent emissions for each greenhouse gas are presented in Figures 1 to 4. The results indicate that at both types of wastewater treatment plants and under both alternative processes, methane has a relatively small contribution to emission burdens compared with other GHGs. The largest contributor is carbon dioxide.

FIGURE 1: SINGLE SLUDGE PLANT BNR

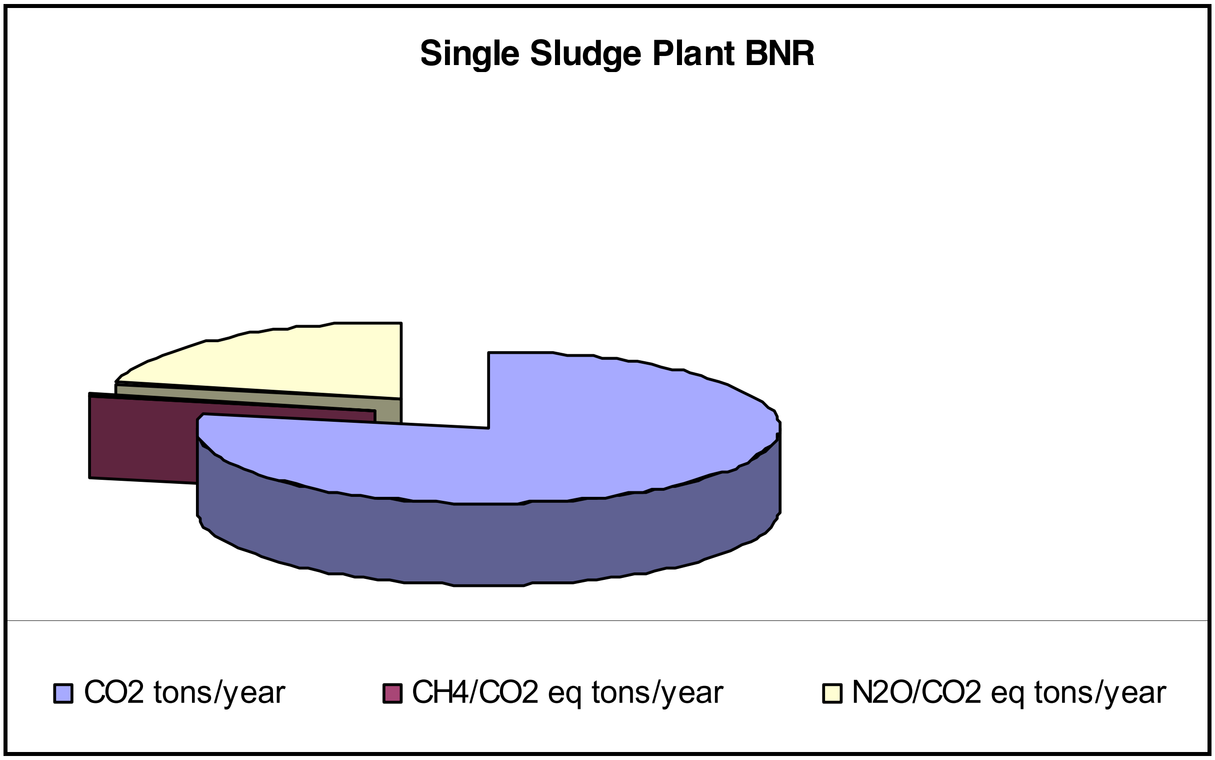
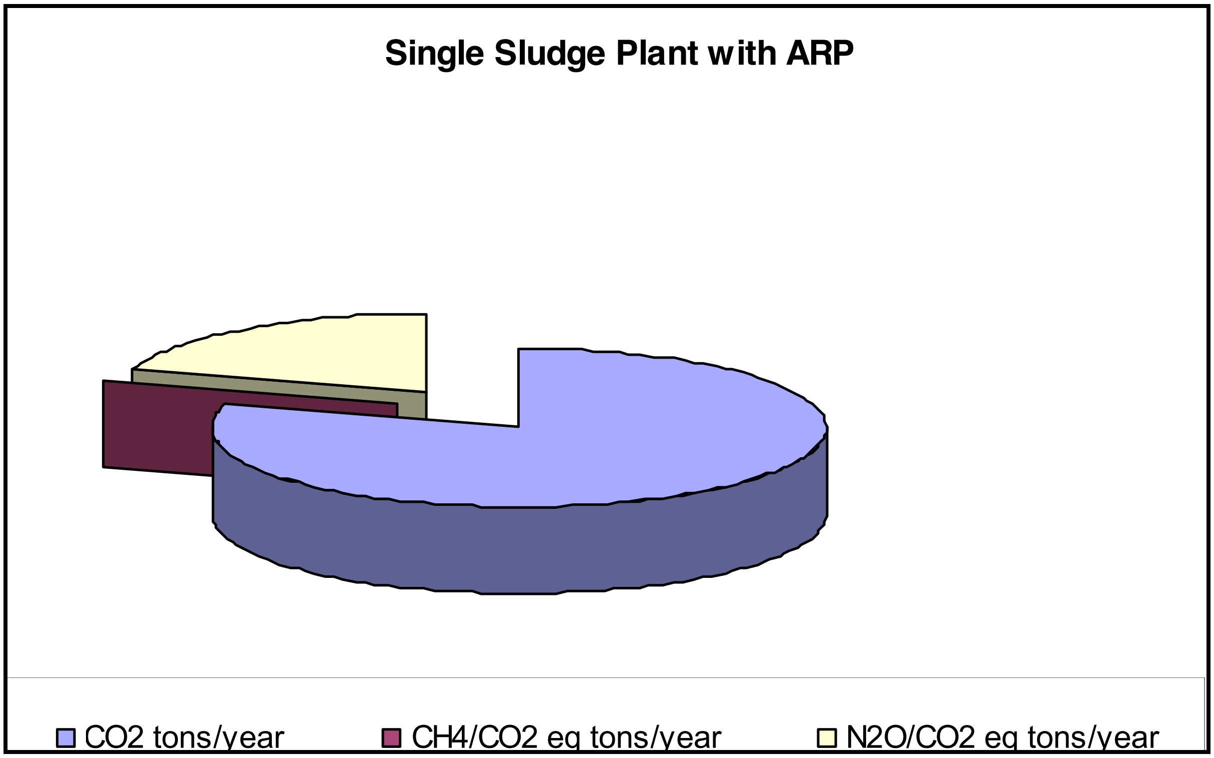


FIGURE 2: SINGLE SLUDGE PLANT WITH APR



6.1 Single-Sludge Plant

The results in Table 10 and in Figures 1 and 2 indicate that CO_2 is the largest contributor to total GHG emissions under both processes. CO_2 emissions comprise about 80 percent of the total GHG impact, while N_2O emissions comprise 20 to 22 percent, and methane is negligible. The ARP benefit is proportionally greatest regarding the N_2O emissions, so that the overall reduction in GHG due to ARP is roughly equally divided between reduction in CO_2 and in N_2O.

TABLE 10: GHG EMISSIONS AT THE SINGLE-SLUDGE WPCP

Alternative	CO_2 (tons/year)	CH_4/CO_2 eq (tons/year)	N_2O/CO_2 eq (tons/year)	Total CO_2 eq (tons/year)	Reductions (tons/year)
BNR	39,238	146	10,453	49,838	3,269
With ARP	37,040	103	9,425	46,569	

Less emissions of each individual greenhouse gas is generated with the utilization of ARP and overall GHG emissions are reduced by 7 percent—primarily due to reduced bacterial action required during BNR because of reduced nitrogen load.

6.2 Two-Sludge Plant

The results in Table 11 and in Figures 3 and 4 indicate that, for the two-sludge plant, CO_2 remains the largest contributor to GHG emissions, with N_2O having a proportionately smaller impact (18 to 20 percent). The ARP benefit is proportionally greatest regarding N_2O emissions, so that the overall reduction in GHG due to ARP is roughly equally divided between reductions in CO_2 and in N_2O.

TABLE 11: GHG EMISSIONS AT THE TWO-SLUDGE WPCP

Alternative	CO_2 (tons/year)	CH_4/CO_2 eq (tons/year)	N_2O/CO_2 eq (tons/year)	Total CO_2 eq (tons/year)	Reductions (tons/year)
BNR	45,875	346	11,563	57,785	5,147
With ARP	42,807	280	9,552	52,638	

Less emissions of each individual greenhouse gas is generated with the utilization of ARP and overall GHG emissions are reduced by 9 percent—primarily due to reduced bacterial action required during BNR because of reduced nitrogen load.

7. CONCLUSIONS

Results of the analysis demonstrate that a substantial reduction (from 7 to 9 percent) in GHG emissions can be obtained by ARP treatment of centrate to remove ammonia in order to reduce the nitrogen load to the BNR operation of either a single-sludge or two-sludge WPCP. Reduction in biological processing of the ammonia-nitrogen with ARP leads to declines in production of both CO_2 and N_2O emissions. In the case of the generic 100-mgd plants considered, this reduction is estimated to be approximately 3,000 to 5,000 tons per year of CO_2

equivalents. This reduction is comparable to reducing truck travel by 2 to 3 million miles annually. Since centrate treated by ARP also reduces the cost for nitrogen reduction relative to the conventional BNR process, ARP is also a cost-efficient method for reducing GHG emissions.

FIGURE 3: TWO SLUDGE PLANT BNR

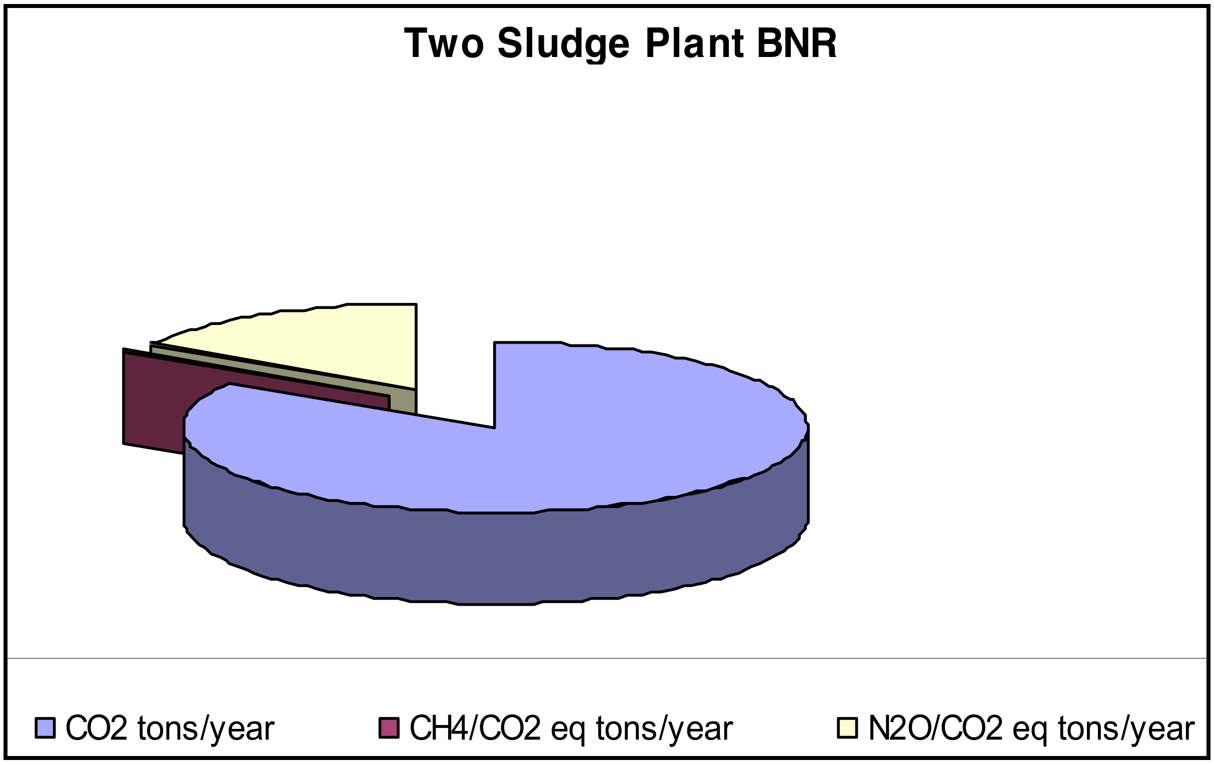
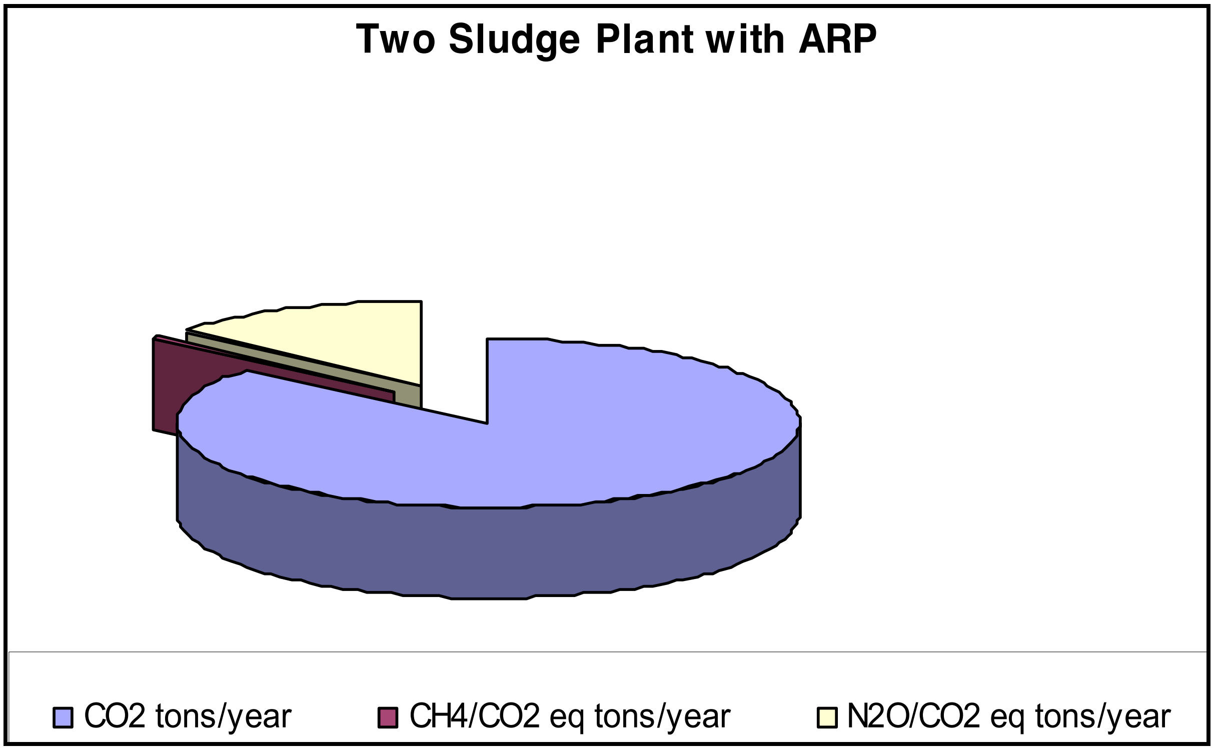


FIGURE 4: TWO SLUDGE PLANT WITH ARP



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Appendix 1

BioWin Assumptions and Results

EXHIBIT 1: BIOWIN MODEL FOR SINGLE SLUDGE WPCP

Flow: 100 MGD
Centrate TN: 795 mg/L at 0.41 MGD

Influent Quality

Flow	MGD	100
TKN	mg/L	25
COD	mg/L	290
CBOD	mg/L	142
TSS	mg/L	138
pH		7.0

Effluent Quality

NH_3-N	mg/L	0.56	0.58
NO_3-N	mg/L	2.54	2.28
TN	mg/L	5.3	5.1
COD	mg/L	33.5	32.5
CBOD	mg/L	8.66	8.28
pH		7.3	7.3

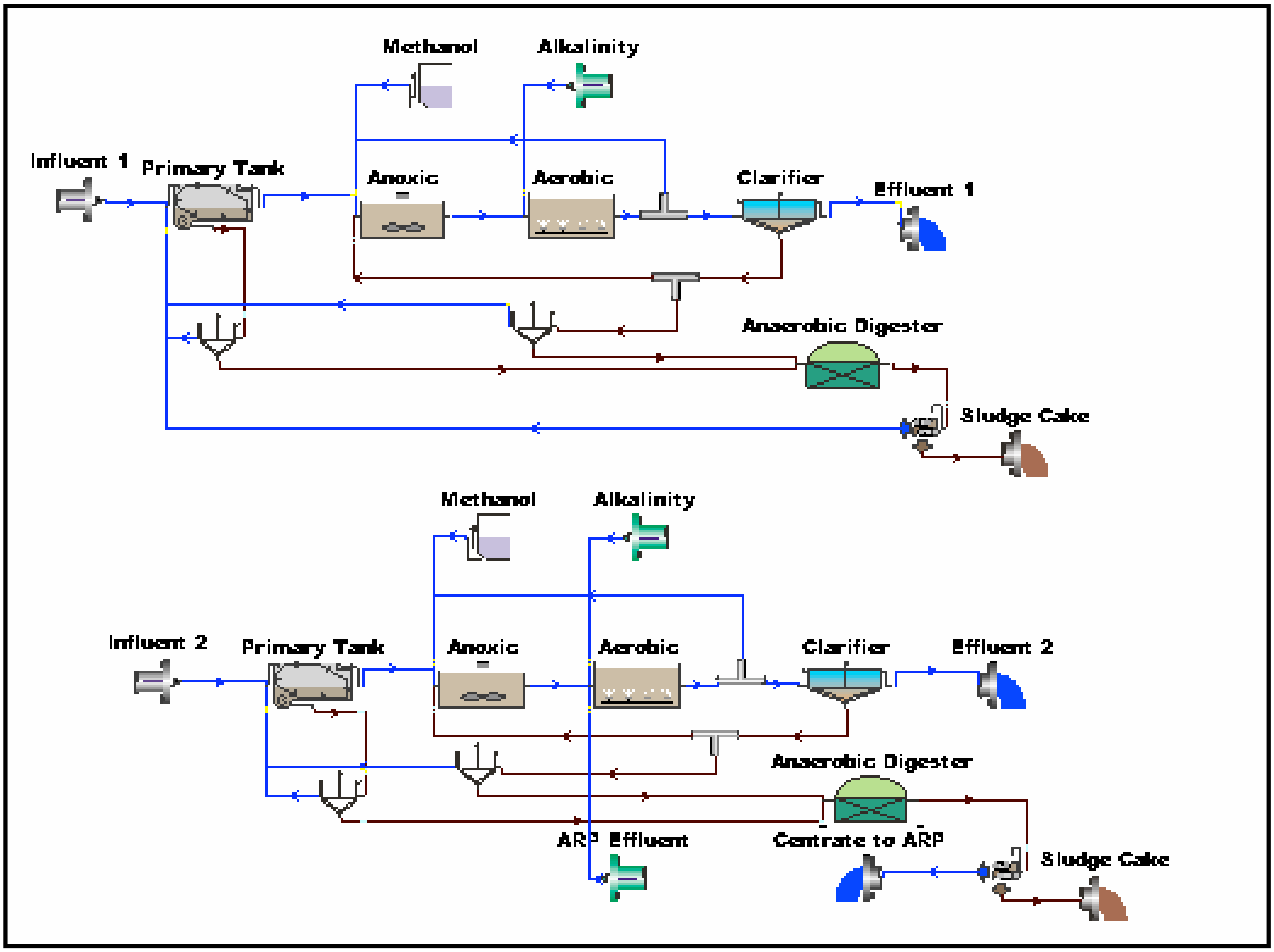

EXHIBIT 2: BIOWIN MODEL FOR TWO SLUDGE WPCP

Flow: 100 MGD
Centrate TN: 795 mg/L at 0.41 MGD

		Influent Quality	
Flow	MGD	100	
TKN	mg/L	25	
COD	mg/L	290	
CBOD	mg/L	142	
TSS	mg/L	138	
		Effluent Quality	
NH_3-N	mg/L	0.06	0.08
NO_3-N	mg/L	0.47	0.46
TN	mg/L	1.96	1.91
COD	mg/L	22.7	22
CBOD	mg/L	3.1	2.9
pH		7.0	7.0

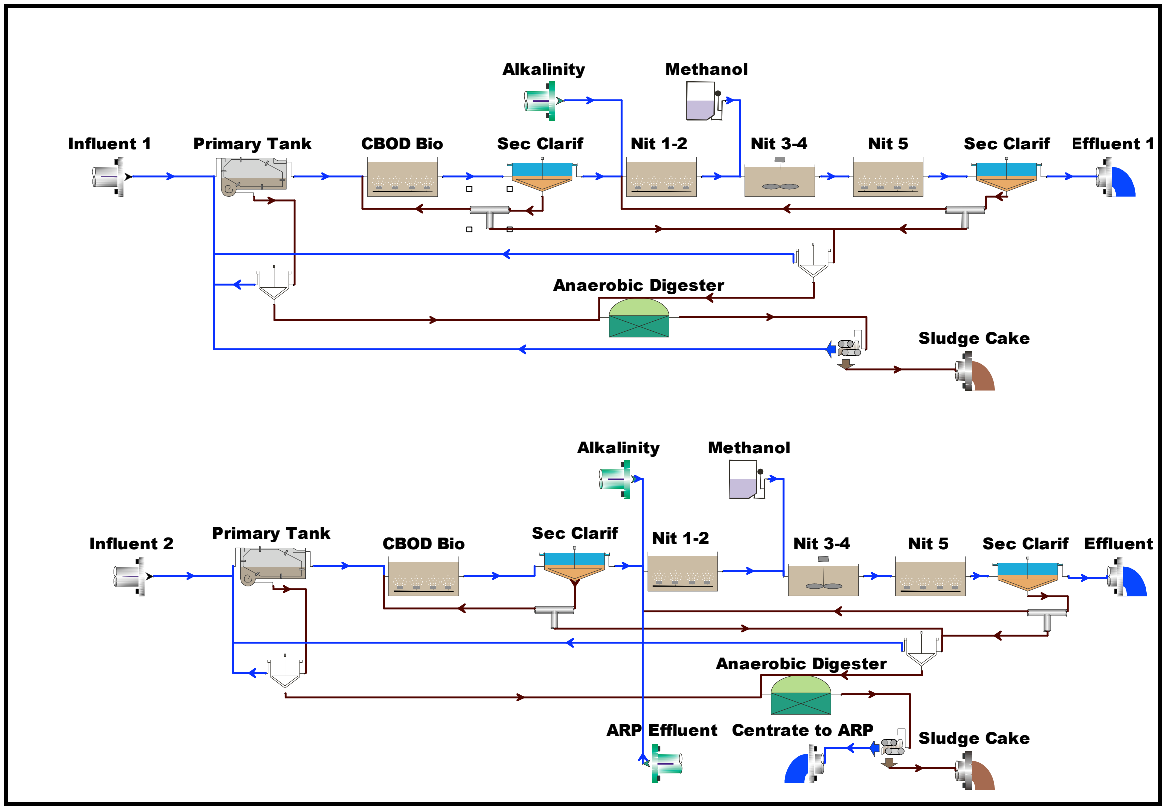

EXHIBIT 3: PARAMETERS FOR ARP IN BIOWIN SIMULATION

I/O for ARP for HydroQual model of ARP return to nitrifier

Assume quantities in mass units
output of 100 ppm NH3-N independent of centrate NH3-N
mass ratios of caustic and acid to NH3 reduction are constant
for each NH3 removed, one HCO3 is lost and one CO3 is gained

units of ammonia removed = (centrate [NH3-N] - 100 ppm)*centrate volume

Inputs	conc. %	g/gNH3-Nremoved
H2SO4	conc.	3.50
NaOH	50%	5.71

Output	conc. %	g/gNH3-Nremoved
(NH4)2SO4	40%	11.79
CaCO3 equ		3.57
COD	[input]	0

EXHIBIT 4: BIOWIN3.0 RESULTS

EXHIBIT 4.1: SINGLE SLUDGE BNR PROCESS

Flow: 100 MGD
Centrate TN: 795 mg/L at 0.41 MGD

		Base Case			
		w/o ARP	**w/ ARP**	**Reduction by ARP**	
N LOADS				**kg/d**	**%**
Influent	kg/d	9500	9500		
WAS GTO	kg/d	40	37		
Primary Sludge GTO	kg/d	54	42		
Centrate	kg/d	1417	156	1261	89%
TOTAL N LOAD	kg/d	11011	9735	1276	12%
N Load to BNR	**kg/d**	**9237**	**8328**		
Sludge Production					
Primary	kg/d	34466	34057	409	1%
WAS	kg/d	20451	19545	906	4%
Dewatered Cake	kg/d	30081	29228	853	3%
AS TKN	kg/d	1508	1431		
Alkalinity					
Alkalinity Feed Flow	m^3/d	250	215		
Feed Concentration	eq/L	10	10		
Delivered Alkalinity	eq/d	2,500,000	2,150,000	350,000	14%
Provided by ARP	eq/d	0	90,035		
TOTAL DELIVERED ALKALINITY	eq/d	2,500,000	2,240,035	259,965	10%
Methanol					
Methanol flow	L/d	12000	8500	3500	29%
Methanol COD	mg/L	1,190,000	1,190,000		
Methanol Load	kg/d	14280	10115	4165	29%

EXHIBIT 4.1: SINGLE SLUDGE BNR PROCESS (CONTINUED)

Oxygen					
Aerobic Tank Vol	m^3	85000	85000		
DOUR	mg/L-hr	30	28		
Oxygen Requirement	**kg/d**	**61200**	**57120**	4080	7%
SRT					
CBOD/BNR Stage	days	6.3	6.4		
Effluent Quality					
NH_3-N	mg/L	0.57	0.58		
NO_3-N	mg/L	2.9	3.05		
NO_2-N	mg/L	0.17	0.18		
TN	mg/L	6.3	6.3		
	kg/d	2360	2360		
COD	mg/L	27.6	27.4		
CBOD	mg/L	5.5	6.4		
pH	su	7.3	7.3		
Sludge					
GT WAS	%TS	2.2	2.1		
GT Prim	%TS	5.6	5.6		
Digester VSSd	%	53	53		
Digester VSSd	kg/d	23588	23179		
Digester gas at 35 C	m^3/d	19155	19170		
Methane content	%	72.5	70.6		
L gas prod/kg VSSd	L/kg	812	827		
L CH4/kg VSSd	L/kg	589	584		
Centrate TKN	mg/L	1990	747		
	kg/day	1417	1047		
NET Oxygen consumed in Nit/Denit	**kg/d**	**13139**	**11725**		
Oxygen used to produce CO2	**kg/d**	**48061**	**45395**		
CO2	**kg/d**	**66083**	**62418**		

EXHIBIT 4.2: TWO-SLUDGE BNR PROCESS

Flow: 100 MGD
Centrate TN: 969 mg/L at 0.49 MGD

		Base Case			
		w/o ARP	w/ ARP	Reduction by ARP	
N LOADS				**kg/d**	**%**
Influent	kg/d	9500	9500		
WAS GTO	kg/d	175	147		
Primary Sludge GTO	kg/d	85	80		
Centrate	kg/d	1777	184	1593	90%
TOTAL N LOAD	kg/d	11537	9911	1626	14%
N Load to BNR	**kg/d**	**10217**	**8439**		
Sludge Production					
Primary	kg/d	34282	33842	440	1%
WAS	kg/d	33251	31991	1260	4%
Dewatered Cake	kg/d	32498	31485	1013	3%
WAS TKN	kg/d	2537	2425		
Alkalinity					
Alkalinity Feed Flow	m^3/d	300	250		
Feed Concentration	eq/L	10	10		
Delivered Alkalinity	eq/d	3,000,000	2,500,000	500,000	17%
Provided by ARP	eq/d	0	113,740		
TOTAL DELIVERED ALKALINITY	eq/d	3,000,000	2,613,740	386,260	13%
Methanol					
Methanol flow	L/d	28500	23000	5500	19%
Methanol COD	mg/L	1,190,000	1,190,000		
Methanol Load	kg/d	33915	27370	6545	19%

EXHIBIT 4.2: TWO-SLUDGE BNR PROCESS (CONTINUED)

Oxygen					
Aerobic Tank Vol	m^3	85000	85000		
DOUR	mg/L-hr	31	28		
Oxygen Requirement	**kg/d**	**63240**	**57120**	6120	10%
SRT					
CBOD Removal Stage	days	1.4	1.4		
BNR Stage	days	11	11		
Effluent Quality					
NH_3-N	mg/L	0.09	0.1		
NO_3-N	mg/L	0.3	0.4		
NO_2-N	mg/L	0.02	0.03		
TN	mg/L	2.6	2.6		
COD	mg/L	21.1	20.2		
CBOD	mg/L	3.3	2.9		
pH		7.3	7.3		
Sludge					
GT WAS	%TS	2.3	2.3		
GT Prim	%TS	5.5	5.5		
Digester VSSd	%	59.1	59.5		
Digester VSSd	kg/d	33059	32451		
Digester gas at 35 C	m^3/d	26678	26378		
Methane content	%	71.5	71.5		
L gas prod/kg VSSd	L/kg	807	813		
L CH4/kg VSSd	L/kg	577	581		
Centrate TKN	mg/L	964	935		
	kg/day	1777	1721		
NET Oxygen consumed in Nit/Denit	**kg/d**	**13056**	**10224**		
Oxygen used to produce CO2	**kg/d**	**50184**	**46896**		
CO2	**kg/d**	**69003**	**64482**		

Appendix 2

Greenhouse Gas Emission Estimates

TABLE 1: CARBON DIOXIDE GENERATED BY ENERGY USE FOR BNR AERATION

Plant	**Alternative**	**Oxygen Demand**	**Electricity Used for Aeration**	**CO_2**	**CO_2 Reductions**
		kg/day	mgw-hr/year	ton/year	ton/year
Single Sludge	**BNR**	61200	2,065	**803**	
	BNR with ARP	57120	1,895	**737**	**66**
Two-Sludge	**BNR**	63240	2,124	**826**	
	BNR with ARP	57120	1,895	**737**	**89**

Notes:

1. The electric power required to aerate was estimated based on the type of blower used at the WWTP. Compressor selection by Jim Gasho, rep for Tuthill Compressors.

	Single sludge kWh/year	Two sludge kWh/year
w/o ARP	2065047	2123862
w/ ARP	1895138	1895138
Reduction	**169909**	**228724**

2. NY State average CO2 emission factor is **0.389** Metric tons/MWH

TABLE 2: CARBON DIOXIDE GENERATED BY ENERGY USE FOR METHANOL AND CAUSTIC PRODUCTION

Plant	**Alternative**	**Dry Caustic Required**	**Energy Required for Caustic Production**		**Methanol Required**		**Energy Required for Metanol Production**		**CO_2**	**CO_2 Reductions**
		ton/year	GJ/year	MWH	kg/year	ton/year	GJ/year	MWH	ton/year	ton/year
Single Sludge	**BNR**	36,500	932,453	2,590	3,473,340	3,473	131,987	367	**1,150**	
	BNR with ARP	32,704	835,478	2,321	2,460,283	2,460	93,491	260	**1,004**	**146**
Two-Sludge	**BNR**	43,800	1,118,944	3,108	8,249,183	8,249	313,469	871	**1,548**	
	BNR with ARP	33,726	861,587	2,393	6,657,235	6,657	252,975	703	**1,204**	**343**

Note:

1. Primary energy consumption is estimated at 47.9 GJ/tonne, crediting the energy content of hydrogen export at 3.35 GJ/ton chlorine.

For these calculations total energy use has been allocated to chlorine production
For one ton of chlorine produced 47.9 GJ energy which should be allocated between chlorine and caustic
For one ton of chlorine produced 1.1 tons of caustic are produced
energy allocated to caustic **25.5** GJ energy per ton of caustic Source: Energy Use and Energy Intensity of the US Chemical Industry, Berkley National Lab, 2000

2. Giga Joules to megawatt-hr conversion factor is **0.00278**
3. NY State average CO2 emission factor is **0.389** Metric tons/MWH
4. Primary energy consumption for methanol production is **38** GJ energy per ton of methanol (most being used in hydrogen production)

Source: Energy Use and Energy Intensity of the US Chemical Industry, Berkley National Lab, 2000

TABLE 3: CARBON DIOXIDE GENERATED BY PRODUCTION OF THE AMMONIA FERTILIZER

Plant	**Alternative**	**Ammonia Produced to Make a Fertilizer**	**CO_2**	**CO_2 Reductions**
		ton/year	ton/year	ton/year
Single Sludge	**BNR**	559	**704**	
	BNR with ARP	0	**0**	**704**
Two-Sludge	**BNR**	706	**890**	
	BNR with ARP	0	**0**	**890**

Note:

1. The CO_2 generated in the process of ammonia production is 1.26 tons per ton of ammonia -- USEPA AP-42.

TABLE 4: CARBON DIOXIDE GENERATED AS A RESULT OF BACTERIA RESPIRATION IN BNR

Plant	**Alternative**	**Total Nitrogen Reduction**	**Oxygen for Ammonia**	**Total Oxygen Required**	**Oxygen for Bacteria Respiration**	**Total CO_2 Produced**		**CO_2 Reduction**
		kg/day	kg/day	kg/day	kg/day	kg/day	t/year	t/year
Single Sludge	**BNR**	7,729	13,139	61,200	48,061	66,083	**24,120**	
	BNR with ARP	6,897	11,725	57,120	45,395	62,418	**22,783**	**1,338**
Two-Sludge	**BNR**	7,680	13,056	63,240	50,184	69,003	**25,186**	
	BNR with ARP	6,014	10,224	57,120	46,896	64,482	**23,536**	**1,650**

Notes:

1.Oxygen in the aerobic tank is consumed to oxidize ammonia. The remaining oxygen produces CO_2 by bacteria respiration.

2.The net amount of oxygen needed for ammonia nit/denit is 1.7 kg of oxygen for kg of nitrogen.

3. The amount of CO_2 produced by respiration is about one mol of CO_2 from one mol of O_2 -- i.e., $44gCO_2/32gO_2$.

TABLE 5: CARBON DIOXIDE GENERATED DURING TRUCK TRANSPORT TO THE WPCP

Plant	Alternative	Dry Caustic Required		Liquid Caustic	Methanol Required		Sulfuric Acid Required		Ammonium Sulfate Produced		Tankers for Ammonium Sulfate	Tankers for Caustic
		g/day	ton/year	gal/year	l/day	gal/year	kg/day	gal/year	kg/day	gal/year	per year	per year
Single Sludge	BNR	100,000,000	36,500	34,649	12,000	1,157,196	0	0	0	0	0	12
	BNR with ARP	89,600,000	32,704	31,046	8,500	819,681	4,414	232,572	14,862	1,165,176	129	10
Two-Sludge	BNR	120,000,000	43,800	41,579	28,500	2,748,341	0	0	0	0	0	14
	BNR with ARP	92,400,000	33,726	32,016	23,000	2,217,959	5,576	293,804	18,775	1,471,947	164	11

Notes:
1. It was assumed that each tanker is 9,000 gallons for transporting methane, sulfuric acid and ammonia sulfate and 3,000 gallons for transporting caustic.
2. Each round trip was assumed to be 500 miles -- the suppliers are in the general vicinity.
3. Caustic amount was converted to gallons based on the caustic density of 1.525 kg/liter at 20°C. The liter to gallon conversion is $2.642X10^{-1}$.
4. Sulfuric Acid amount was converted to gallons based on its density of 1.83 kg/liter at 20°C.
5. Energy Intensity for trucks obtained from Energy Information Administration's Transportation Energy Data Book, Edition 26, 2007, Table 2.16 20539 Btus/vehicle Mile
6. Emission Coefficients - Energy Information Administration, Voluntary Reporting of Greenhouse Gases Program, fuel and energy sources codes and emission coeffecients. 161.386 Lbs CO_2 per mBtus
7. Ammonia sulfate produced is a 40% solution in water. Its density is 1.23 kg/liter at 20°C.
8. Ammonia sulfate solution is delivered to the fertilizer plant at a 500 mile round trip.
9. Sludge truck assumed to hold 10 metric tons (approximately 25,000 lb) of sludge.
10. Sludge was conservatively assumed to be sent to a 1000 mile distance (2000 mile round trip).
11. Ammonia sulfate produced in the ARP:

Single Sludge BNR Process

calculation of ammonia and product in kg/d

	w/o ARP	w/ ARP	recovered by ARP
Centrate N	1417	156	1261
ammonia	0		1531
ammonium sulfate	0		5945
as 40% solution	0		**14862**

Two-Sludge BNR Process

calculation of ammonia and product in kg/d

	w/o ARP	w/ ARP	recovered by ARP
Centrate N	1777	184	1593
ammonia			1934
ammonium sulfate			7510
as 40% solution			**18775**

TABLE 5: (CONTINUED) CARBON DIOXIDE GENERATED DURING TRUCK TRANSPORT FROM THE WPCP

Plant	Tankers for Methanol	Tankers for Sulfuric Acid	Tanker VMT	Sludge Produced		Trucks for Sludge	Truck VMT	Total mBtus	CO_2 Emissions		CO_2 Reductions
	per year	per year	per year	kg/day	ton/year	per year	per year	per year	lb/year	tons/year	tons/year
Single Sludge	129	0	70,064	1,417	517	52	103,441	3564	575,117	**261**	
	91	26	128,365	1,047	382	38	76,431	4206	678,838	**308**	**-47**
Two-Sludge	305	0	159,615	1,777	649	65	129,721	5943	959,065	**435**	
	246	33	226,653	1,721	628	63	125,633	7236	1,167,726	**530**	**-95**

Notes:

1. It was assumed that each tanker is 9,000 gallons for transporting methane, sulfuric acid and ammonia sulfate and 3,000 gallons for transporting caustic.
2. Each round trip was assumed to be 500 miles -- the suppliers are in the general vicinity.
3. Caustic amount was converted to gallons based on the caustic density of 1.525 kg/liter at 20°C. The liter to gallon conversion is $2.642X10^{-1}$.
4. Sulfuric Acid amount was converted to gallons based on its density of 1.83 kg/liter at 20°C.
5. Energy Intensity for trucks obtained from Energy Information Administration's Transportation Energy Data Book, Edition 26, 2007, Table 2.16 — 20539 Btus/vehicle Mile
6. Emission Coefficients - Energy Information Administration, Voluntary Reporting of Greenhouse Gases Program, fuel and energy sources codes and emission coeffecients. — 161.386 Lbs CO_2 per mBtus
7. Ammonia sulfate produced is a 40% solution in water. Its density is 1.23 kg/liter at 20°C.
8. Ammonia sulfate solution is delivered to the fertilizer plant at a 500 mile round trip.
9. Sludge truck assumed to hold 10 metric tons (approximately 25,000 lb) of sludge.
10. Sludge was conservatively assumed to be sent to a 1000 mile distance (2000 mile round trip).
11. Ammonia sulfate produced in the ARP:

Single Sludge BNR Process

calculation of ammonia and product in kg/d

	w/o ARP	w/ ARP	recovered by ARP
Centrate N	1417	156	1261
ammonia	0		1531
ammonium sulfate	0		5945
as 40% solution	0		**14862**

Two-Sludge BNR Process

calculation of ammonia and product in kg/d

	w/o ARP	w/ ARP	recovered by ARP
Centrate N	1777	184	1593
ammonia			1934
ammonium sulfate			7510
as 40% solution			**18775**

TABLE 6: CARBON DIOXIDE FROM ANAEROBIC DIGESTION AND COMBUSTION OF METHANE

Plant	**Alternative**	**Methane**	**CO_2 from Combustion**	**CO_2 from Digester**			**CO_2**	**CO_2 Reductions**
		ton/year	ton/year	m^3/day		ton/year	ton/year	ton/year
				at 35°C	at 25°C			
Single Sludge	**BNR**	3,216	8,844	5,268	5,095	3,355	**12,199**	
	BNR with ARP	3,134	8,619	5,636	5,451	3,589	**12,209**	**225**
Two-Sludge	**BNR**	4,418	12,148	7,603	7,354	4,842	**16,990**	
	BNR with ARP	4,368	12,012	7,518	7,271	4,788	**16,799**	**137**

Notes:

1. The amount of CO_2 produced is stoichiometric, one mol of CO_2 from one mol of CH_4 -- i.e., 44g CO_2/16g CH_4)
2. CO_2 density is 1.804 kg/m^3 at 25°C.
3. CO_2 digester refers to direct emissions from the anaerobic digester as part of the digester gas.
4. The digester gas is computed at 35°C while density at STP is given at 25°C.

TABLE 7: TOTAL METHANE GENERATED AT THE WPCP

Plant	**Alternative**	**Anaerobic Digester Methane**			**Methanol Required**		**CH_4 from Methanol Production**	**Tanker and Truck VMT**	**Truck Methane**	**Total CH_4**	**Total CH_4 Reductions**
		m^3/day		ton/year	l/day	kg/year	ton/year	per year	ton/year	tons/year	tons/year
		at 35°C	at 25°C								
Single Sludge	**BNR**	13,887	13,432	**3,216**	12,000	3,473,340	6.9	173,505	0.00088	**6.94756**	
	BNR with ARP	13,534	13,090	**3,134**	8,500	2,460,283	4.9	204,796	0.00104	**4.92161**	**84**
Two-Sludge	**BNR**	19,075	18,449	**4,418**	28,500	8,249,183	16.5	289,336	0.0015	**16.4998**	
	BNR with ARP	18,860	18,242	**4,368**	23,000	6,657,235	13.3	352,286	0.0018	**13.3163**	**53**

Notes:

1. Methane generated in the anaerobic digester was as follows:

			w/o ARP	w/ARP
Single Sludge	Digester gas	m^3/day	19155	19170
	Methane content	%	72.5	70.6
Two Sludge	Digester gas	m^3/day	26678	26378
	Methane content	%	71.5	71.5

2. Methane density is 0.656 kg/m^3 at 25°C.
3. The digester gas is at 35°C while STP density is given at 25°C.
4. Methane generated in the digester is assumed to be fully combusted and its GHG contribution is accounted for in combustion tab.
5. Methane generated by heavy-duty diesel truck is 0.0051 g/mile (US GHG Inventory, 2005)
6. In the absence of an authoritative estimate, the methane emissions from the anoxic zone of the BNR was not included.
   The reduction would be a small difference between relatively small numbers and is not likely to be material.
7. Methane is also generated in the methanol production at the rate of 2g/kg (Energy Information Administration , Voluntary Reporting of Greenhouse Gases Program).
8. Methanol density is 0.793 kg/liter.

TABLE 8: TOTAL NITROUS OXIDE GENERATED AT THE WPCP

Plant	Alternative	Total Nitrogen Load	BNR Nitrous Oxide		Tanker Truck VMT	Nitrous Oxide	Total Nitrous Oxide	Total N_2O Reductions
		kg/day	kg/day	ton/year	per year	ton/year	ton/year	tons/year
Single Sludge	BNR	9237	92	34	173,505	0.00521	**34**	
	BNR with ARP	8328	83	30	204,796	0.00614	**30**	**3**
Two-Sludge	BNR	10217	102	37	289,336	0.0087	**37**	
	BNR with ARP	8439	84	31	352,286	0.0106	**31**	**6**

Notes:

1. Nitrous Oxide generated by heavy-duty diesel truck is 0.03 g/mile (US GHG Inventory, 2005).
2. BNR N_2O emission factor is 44/28*0.005 kg N_2O-N per kg sewage-N produced (2006 IPCC National Inventories Guidelines) or 0.01 kg N_2O/kg sewage-N as given by (DOE, 2007).