CITY OF RALEIGH

Biosolids Management Master Plan Update

June 2013

CDM Smith

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June 27, 2013

Aaron Brower, City of Raleigh
1 Exchange Plaza, Suite 520
219 Fayetteville St.
Raleigh, NC 27601

Subject: Biosolids Management Master Plan Update

Dear Aaron:

Enclosed please find eight copies of the City of Raleigh Biosolids Management Master Plan Update Report. A CD with a .pdf of the report is also included. This final report incorporates feedback received from the entire Biosolids project team on the draft master plan. We appreciate this opportunity to work with you and look forward to continuing to assist the City in the implementation of the recommended plan.

Meanwhile, please contact me if you have any questions.

Sincerely,

K. Richard Tsang

K. Richard Tsang, P.E., Ph.D., BCEE
Senior Vice President
CDM Smith Inc.

City of Raleigh
Biosolids Management Master Plan Update
Final Report

June 2013

CDM Smith Project No. 6679-91380

NORTH CAROLINA PROFESSIONAL SEAL 18581 ENGINEER K. RICHARD TSANG

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Executive Summary

Background

Since 2006, the City of Raleigh Public Utilities Department (CORPUD) has maintained an Environmental Management System (EMS) for biosolids management at the Neuse River Wastewater Treatment Plant (NRWWTP). This program demonstrates the City's commitment to continual improvement, operational excellence, and environmental protection.

Currently, biosolids at NRWWTP are processed via a combination of aerobic digestion/land application, alkaline stabilization (e.g. "Raleigh Plus"), and off-site composting. To support the goal of continual improvement, CORPUD conducted a biosolids management master plan in 2008. This study recommended that the City implement anaerobic digestion with thermal drying. Anaerobic digestion provides a sustainable source of energy in the form of biogas, which can be used on site. Thermal drying further diversifies the potential outlets for biosolids.

Due to economic conditions, the recommendations have not been fully implemented. The purpose of the present study is to update the recommendations from the 2008 Master Plan to reflect the latest biosolids management technologies and current economic realities. In addition, the scope of the Master Plan was expanded to include consideration of CORPUD's E.M. Johnson Water Treatment Plant (WTP), and D.E. Benton WTP.

This study updates the 2008 master plan in the following ways:

- Revises projected waste loading and biosolids production
- Revisits proposed improvements and considers additional biosolids management strategies including thermal hydrolysis, co-digestion of organic waste, composting, commercial fertilizer production, and hybrid solar-thermal drying
- Manages implementation cost by leveraging new technologies and proposing alternative design for less-costly anaerobic digesters
- Studies solar drying and combined heat and power generation to enhance project sustainability
- Quantifies estimated greenhouse gas emission reductions
- Identifies costs, advantages, and disadvantages of continuing current operations through 2035

Biosolids and Residuals Production

The most recent wastewater flow projections available are contained in the 2008 Biosolids Management Master Plan (2008 MP), which estimated influent flows for year 2010 through 2025 based on projected flows from the Neuse River Wastewater Treatment Plant Environmental Assessment. The available projected flows were compared against historical treated effluent from NRWWTP for 2007-2011, as shown in **Figure ES-1**. Historical flows have remained relatively stable at 42 mgd in recent years, due to the drought in 2007 as well as effective water conservation practices implemented by CORPUD. Influent flow is considerably lower than projections for this period.

In order to estimate sludge production, the 2008 flow projections were shifted forward in time by 6 years to intersect historical flows, while maintaining the same growth pattern. These shifted projections are indicated by the dashed line in Figure2-1. For example, the projected flow from the 2008 MP in 2025 was 77.8 mgd. With the shifted projections, the projected flow is approximately 69.5 mgd in 2025, while 77.8 mgd occurs 6 years later, in 2031.

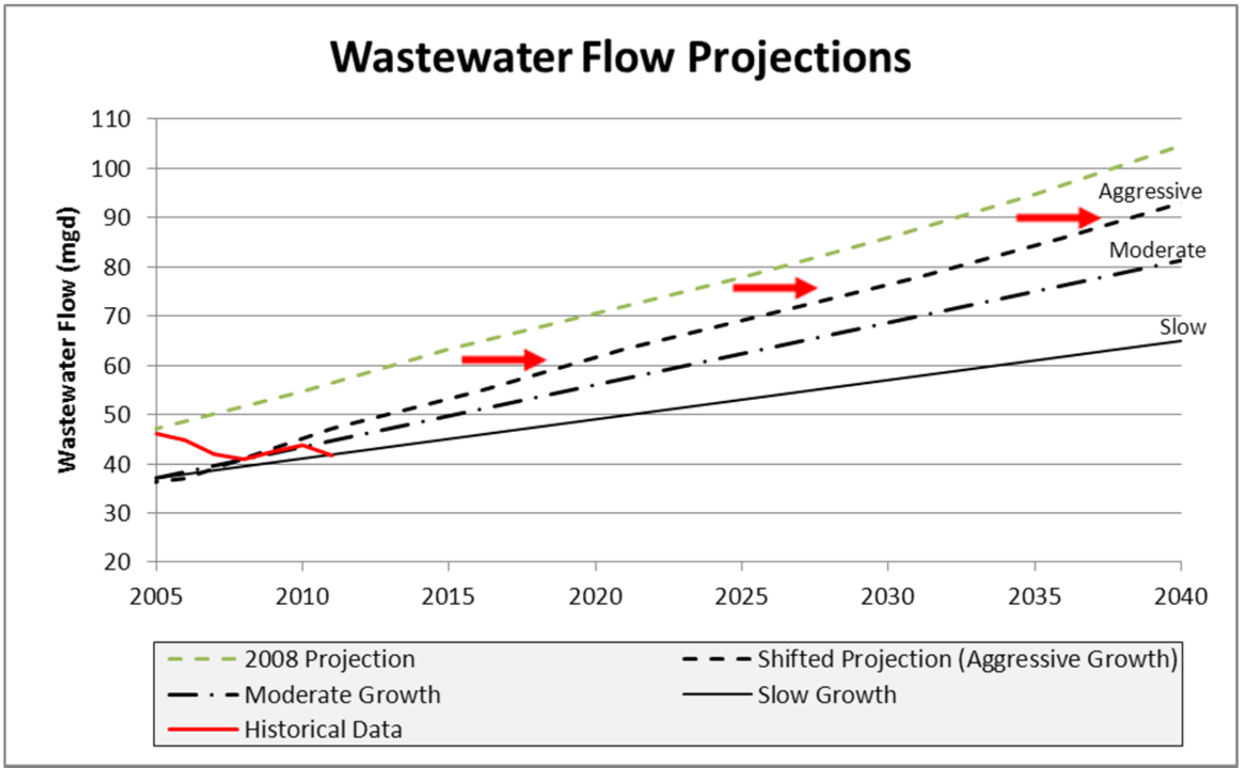

Figure ES-1 Comparison of historical and projected wastewater flows at NRWWTP

Given recent trends, the shifted projections are considered to represent aggressive assumptions about growth. The slope of this projection was adjusted based on historical flow data to create two additional scenarios representing “moderate” and “slow” growth. These are also shown on the figure. Under moderate and slow growth scenarios, wastewater flow in 2035 is projected to be 75 mgd or 61 mgd, respectively.

Operations data from 2009-2011 were used to estimate the annual average sludge production at Neuse River WWTP. **Table ES-1** summarizes the estimated sludge production during the last three years. Also shown is the sludge production rate (lb/MG), which is simply sludge production, normalized by the annual average wastewater flow. These rates are the basis for projecting future sludge quantities.

Table ES-1 Historical Sludge Production, 2009-2011

Process	Sludge Produced, dry lb/day			Sludge Production Rate, dry lb/MG		
	Average	30-day Max	14-day Max	Average	30-day Max	14-day Max
Co-settled Sludge (to dewatering)	67,816	81,319	86,850	1,590	1,907	2,036
Waste Activated Sludge (to digesters)	11,165	13,388	14,298	262	314	335
TOTAL	**78,981**	**94,707**	**101,149**	**1,852**	**2,221**	**2,372**
Peaking Factor	1.00	1.20	1.28	1.00	1.20	1.28

The sludge production rates developed above were combined with the projected wastewater flows to estimate the total quantity of sludge that must be processed in the future. These projections are illustrated in **Figure ES-2.** For comparison, the estimated sludge production using production rates and flow projections from the 2008 Master Plan are also shown. Note that only annual average sludge production is shown. Peaking factors listed in Table 2-3 can be used to estimate 30- and 14-day peaks. For this master plan update, we recommend using the moderate growth scenario and year 2035 as the basis for sizing improvements. Under this growth scenario, the NRWWTP will reach 75 mgd in 2035, at which time it will produce an average of 139,000 dry lb/day (69.5 dry tons/d) of sludge.

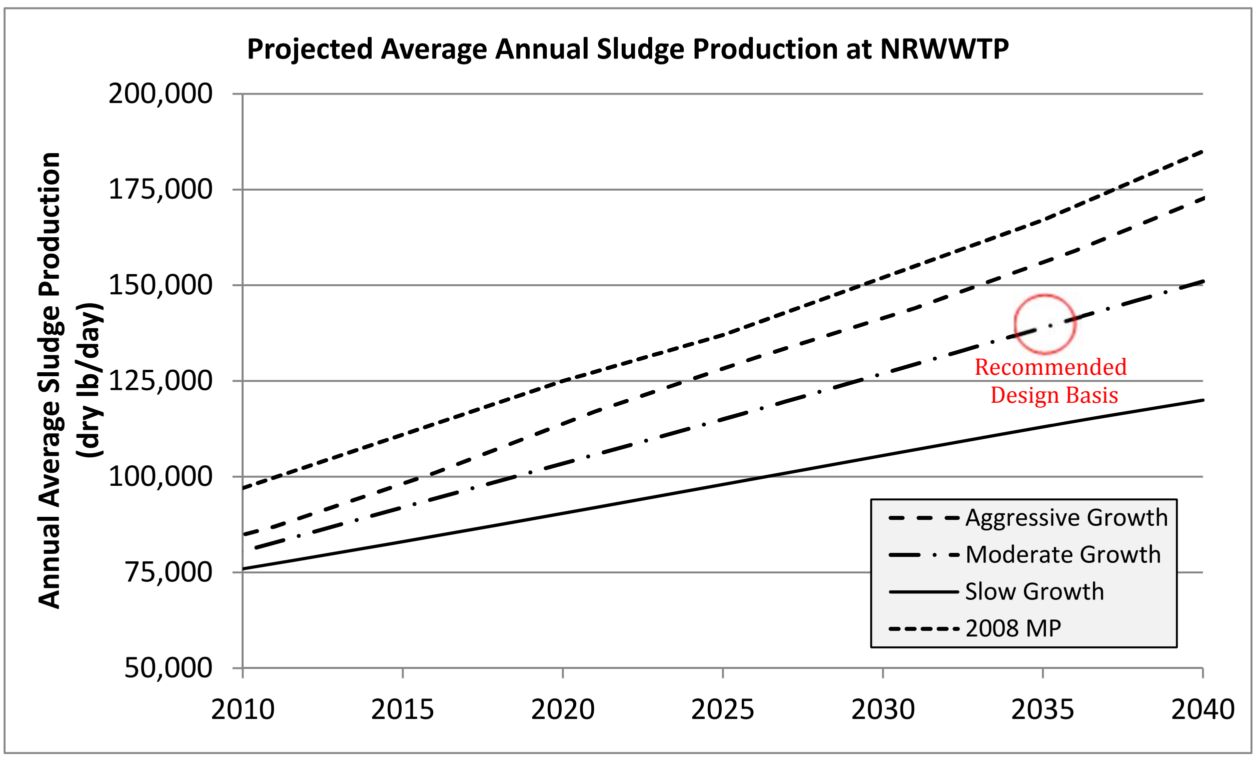

Figure ES-2 Projected average annual sludge production at NRWWTP

In addition to sludge production, future quantities of water treatment plant residuals were also estimated, in order to provide a holistic view of CORPUD's solids management needs. In 2040, disposal requirements will reach between 16 and 21 dry tons per day. These projections are discussed further in Section 2.

Technologies

Table ES-2 lists the biosolids processing technologies considered in the development of management alternatives. Technologies with an asterisk were not a part of the 2008 MP. All technologies were screened for compatibility with CORPUD's objectives and process needs. Technologies in bold were evaluated in detail as part of the alternatives discussed below.

Table ES-2 Biosolids Processing Technologies Considered

Treatment Stage	Process
Thickening	▪ Gravity Belt Thickening ▪ Rotary Drum Thickening*
Stabilization	▪ Anaerobic Digestion ▪ Alkaline Stabilization ▪ Thermal Hydrolysis ▪ Co-digestion of organic waste ▪ Co-composting with yard waste*
Dewatering	▪ Belt Filter Press ▪ Centrifuge
Drying and Thermal Processing	▪ Solar Dryer* ▪ Solar pre-Dryer / Thermal Dryer* ▪ Thermal Dryer ▪ Incineration ▪ Pyrolysis* ▪ Gasification* ▪ Commercial Fertilizer Production*
Disposal	▪ Product Marketing ▪ Land Application ▪ Third-party Composting ▪ Landfill Disposal
Nutrient Management	▪ Phosphorous recovery*

Evaluation Criteria

Each biosolids management alternative was evaluated based on capital cost, operating cost, greenhouse gas emission reduction, and non-cost factors.

Capital Cost

The conceptual opinion of probable construction cost was developed to compare alternatives relative to one another. In addition to direct construction costs (equipment, labor, and materials), capital cost estimates include a number of indirect costs, which follow the framework described in the 2008 Master Plan and are described in Section 4. The final cost of any project described in this report will depend on project complexity, actual labor and material costs, competitive market conditions, actual site conditions, final scope of work, implementation schedule, and engineering. The cost of buffer zones to reduce visual, odor, traffic and noise impacts was not included in this analysis.

Operations and Maintenance Cost

In addition to capital costs, total project life-cycle costs are influenced by the ongoing operations and maintenance (O&M) costs associated with the selected treatment technologies. O&M unit costs ($/dry ton) for each residuals unit process were developed based on the mass of material entering the specific unit process and on current operating costs for power, labor, and chemicals. For equipment not currently installed at NRWWTP, information provided by manufacturers and observed at similar facilities was also utilized for this analysis. These unit process costs were combined to develop overall management strategy operations and maintenance unit costs (e.g., $/dry ton raw material) for each management option.

Economic assumptions from the Falls Lake Dam Hydroelectric Project Pre-Feasibility Study (2011), including escalation (3.0%), bond issue rate (4.7%), and discount rate (4.7%) were used to develop net present worth O&M costs. Construction of the proposed facilities was assumed to be completed by 2016, which would be the first year of operation. Life cycle operating costs were developed for each of the management strategies from 2016 through 2035. For analysis of the combined heat and power system, discussed in Section 6, avoided-cost electricity prices were escalated separately using the base scenario from the schedule of projected prices presented in the above report. This schedule is provided in **Appendix B**.

Sensitivity Analysis

A sensitivity analysis was performed for the lifecycle O&M costs in which the price of electricity was increased and decreased by 20%. The impact of this change on present worth O&M costs was negligible, however, at approximately 3%. Biosolids O&M costs are driven much more strongly by labor and chemical expenses than energy prices.

Estimated Greenhouse Gas Emissions

The lifecycle greenhouse gas (GHG) emissions associated with each management alternative were estimated using nominal assumptions about the treatment processes and disposal outlets involved. GHG emissions are reported in metric tons of CO2 equivalents (CO2e). A typical passenger vehicle will generate approximately 5 metric tons CO2e of emissions during the course of a year.

Non-Cost Factors

A series of non-cost performance criteria was developed in concert with CORPUD staff. The relative priority of each criteria was estimated by surveying a cross-section of CORPUD staff, including management, operations, maintenance, and other functional roles within the organization. **Table ES-3** lists the non-cost criteria. As shown, regulatory requirements, public health and environmental impacts, and outlet diversification received the highest priority.

CDM Smith, in collaboration with CORPUD, used this information to develop a score representing the extent to which each alternative met the organization's objectives. The methodology is discussed in Section 4, and scores for each alternative are presented below.

Table ES-3 Non-Cost Evaluation Criteria

Highest Priority	Medium Priority	Lower Priority
▪ Regulatory Requirements ▪ Public Health and Environmental Impacts ▪ Outlet Diversification	▪ Reliability ▪ Operator Friendliness ▪ Ease of Maintenance	▪ Constructability ▪ Flexibility/Adaptability ▪ Side Stream Impacts ▪ Public Acceptance ▪ Sustainability

Biosolids Management Alternatives

Three biosolids management alternatives were developed and evaluated in detail.

- **Alternative 1** represents a continuation of the existing management strategy. Provisions are made to refurbish the existing aerobic digesters, belt filter presses, conveyance systems, and truck loading station when they reach the end of their design lives.
- **Alternative 2** implements conventional anaerobic digestion and solar dryers. It includes a new gravity belt thickening building, three 2.75 MG anaerobic digesters, a biogas storage facility, dewatering (either in the existing, refurbished building or a new facility), and 19 solar dryers. Solar drying capacity is sufficient to replace alkaline stabilization.
- **Alternative 3** adds thermal hydrolysis (THP) to the conventional anaerobic digestion process, increasing biogas yield and volatile solids reduction while decreasing required digester volume. It includes a pre-screening building, pre-dewatering building, THP equipment, two 1.6 MG digesters, final dewatering (either in the existing, refurbished building or a new facility), and 8 solar dryers.

Table ES-4 summarizes the capital cost, O&M cost, non-cost rating, and greenhouse gas impact of the alternatives discussed above. As expected, Alternative 1 (the base case) has a significantly lower capital cost than either Alternative 2 or Alternative 3. However, O&M costs are considerably higher, such that the 20-year lifecycle cost of continuing the current management strategy is comparable to that of implementing anaerobic digestion. Alternative 3, which includes thermal hydrolysis, has the lowest lifecycle cost, which is a result of savings in both capital and operating costs. Under this alternative the digesters and solar dryers are both smaller than in Alternative 2. Although thermal hydrolysis plus anaerobic digestion are more costly to operate, per unit of solids, than conventional anaerobic digestion (see Section 4), the volume of solids requiring dewatering and disposal is significantly reduced. This fact results in substantial cost savings in overall operating and disposal costs.

Both Alternative 2 and 3 come significantly closer to achieving CORPUD's performance goals than Alternative 1, as evidenced by the non-cost performance ratings. In addition, Alternative 2 offers a significantly greater GHG offset than the base case (a fourfold increase), while Alternative 3 offers an even larger offset (twelve times greater than the base case).

Table ES-4 Comparison of Biosolids Management Alternative Performance

Evaluation Factor	Alternative 1	Alternative 2	Alternative 3
Capital Cost	$28.3 M	$97.5 M	$81.2 M
NPV O&M Cost for Treatment	$8.9 M	$7.5 M	$12.3 M
NPV O&M Cost for Dewatering	$10.9 M	$13.9 M	$6.7 M
NPV O&M Cost for End Use	$62.3	$12.7 M	$8.6 M
Total Lifecycle Cost	**$110.4 M**	**$131.6 M**	**$108.8 M**
NPV O&M Cost per DT Biosolids Disposed	$237	$144	$140
Non-Cost Rating (%)	53%	83%	82%
GHG Emissions Offset (metric tons CO_2e/yr)	1,000	5,000	14,000

Combined Heat and Power Generation

Use of a Combined Heat and Power (CHP) system in conjunction with Alternatives 2 or 3 would harness the biogas produced from anaerobic digestion to produce both heat and electricity. This electricity can be used in several ways, including net metering, parallel generation, or sale to the utility, to maximize the economic value of the system. Electricity produced by renewable sources also generates Renewable Energy Credits (RECs), which are issued by a third party who verifies that power is being produced by renewable means. These credits can be purchased by electric utilities or other organizations. All electricity produced by a CHP system using biogas would qualify to produce RECs.

Several types of CHP equipment were evaluated, including internal combustion engines, gas turbines, microturbines, fuel cells, and steam turbines. Internal combustion engines are recommended due to their high efficiency and lower capital cost.

The estimated capital costs of an internal-combustion CHP system, in present-value 2012 dollars, is estimated to be $7.9 million for Alternative 2 and $7.8 million for Alternative 3. This cost includes the engine generators, biogas pre-treatment systems, a concrete slab, hot water and digester gas piping, and electrical work required to make the interconnection with the utility grid. However, it does not include the cost to provide natural gas service to NRWWTP. Natural gas may be needed to supplement the digester boilers if all biogas is used to generate power. **Table ES-5** summarizes the results of a lifecycle cost analysis, which was performed by calculating net revenue as follows:

Net Revenue = Revenue from Electricity + Revenue from RECs – Supplemental Natural Gas Cost – Maintenance Cost

Based on projected biogas production, it appears that a CHP system is economically favorable for Alternative 3, with payback periods of 12 to 13 years. For Alternative 2, the payback period appears to be slightly longer than 20 years. However, it is important to note that several factors such as energy cost, REC value, and the cost of supplemental natural gas may deviate significantly from projections, increasing or decreasing the projected payback period.

Table ES-5 Lifecycle Cost of CHP Engines

Alternative		Biogas Available	Engine Size	Sale Type	Capital Cost[1]	Net Revenue[2]	Total NPV Revenue	GHG Offset[3]	Payback Period
2	Anaerobic Digestion	13-19 MMBTU/hr	1 @ 1,029 kW	Net Metering	$ 6.4M	$ 5.3M	-$1.1 M	98,700	>20
			2 @ 1,029 kW	Parallel Generation	$ 7.9M	$ 6.3M	-$1.6 M	140,000	>20
			2 @ 1,029 kW	Sale to Utility	$ 7.9M	$ 6.6M	-$1.3 M	140,000	>20
3	Thermal Hydrolysis	16-24 MMBTU/hr	1 @ 1,750 kW	Parallel Generation	$ 7.8M	$ 11.8M	$4.0 M	173,000	12 yrs
			1 @ 1,750 kW	Sale to Utility	$ 7.8M	$ 11.1M	$3.3 M	173,000	13 yrs

1 Present value capital cost. Engines are installed in two phases, beginning in 2016. All costs are reported in 2012 dollars.

2 20-year net present value, beginning in 2016. Includes revenue (or avoided cost) from the sale of electricity and Renewable Energy Credits, less O&M costs. RECs from power are assumed to be sold at $5/MWh. Natural gas cost = $8.00/MMBTU. Cost does not consider tax credits or the sale of thermal RECs. Electricity prices for Net Metering and Parallel Generation are inflated according to the schedule prepared for the Falls Lake Hydropower Study, available in Appendix B. Projected electricity prices included consideration of the impact of the Duke – Progress Energy merger.

3 Metric tons of CO_2 equivalent emissions avoided from electricity generation over the lifecycle of the engine

Recommended Capital Improvement Plan

Alternative 3 (thermal hydrolysis plus solar drying) is the recommended management strategy for CORPUD, due to its low life cycle cost, high non-cost score, and alignment with CORPUD's stated priorities (noted above).

Anaerobic digestion coupled with THP will provide a high degree of operational flexibility. Increased volatile solids destruction will reduce the quantity of solids that must be dewatered and transported to end use. The high temperatures involved in THP will facilitate the production of Class A biosolids, improving outlet diversification. Solar dryers will provide another potential pathway to Class A biosolids (with or without THP pre-treatment) that supports public health and regulatory compliance while promoting sustainability. Testing would be required to determine whether the degree of pathogen reduction achieved in the solar dryers meets the threshold for Class A product without thermal hydrolysis.

Refer to **Figure 5-5** for a process schematic and mass balance of this option. The proposed layout of the facilities is shown on **Figure 5-6. Table ES-6** provides a summary of the capital costs associated with each of the facilities included in Alternative 3, as well as the cost of a CHP engine generator and additional dewatered cake storage, which is recommended to facilitate the transition to the new processes (see discussion below).

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Table ES-6 Summary of Capital Costs for Recommended Alternative, CHP engine, and Cake Storage

Facility	Equipment Cost	Labor & Materials Cost	Total Cost[1]
Pre-Screening Building	$0.6 M	$1.1 M	$1.7 M
Pre-Dewatering Building	$3.8 M	$3.1 M	$6.9 M
Thermal Hydrolysis Process	$7.3 M	$1.6 M	$8.9 M
Anaerobic Digesters	$3.5 M	$7.2 M	$10.7 M
Replace Existing Belt Filter Presses	$1.6 M	$1.4 M	$3.0 M
Replace Conveyance Equipment (2028)	$0.8 M	$0.3 M	$1.1 M
Replace Truck Loading Station (2028)	$0.9 M	$0.3 M	$1.2 M
Solar Dryers	$7.5 M	$5.2 M	$12.7 M
Subtotal Alternative 3 Process Facilities	**$26.0 M**	**$20.2 M**	**$46.2 M**
Cake Storage Improvements	-	$0.8 M	$0.8 M
Combined Heat and Power Engine[2]	$3.2 M	$1.5 M	$4.7 M
Subtotal Direct Construction Cost	**$29.2 M**	**$22.5 M**	**$51.7 M**
Subtotal Direct Construction Cost + Contractor OH&P			**$66.3 M**
Total Capital Cost (w/Contingency, Admin, Engineering)[3]			**$90.9 M**

[1] All capital costs are reported in December 2012 dollars (ENR CCI = 9412.25), with the exception of Conveyance and Truck Loading replacement, which are assumed installed in 2028, at the end of the current facility design life. These costs are escalated assuming annual inflation of 4.5% for capital costs and a 4.7% nominal discount rate.

[2] Capital cost may be significantly reduced or eliminated if third-party financing is used.

[3] Includes markups for taxes, permits, bonds, insurance, contractor's general conditions, overhead and profit, engineering services during design and construction, administrative costs, and contingency. A detailed description of these markups is provided in Section 4.

Phased Implementation Schedule

Phased implementation of these facilities is recommended as a means of rendering the large capital cost more compatible with the City's budget. Per discussion with CORPUD at Workshop No. 4, implementation was broken into phases with the goal of limiting capital outlays to approximately $40 million every five years. Three implementation options are presented below for consideration. For planning purposes, Phase 1 was assumed to occur in 2016, and Phase 2, five years later in 2021.

All options include a third phase of repair and replacement, which is included for planning purposes in 2028, when the existing truck loading station and biosolids conveyance equipment may be nearing the end of their design life. While it is possible that much of this equipment will still be in serviceable condition at that time, the cost for complete replacement of these facilities is included below for planning purposes.

Implementation Option 1: THP and Anaerobic Digestion in Phase 1

This implementation option brings the anaerobic digestion and THP processes online as soon as possible, with the majority of the proposed facilities constructed in Phase 1. Only the solar dryers and belt filter press replacement are delayed until Phase 2.

Implementing this option will allow production of Class A dewatered biosolids through thermal hydrolysis and anaerobic digestion. The main outlet of this product will still be agricultural land so additional covered cake storage is recommended. This implementation option includes a cost for covering the remainder of the existing storage area to provide additional flexibility in the event that wet weather interferes with land application.

This option has the advantage of enabling NRWWTP to convert the entire treatment process over to anaerobic digestion in a single phase, providing savings in operating costs because parallel treatment trains (e.g., aerobic digestion) do not need to remain online. This option also allows the City to begin producing energy from biogas as soon as possible.

Implementation Option 2: Solar Dryers in Phase 1

A second option is to construct all eight of the solar drying modules in Phase 1, along with the proposed pre-screening and pre-dewatering facilities. Construction of the dewatered cake bins would be deferred until Phase II, allowing the lower level of the pre-dewatering building to be configured for truck loading. These facilities would be used in conjunction with the existing treatment processes until Phase II. To ensure continued reliable operation, replacement of the existing belt filter presses would also occur during Phase 1.

The new dewatering facilities and solar dryers would be able to dry a portion of the biosolids from the current process, and allow CORPUD to immediately improve on the diversity of biosolids products while adding an alternate means of producing Class A biosolids. When all phases are complete, the eight solar dryers will have sufficient capacity to replace the existing alkaline stabilization process, provided that biosolids continue to be sent to composting at the contracted rate. Before anaerobic digestion comes online, the solar dryers can be used to reduce the solids loading to alkaline stabilization, but they will not have the capacity to replace it entirely.

The second phase will consist of the thermal hydrolysis process, both anaerobic digesters, and the combined heat and power (CHP) engine generator. In addition, the pre-dewatering building will be reconfigured to feed the THP process by adding dewatered cake bins and pumps. This phase will include construction of a pipeline to convey digested sludge back to the existing biosolids day tanks, allowing the existing final dewatering facilities to remain in service. The disadvantage of this option is the potential odor risk of solar drying raw sludge and the quality of the final dried product. Dried product from undigested sludge has known to produce odor when rewetted.

Implementation Option 3: Anaerobic Digestion and Solar Drying

In this option, the solar dryers and anaerobic digesters are constructed in Phase 1, separately from the THP process. However, without the benefits achieved by thermal hydrolysis, the digesters could only be used to treat a portion of the NRWWTP biosolids (even in 2016). As such, some of the existing treatment systems would need to remain online.

Phase II would include construction of the THP process, pre-screening and pre-dewatering facilities, and final dewatering improvements.

This option allows the City to rapidly improve the sustainable features to its biosolids management strategy by implementing digestion, combined heat and power, and solar drying in the first phase, at the cost of some added operational complexity associated with keeping existing systems in service.

Table ES-7 summarizes the capital improvement costs associated with each of the above options. Costs are reported in net present value terms, reflecting a 4.5% annual capital cost inflation rate and a 4.7% discount rate.

Table ES-7 Summary of Capital Improvement Options

Phase	Year	Description	Cost
Option 1: THP and Anaerobic Digestion			
Phase 1	2016	Pre-screening, pre-dewatering, thermal hydrolysis, anaerobic digesters, CHP engine, additional cake storage	$59.3 M
Phase 2	2021	Eight solar drying modules, BFP replacement and final dewatering building improvements	$26.2 M
Phase 3	2028	Replace existing conveyance equipment and truck loading station	$4.3 M
Option 2: Solar Drying and Pre-Dewatering			
Phase 1	2016	Pre-screening, pre-dewatering, eight solar drying modules	$38.2 M
Phase 2	2021	Thermal hydrolysis, two anaerobic digesters, CHP engine	$45.9 M
Phase 3	2028	Replace existing conveyance equipment and truck loading station	$4.3 M
Option 3: Anaerobic Digestion and Solar Drying			
Phase 1	2016	Anaerobic digesters, eight solar drying modules, CHP engine	$49.4 M
Phase 2	2021	Pre-screening, pre-dewatering, thermal hydrolysis, BFP replacement and final dewatering building improvements	$34.8 M
Phase 3	2028	Replace existing conveyance equipment and truck loading station	$4.3 M

Recommendation

The City has expressed a clear interest in moving towards anaerobic digestion for the treatment of biosolids. As discussed above, this technology will offer numerous benefits that support CORPUD's goals for the biosolids program. As such, option 1 is the recommended implementation approach, as it allows anaerobic digestion, thermal hydrolysis, and combined heat and power to be implemented immediately. These improvements will allow alternative production of Class A biosolids, reduction of energy use at the NRWWTP, and significantly improve the sustainability of the biosolids management program for the City of Raleigh.

Section 1
Background and Introduction

1.1 Background

Since 2006, the City of Raleigh Public Utilities Department (CORPUD) has maintained an Environmental Management System (EMS) for biosolids management at the Neuse River Wastewater Treatment Plant (NRWWTP). This program demonstrates the City's commitment to continual improvement, operational excellence, and environmental protection.

Currently, biosolids at NRWWTP are processed via a combination of aerobic digestion/land application, alkaline stabilization (e.g. "Raleigh Plus"), and off-site composting. To support the goal of continual improvement, CORPUD conducted a biosolids management master plan in 2008. This study recommended that the City implement anaerobic digestion with thermal drying. Anaerobic digestion provides a sustainable source of energy in the form of biogas, which can be used on site. Thermal drying further diversifies the potential outlets for biosolids.

Due to economic conditions, the recommendations have not been fully implemented. The purpose of the present study is to update the recommendations from the 2008 Master Plan to reflect the latest biosolids management technologies and current economic realities. In addition, the scope of the Master Plan was expanded to include consideration of CORPUD's Little River WWTP, Smith Creek WWTP, E.M. Johnson Water Treatment Plant (WTP), and D.E. Benton WTP.

1.2 Program Goals and Objectives

The City's objective for the Biosolids Management Master Plan Update is to maintain a diversified biosolids management program that is efficient and effective, provides for maximum flexibility to adapt to changing conditions (economic, regulatory, environmental, social, technical, etc.), and allows the City to produce a final product that can be readily marketed and distributed for beneficial uses.

Accordingly, this study will recommend strategies that help the City achieve an exemplary biosolids management program that protects the environment and maintains public health at a fair and reasonable cost.

To accomplish these objectives, CDM Smith will execute the project in accordance with the principles of conduct specified in the National Biosolids Partnership's Code of Good Practice. These are:

- Compliance: To commit to compliance with all applicable federal, state, and local requirements regarding residuals production at CORPUD facilities, including management, transportation, storage, and end-use of biosolids.
- Product: To provide biosolids that meet the applicable standards for their intended use.
- EMS: To develop an EMS for biosolids that includes a method of independent third-party verification to ensure effective ongoing biosolids operations.

- Quality Monitoring: To enhance the monitoring of biosolids production and management practices.
- Quality Practices: To require good housekeeping practices for biosolids production, processing, transport, and storage, and during final-use operations.
- Contingency and Emergency Response Plans: To develop and maintain response plans for unanticipated events, such as inclement weather, spills, and equipment malfunctions.
- Sustainable Management Practices: To enhance the environment by committing to sustainable, environmentally acceptable biosolids management practices and operations through an EMS.
- Preventive Maintenance: To enhance our preventive maintenance program on equipment used to manage biosolids and wastewater solids.
- Continual Improvement: To seek continual improvements in all aspects of biosolids management.
- Communication: To provide methods of effective communication with gatekeepers, stakeholders, and interested citizens regarding the key elements of the EMS, including information relative to system performance.

1.3 Report Outline

This report presents the data, assumptions, and approach used to evaluate additional alternatives for biosolids management at CORPUD's facilities. The remaining sections are organized as follows:

- Section 2: Biosolids and Residuals Production
- Section 3: Overview of Biosolids Management Strategies and Processing Technologies
- Section 4: Biosolids and Residuals Management Alternatives Evaluation Criteria
- Section 5: Detailed Evaluation of Selected Biosolids Management Strategies
- Section 6: Energy Recovery and Utilization
- Section 7: Recommended Capital Improvement Plan

Section 2

Biosolids and Residuals Production

CDM Smith estimated future biosolids and residuals production from CORPUD's water and wastewater treatment facilities based on historical data and input from CORPUD staff. This section summarizes the assumptions and methodology used to develop the projections.

2.1 Projected Wastewater Treatment Plant Residuals

The 2008 study developed estimates of future sludge production at CORPUD's wastewater treatment facilities. As part of this study, CDM Smith updated these projections to reflect the impact of new water conservation measures and changing economic conditions.

2.1.1 Projected and Historical Influent Wastewater Flows

The most recent wastewater flow projections available are contained in the 2008 Biosolids Management Master Plan (2008 MP), which estimated influent flows for year 2010 through 2025 based on projected flows from the Neuse River Wastewater Treatment Plant Environmental Assessment. In the 2008 MP, flows for year 2030 through year 2040 were estimated based on a linear extrapolation of the flow increase for the 2015 through 2025 period.

The available projected flows were compared against historical treated effluent from NRWWTP for 2007-2011. Because plant influent flow data were not available, plant effluent was assumed to equal plant influent flow minus reuse water. **Figure 2-1** shows the projected flows (dotted line) and the historical flows (solid red line). As shown, historical flows have remained relatively stable at 42 mgd in recent years, due to the drought in 2007 as well as effective water conservation practices implemented by CORPUD. Influent flow is considerably lower than projections for this period.

In order to estimate sludge production, the 2008 flow projections were shifted forward in time by 6 years to intersect historical flows, while maintaining the same growth pattern. These shifted projections are indicated by the dashed line in Figure2-1. For example, the projected flow from the 2008 MP in 2025 was 77.8 mgd. With the shifted projections, the projected flow is approximately 69.5 mgd in 2025, while 77.8 mgd occurs 6 years later, in 2031.

Given recent trends, the shifted projections are considered to represent aggressive assumptions about growth. The slope of this projection was adjusted based on historical flow data to create two additional scenarios representing "moderate" and "slow" growth. These are also shown on the figure. Under moderate and slow growth scenarios, wastewater flow in 2035 is projected to be 75 mgd or 61 mgd, respectively.

Based on available data and information from City staff, there appears to be negligible growth in wastewater flows within the service area served by Little Creek WWTP. Over the 2009-2011 period, average flows to LCWWTP actually decreased from 0.67 mgd to 0.62 mgd. Given the lack of growth, it was assumed that flow to LCWWTP would remain constant during the planning period.

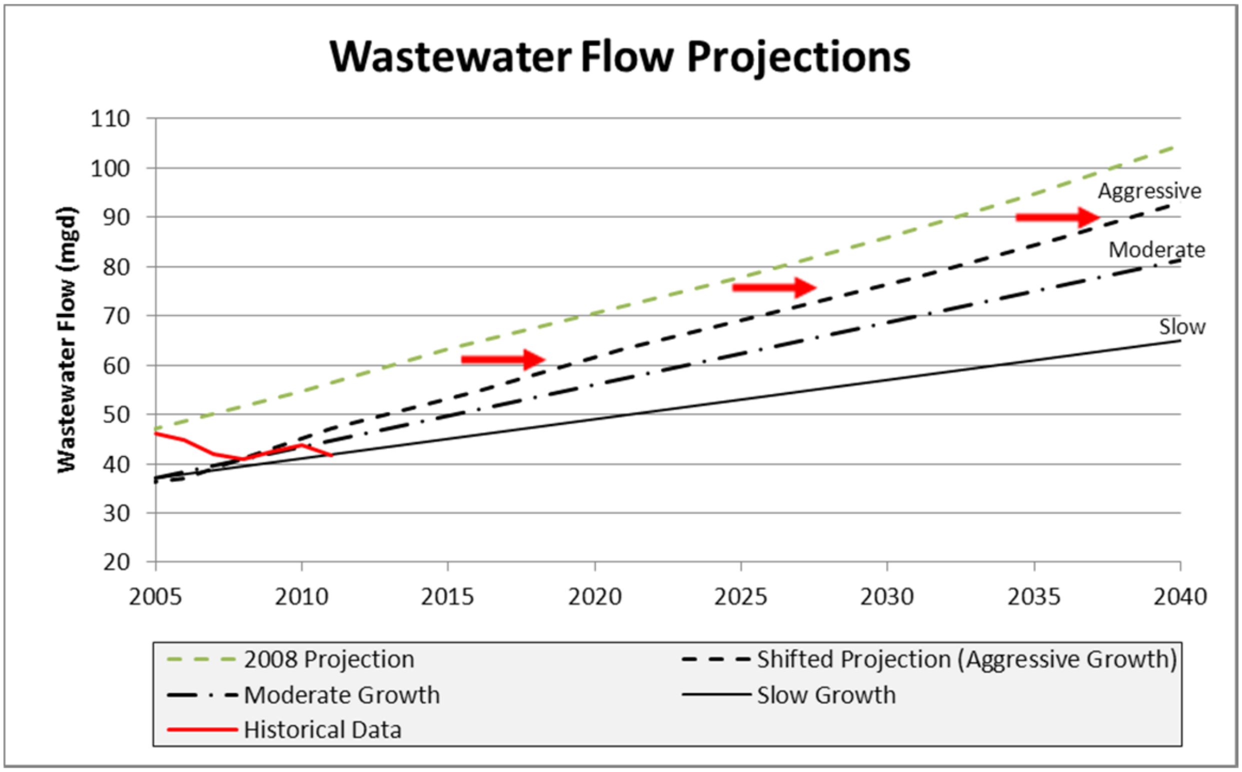


Figure 2-1 Comparison of Historical and Projected Wastewater Flows at NRWWTP

2.1.2 Historical Influent Characteristics

Influent solids loading to the NRWWTP from 2009-2011 was compared against data presented in the 2008 Master Plan. As shown in **Table 2-1,** average BOD and TSS concentrations in the influent have increased significantly since the previous study. However, the 7-day peaking factors are somewhat lower, indicating a more stable loading rate. The increases in solids loading may be a result of lower wastewater flows due to water conservation measures and drought, as noted above.

Table 2-1 Summary of Historical Loading

Parameter	Influent BOD		Influent TSS	
	2004-06	2009-11	2004-06	2009-11
Annual Average Concentration, mg/L	211	279	220	334
7-day Maximum Load / Annual Average	1.53	1.33	1.75	1.67
30-day Maximum Load / Annual Average	1.17	1.22	1.23	1.24

2.1.3 Historical Sludge Production Rates at NRWWTP

Operations data from 2009-2011 were used to estimate the annual average sludge production at Neuse River WWTP. Because Smith Creek WWTP and Benton WTP send their residuals to the sanitary sewer, and ultimately to NRWWTP, they are included in the totals reported below as well. The current practice at NRWWTP involves co-settling a large fraction of the waste activated sludge (WAS) with the primary sludge. A certain quantity of WAS is diverted to the uncovered aerobic digesters (UCADs) for subsequent gravity belt thickening and aerobic digestion in the covered aerobic digesters (CADs). Digested solids are land applied as Class B biosolids in liquid form. **Figure 2-2** shows a schematic process diagram of the existing biosolids management strategy.

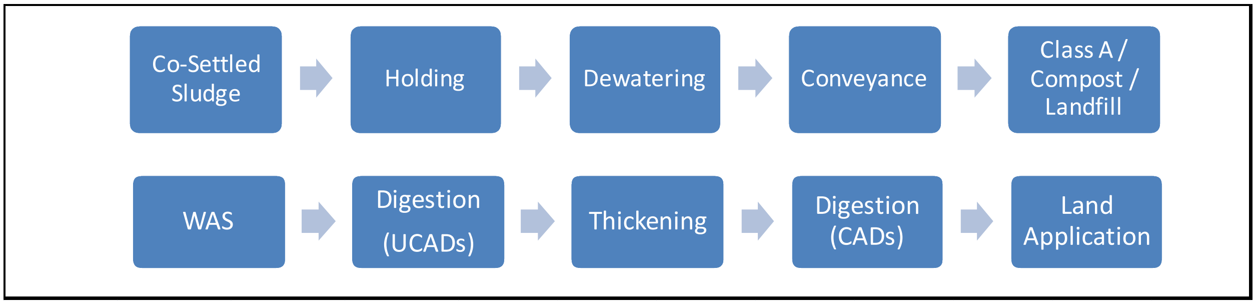


Figure 2-2 Solids Processing Flow Diagram Used in this Analysis

Table 2-2 summarizes the historical distribution of biosolids from NRWWTP between the various outlets available. The production of co-settled sludge was estimated based on flow and concentration measurements of the sludge exiting the primary clarifiers. The quantity of diverted WAS was estimated from the solids hauled to Class B land application (shown in Table 2-2), assuming various process parameters developed from operations data (volatile solids fraction = 71%, 95% solids capture in the thickening process, combined volatile solids reduction of 40% through the uncovered and covered aerobic digesters, respectively).

Table 2-2 Summary of Biosolids Distribution from NRWWTP, 2007-2012

Year	Class A	Compost	Class B	Landfill	Total
	Dry lb/day[a, b]	Dry lb/day[a]	Dry lb/day[a]	Dry lb/day[a]	Dry lb/day[a]
2007	38,436	24,201	3,200	1,527	67,364
2008	35,904	25,703	4,528	1,787	67,921
2009	28,775	26,936	9,012	0	64,722
2010	30,663	31,295	6,155	0	68,113
2011	29,465	29,949	7,562	0	66,976
2012[c]	33,919	29,734	8,585	0	72,238
				Average	**67,889**

[a] Annual average
[b] Does not include weight of lime added
[c] Estimated based on Jan-May data

Table 2-3 summarizes the estimated sludge production during the last three years. Also shown is the sludge production rate (lb/MG), which is simply sludge production, normalized by the annual average wastewater flow. These rates are the basis for projecting future sludge quantities, as discussed in the next section.

Table 2-3 Historical Raw Sludge Production, 2009-2011

Process	Sludge Produced, dry lb/day			Sludge Production Rate, dry lb/MG		
	Average	30-day Max	14-day Max	Average	30-day Max	14-day Max
Co-settled Sludge (to dewatering)	67,816	81,319	86,850	1,590	1,907	2,036
Waste Activated Sludge (to digesters)	11,165	13,388	14,298	262	314	335
Total	**78,981**	**94,707**	**101,149**	**1,852**	**2,221**	**2,372**
Peaking Factor	1.00	1.20	1.28	1.00	1.20	1.28

The estimated annual average sludge production compares favorably with the historical distribution data, but must be interpreted with some care. Note that the values in Table 2-3 represent sludge produced, while Table 2-2 lists (digested) biosolids. As such, the estimated quantity of WAS in Table 2-3 (11,165 lb/day) is somewhat higher than the historical values (7,500 – 9,000 lb/day in the last 3 years). The quantity of co-settled sludge (67,816 dry lb/day) is comparable to the total biosolids distributed to Class A, Raleigh Plus, and the landfill (55,000 – 62,000 lb/day).

Table 2-4 compares the current estimates of sludge production with the 2008 Master Plan, which contained sludge production rates based on historical data for the 2004-2006 period, and on the results of a BIOWIN™ process model simulating 75-mgd average daily flow conditions. The 2008 estimates assumed that co-settling of sludge was discontinued.

Table 2-4 Comparison of Sludge Production Estimates from 2008 MP and Present Study

Conditions	Sludge Produced, dry lb/day		Sludge Production Rate, dry lb/MG	
	2008 MP (at 75 mgd)	2009-11 (at 42 mgd)	2008 MP	2009-11
Annual Average	132,280	78,981	1,765	1,852
30-day Maximum	158,105	94,707	2,110	2,221
Peaking Factor	1.20	1.20	1.20	1.20

As shown, the estimated production rates (lb/MG) compare well with the 2008 production estimates. The current estimate is slightly higher than the 2008 estimates, reflecting the increased influent solids and organic loadings noted in Table 2-1 above.

2.1.4 Historical Sludge Production Rates at LCWWTP

Monthly operations data from Little Creek WWTP was used to estimate the biosolids production at this facility following a similar approach to that used for NRWWTP. **Table 2-5** summarizes the influent flow, sludge production, and sludge production rate. As shown, the rate of sludge production per unit of flow treated is somewhat lower than at NRWWTP.

Table 2-5 Summary of Estimated Sludge Production at Little Creek WWTP

Year	Average Influent Flow, MGD	Sludge Produced, dry lb/day	Sludge Production Rate, dry lb/MG
2009	0.67	174,260	717
2010	0.66	310,540	1,298
2011	0.62	261,700	1,165
Average	0.65	248,800	1,060

2.1.5 Forecast Biosolids Production Rates

The sludge production rates developed above were combined with the projected wastewater flows to estimate the total quantity of sludge that must be processed in the future. These projections are illustrated in **Figure 2-3.** For comparison, the estimated sludge production using production rates and flow projections from the 2008 Master Plan are also shown. Note that only annual average sludge production is shown. Peaking factors listed in Table 2-3 can be used to estimate 30- and 14-day peaks. The wastewater flows corresponding to each scenario are shown in Figure 2-1.

For this master plan update, we recommend using the moderate growth scenario and year 2035 as the basis for sizing improvements. Under this growth scenario, the NRWWTP will reach 75 mgd in 2035, at which time it will produce an average of 139,000 dry lb/day (69.5 dry tons/d) of sludge. As noted above, flows and biosolids production at LCWWTP are not expected to increase significantly above current levels.

2.2 Recent Upgrades to Sludge Processing Facilities

Since the last study was completed in 2008, CORPUD has completed several improvements to the NRWWTP's solids processing facilities. A new centrifuge building housing a single Alfa Laval G2-115 centrifuge and polymer system was constructed. This new facility is located near the belt filter presses and is integrated with the conveyance system to the alkaline stabilization and truck loading facilities. This centrifuge is used primarily to dewater material for third-party composting. Operating data indicate that the new centrifuge typically achieves 24%-26% solids, while the belt filter presses achieve 21%-22% solids concentration.

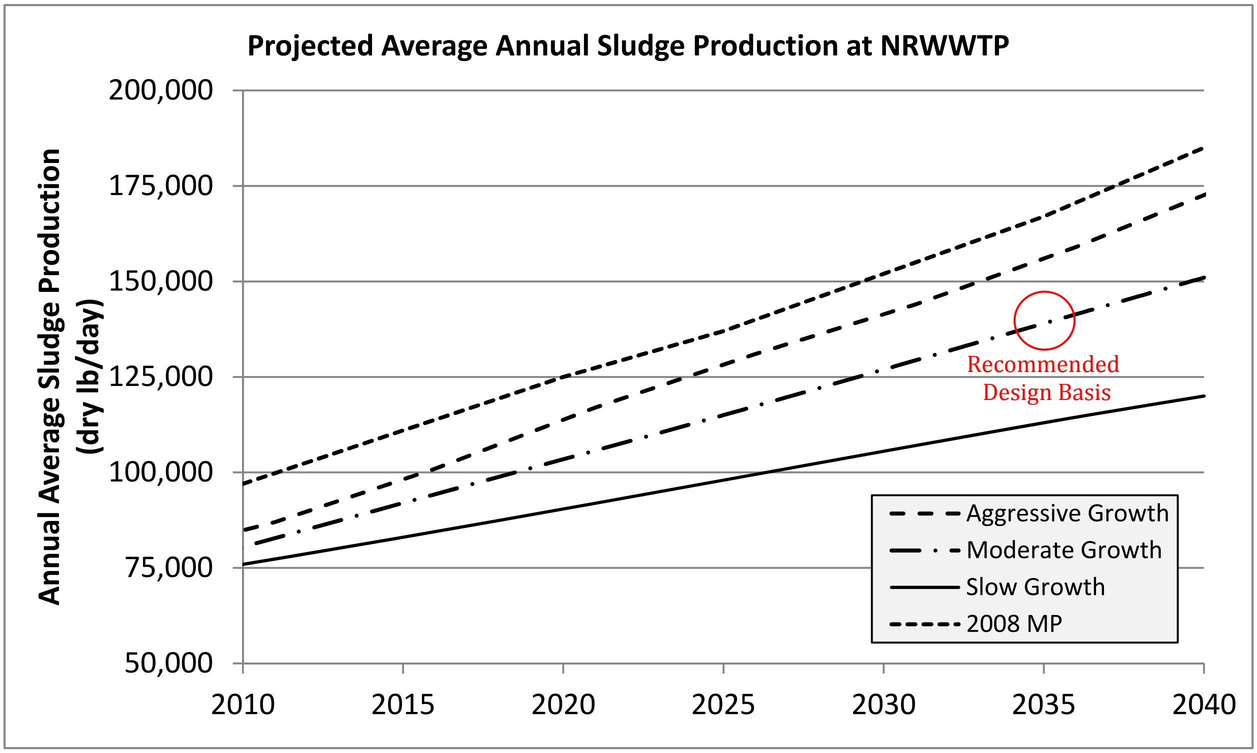


Figure 2-3 Projected Average Annual Sludge Production at NRWWTP.

In addition, the aeration systems in two of the UCADs have been repaired, allowing these basins to become a regular part of the solids treatment process, as discussed in the previous section.

Significant upgrades to the NRWWTP's liquid treatment train are underway. These include new primary clarifiers (replacing the existing), a new influent pump station, and additional secondary clarifiers.

As part of this study, CORPUD requested that CDM Smith document the sludge processing capacity of the existing facilities at the NRWWTP. Assuming current operational practices continue, the existing facilities are capable of processing sludge equivalent to 75 mgd of liquid treatment during maximum month conditions with a 16hr/day, 6 day/week dewatering schedule. If one dewatering unit is out of service, the operating hours of the remaining units must be extended to approximately 18 hr/day x 7 days/week.

2.3 Projected Water Treatment Plant Residuals

In addition to sludge production, future quantities of water treatment plant residuals were also estimated, in order to provide a holistic view of CORPUD's solids management needs. CORPUD provided CDM Smith with potable water demand projections through the year 2040 (prepared by others). These were used in conjunction with operating data from the E.M. Johnson and D.E. Benton WTPs to estimate the quantity of residuals generated in the future.

2.3.1 Population Projections

Population projections were retrieved from three different sources, listed below:

- Population projections from the Little River Dam EIS update, prepared in 2010. These contain multiple scenarios (Low, Medium, High, and 3% growth) that create a "cone of probability" of future population levels. The "median growth" scenario from this work was published in the *Triangle Regional Water Supply Plan* in February 2012.

- The "original" scenario used in the Purpose and Need document for the Little River Dam project.
- Draft scenarios from new modeling work by the Capital Area Metropolitan Planning Organization (CAMPO). The two scenarios provided were designated "Community Planning" and "Trend Development" and estimate the population in 2040 only.

These projections are summarized in **Table 2-6**. For 2040, they suggest a range of 809,900 to 1,092,300 as the 2040 population within the CORPUD service area (comprising Raleigh, Garner, Knightdale, Rolesville, Wake Forest, Wendell, and Zebulon).

Table 2-6 Summary of Population Projection Scenarios

Scenario	2010	2020	2030	2040
Low Growth	450,000	515,000	650,000	809,900
Median Growth	450,000	683,300	844,500	955,700
High Growth	450,000	700,000	880,000	1,075,300
3% Growth	450,000	600,000	805,000	1,092,300
"Original" Projection	489,000	638,800	782,960	896,200
CAMPO - "Community Planning"	483,300	-	-	881,600
CAMPO - "Trend Development"	483,300	-	-	877,700

2.3.2 Potable Water Demand

Potable water demand projections based on the "original" and Little River Dam EIS Update scenarios were provided. All scenarios assume that water-efficient construction and conservation practices seen between 2000 and 2009 will continue, causing future per-capita water demand to decrease. The "original" scenario projections assume per-capita demand will decrease from 110 gpcd in 2010 to 103.1 gpcd in 2040, while the Little River EIS scenarios assume that demand will decrease from 106.6 gpcd in 2010 to 95.2 gpcd in 2040. The assumptions from the Little River EIS scenarios (95 gpcd in 2040) were used in conjunction with the CAMPO population projections to develop a third estimate of potable water demand. **Table 2-7** summarizes the projected water demands and associated assumptions; projected water demand over time is shown in **Figure 2-4**.

Note that under the 3% growth scenario, the total max day demand in 2040 (154 mgd) exceeds the combined anticipated capacity of the Raleigh WTPs. E.M. Johnson WTP currently has a maximum rated capacity of 86 mgd, with a planned expansion to 120 mgd. D.E. Benton WTP has a maximum rated capacity of 20 mgd, for a total capacity of 140 mgd.

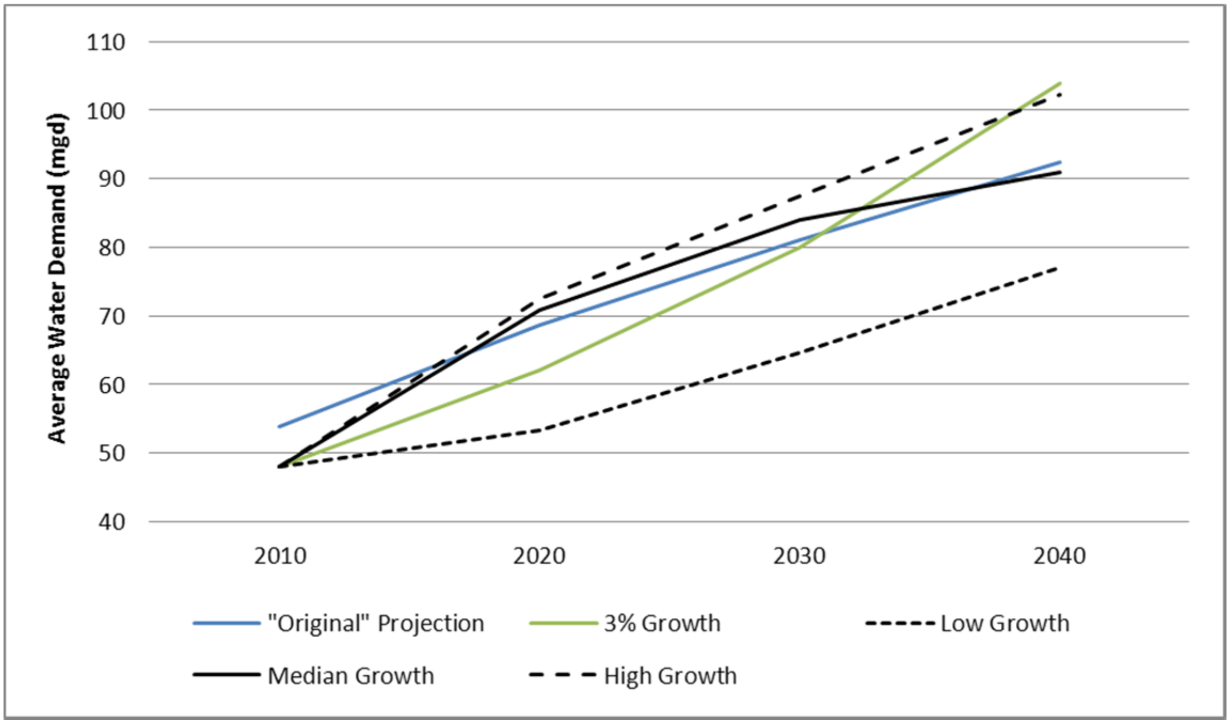


Figure 2-4: Water Demand Projection Scenarios

Table 2-7 Summary of Projected Water Demand in 2040

Scenario	Gallons/ capita/ day	Average Day Demand (mgd)	Peaking Factor	Max Day Demand (mgd)
Low Growth	95.2	77	1.48	114
Median Growth	95.2	91	1.48	135
High Growth	95.2	102	1.48	152[a]
3% Growth	95.2	104	1.48	154[a]
"Original" Projection	103.1	92	1.48	137
CAMPO - "Community Planning"	95.2	84	1.48	124
CAMPO - "Trend Development"	95.2	83	1.48	124

[a] Exceeds the anticipated capacity of Raleigh WTPs in 2040.

Figure 2-5 summarizes the projected population and average water demand in 2040 according to each scenario. The “median growth” scenario, indicated in green, was included in the Triangle Regional Water Supply Plan and represents the approximate midpoint of all the projections. In order to bracket the range of possible future conditions, the Low Growth, Median Growth, and 3% Growth scenarios were used to estimate water treatment plant residuals production.

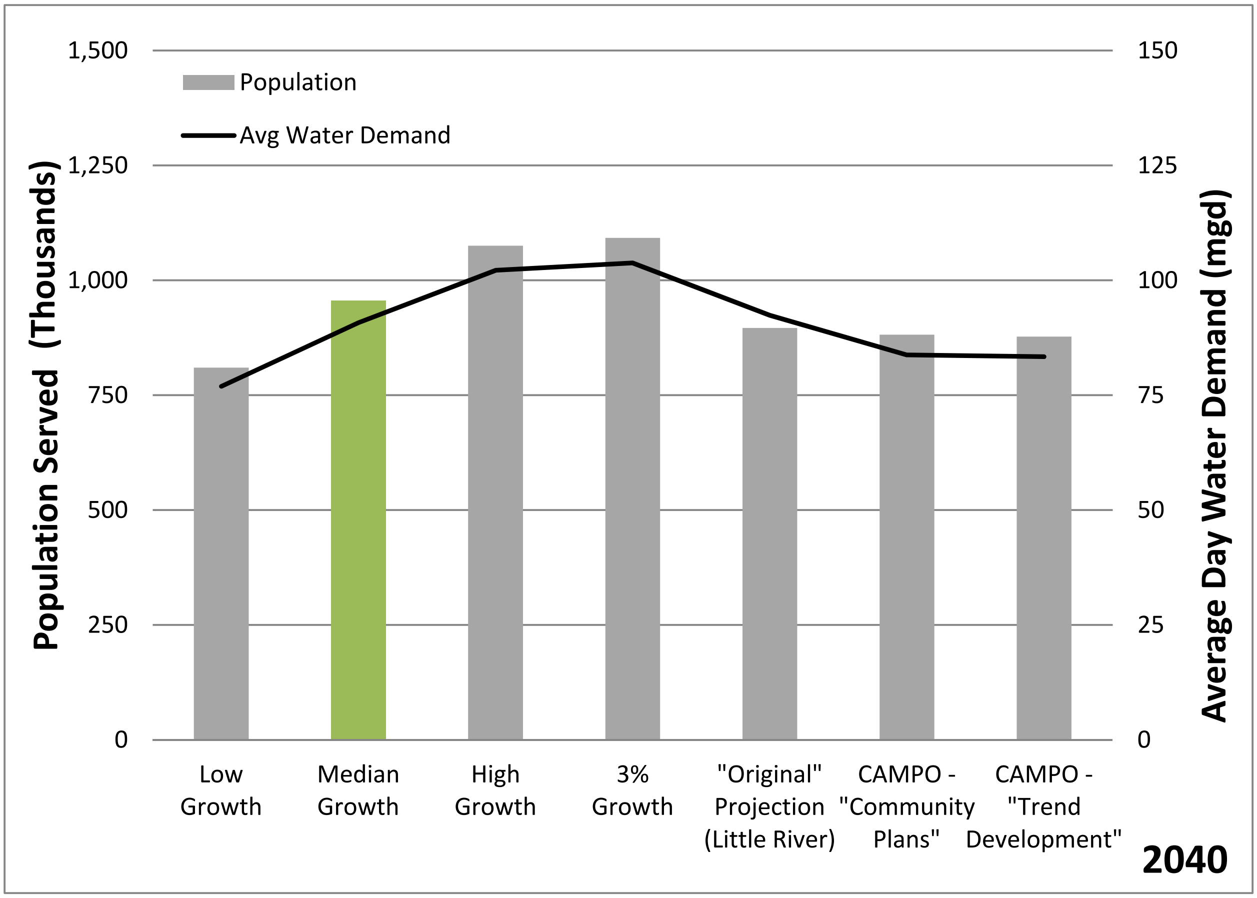


Figure 2-5 Comparison of Projected Service Area Populations in 2040. The scenario indicated in green was published in the *Triangle Regional Water Supply Plan.*

Discussion with City staff indicated that E.M. Johnson WTP treats a minimum of 38 mgd at all times, while D.E. Benton WTP treats a minimum of 5 mgd. Based on this information and historical average flow data provided, it was assumed that D.E. Benton will treat 1/6th of the total potable water demand (up to its capacity of 20 mgd),while E.M. Johnson will treat the remaining flow. This assumption has implications for the overall production of residuals due to the significantly different production rates between the two WTPs, as noted below.

2.3.3 Residuals Production Rates

Residuals were estimated by combining the projected potable water demand with production rates (e.g. lb residuals/MG treated). For E.M. Johnson WTP, these rates were developed in the *Wastewater Collection and Pumping Improvements Preliminary Engineering Report*. For Benton WTP, 2 years of operating data were provided, which included an estimate of the solids produced by the plant. This information allowed the lb/MG production rate to be calculated directly.

The residuals production rates are summarized in **Table 2-8**. As shown, D.E. Benton WTP produces significantly more residuals per unit of flow treated than E.M. Johnson WTP. Differences in raw water quality, coagulant dose, or process configuration are the most likely explanations for this difference.

Table 2-8 Residuals Production Rates for Raleigh WTPs

Facility	Average Residuals Production	Max 30-day Residuals Production	Average Production Rate	Max 30-day Peaking Factor
	Dry lb/day	Dry lb/day	Dry lb/MG	-
E.M. Johnson WTP	16,000[1]	26,700[1]	400	1.67
D.E. Benton WTP[2]	5,200	7,800	650	1.50

[1] Estimated from design residuals production rates developed in previous study

[2] Developed from July 2010 – June 2012 operating data

The projected flow and residuals production at EMJ WTP is summarized in **Table 2-9** for each of the three water demand scenarios under consideration. Peak 30-day residuals production is projected to increase between 60% and 120% by 2040, depending on the scenario. As noted above, the max day flow to EMJ exceeds its expanded treatment capacity in 2040 under the 3% growth scenario.

Table 2-10 summarizes the projected water demand and residuals production at D.E. Benton WTP. As noted above, it is assumed that DEB WTP treats 1/6th of the total potable water demand, up to its 20 mgd capacity. Capacity is reached by 2030 under the median growth scenario, and in 2040 under the 3% growth scenario. Peak 30-day residuals production is expected to increase by 60% to 75% over current levels by 2040.

Table 2-9 Projected Water Demand and Residuals Production at E.M. Johnson WTP

Scenario	Parameter	Unit	2010	2020	2030	2040
Low Growth	Avg Day Water Treated	mgd	40.0	44.5	53.8	64.3
	Avg Day Residuals	dry lb/day	16,000	17,800	21,500	25,700
	Max Day Water Treated	mgd	59.2	65.8	79.7	95.1
	Peak 30-day Residuals	dry lb/day	26,700	29,700	36,000	42,900
Median Growth	Avg Day Water Treated	mgd	40.0	59.0	70.0	77.1
	Avg Day Residuals	dry lb/day	16,000	23,600	28,000	30,800
	Max Day Water Treated	mgd	59.2	87.3	104.2	114.7
	Peak 30-day Residuals	dry lb/day	26,800	39,400	46,800	51,500
3% Growth	Avg Day Water Treated	mgd	40.0	51.8	66.7	90.1
	Avg Day Residuals	dry lb/day	16,000	20,700	26,700	36,000
	Max Day Water Treated	mgd	59.2	76.7	98.7	133.9
	Peak 30-day Residuals	dry lb/day	26,800	34,600	44,500	60,200

Table 2-10 Projected Water Demand and Residuals Production at D.E. Benton WTP

Scenario	Parameter	Unit	2010	2020	2030	2040
Low Growth	Avg Day Water Treated	mgd	8.0	8.9	10.8	12.9
	Avg Day Residuals	dry lb/day	5,200	5,800	7,000	8,400
	Max Day Water Treated	mgd	11.8	13.2	15.9	19.0
	Peak 30-day Residuals	dry lb/day	7,800	8,700	10,500	12,500
Median Growth	Avg Day Water Treated	mgd	8.0	11.8	13.9	13.9
	Avg Day Residuals	dry lb/day	5,200	7,700	9,000	9,000
	Max Day Water Treated	mgd	11.8	17.5	20.0	20.0
	Peak 30-day Residuals	dry lb/day	7,800	11,500	13,600	13,600
3% Growth	Avg Day Water Treated	mgd	8.0	10.4	13.3	13.9
	Avg Day Residuals	dry lb/day	5,200	6,700	8,700	9,000
	Max Day Water Treated	mgd	11.8	15.3	19.7	20.0
	Peak 30-day Residuals	dry lb/day	7,800	10,100	13,000	13,600

The total quantity of dewatered residuals requiring disposal was calculated by adding the contributions from both WTPs and assuming 95% solids capture through dewatering. This information is summarized in **Figure 2-6**. In 2040, disposal requirements will reach between 16 and 21 dry tons per day. Because of the relatively small difference between scenarios, it is recommended that the "median growth" scenario be used as the basis for further analysis.

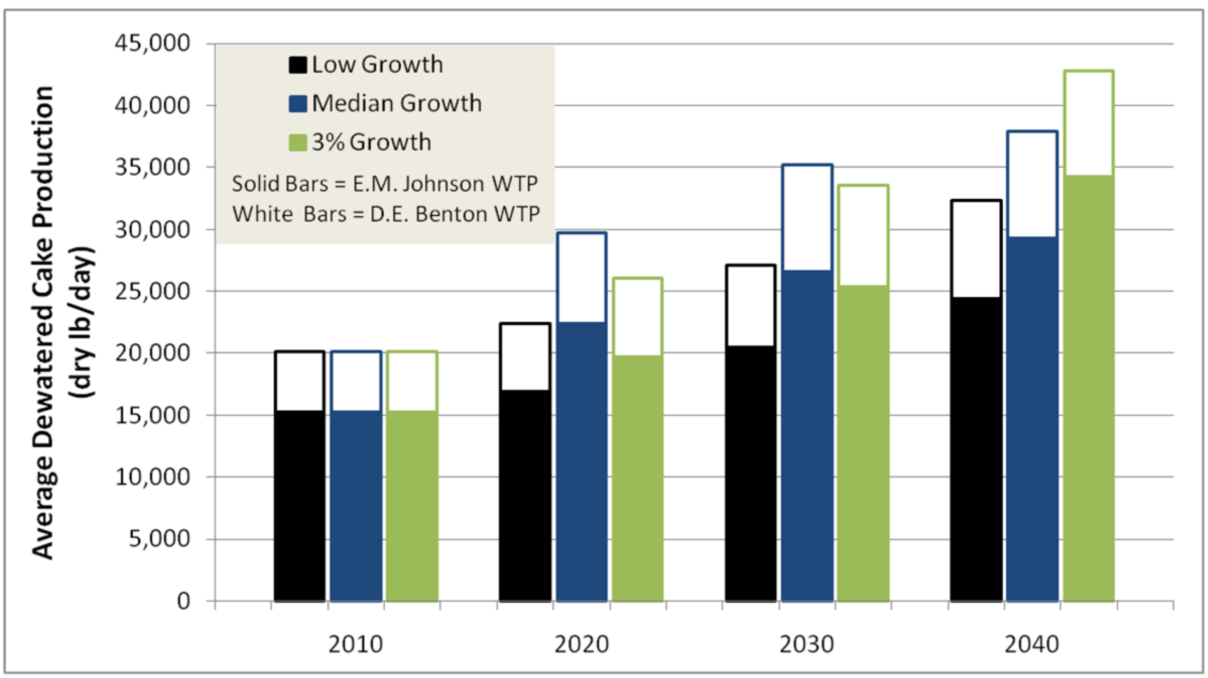


Figure 2-6 Projected average day residuals production from Raleigh water treatment plants

Section 3

Overview of Biosolids Management Strategies and Processing Technologies

The purpose of this section is to present an overview of alternative biosolids treatment technologies considered for the City of Raleigh's long-term biosolids management strategy. The alternatives considered represent a range of processes that includes thickening, stabilization, dewatering, drying, and final disposal.

3.1 Biosolids Processing Technologies

3.1.1 Thickening

3.1.1.1 Gravity Belt Thickening

Gravity belt thickening (GBT) (**Figure 3-1**) is a solid-liquid separation process that relies on coagulation and flocculation of the solids in a dilute slurry as well as drainage of free water through an open-mesh filter belt. In the 2008 Master Plan, CDM Smith recommended gravity belt thickeners because they are a common and proven choice for many municipalities. This technology is a low-energy process that provides three to five-fold reductions in volume with polymer addition, assuming the thickening equipment is operating within its design parameters. Therefore, O&M costs for GBTs are typically lower than other thickening technologies.

Figure 3-1 Gravity Belt Thickener

Figure 3-2 Rotary Drum Thickener

3.1.1.2 Rotary Drum Thickening

A rotary drum thickener (RDT) is similar to a gravity belt thickener, achieving solid-liquid separation from the drainage of free water through the porous media within a rotating drum. The porous media can be a drum with wedge wires, perforations, stainless steel fabric, polyester fabric or a combination of fabrics. RDT is suitable for thickening WAS, anaerobically and aerobically digested sludge, and some industrial sludges. It is typically employed in small to medium-sized wastewater treatment plants. An example of a RDT is shown in **Figure 3-2.**

3.1.1.3 Alternatives Screening

Gravity belt thickening has been used successfully at the NRWWTP for many years. Although staff have noted some limitations caused by the design of the thickener feed piping, the technology itself has met treatment objectives at a low cost. The hydraulic limitations can be addressed by future improvements. Alternatives developed in this study assumed gravity belt thickening (where required). Rotary drum thickeners were not evaluated further due to their smaller capacity and higher operating cost.

3.1.2 Stabilization

3.1.2.1 Anaerobic Digestion

Anaerobic digestion (AD) is a critical element of the biosolids management strategy proposed by CDM Smith for the City of Raleigh. Anaerobic digestion has been used at WWTPs for many years to produce a stabilized biosolids product. Key components of an AD system include the reaction tank (digester), microorganisms, a mixing system and a heating system. The microbe-rich environment inside the digester is deprived of dissolved oxygen and nitrate to facilitate the conversion of volatile solids to digester gas and water. Egg-shaped digesters (as shown in **Figure 3-3**) are advantageous because they minimize scum formation and facilitate grit removal, though they are more costly to construct. Good performance can also be obtained from a less-expensive cylindrical design with a sloped floor.

Anaerobic digesters are typically designed to operate at either mesophillic (90-100 degrees F) or thermophillic (120-135 degrees F) temperatures and require tank mixing. According to 40 CFR Part 503, sewage sludge is considered a Class B biosolid with respect to pathogens if it meets the required minimum retention time of 15 days at 35-55 degrees C (95-131 degrees F). Vector attraction reduction requirements are fulfilled when volatile solids reduction in the sludge is at least 38%. A properly designed and operated digestion system will meet these criteria and produce biosolids suitable for land application.

A useful byproduct of AD, digester gas, typically consists of approximately 65% methane and 35% carbon dioxide and has a heating value of 600 BTU/cubic foot. Energy available in the digester gas can be recovered and used to power a variety of processes including the digester sludge heating and thermal drying systems.

3.1.2.2 Co-digestion

Co-digestion is a variation of anaerobic digestion in which biosolids are combined with fat, oil, and grease (FOG; collected in grease traps and sewers) and/or food-wastes prior to digestion.

Figure 3-3 Egg-shaped anaerobic digesters

Co-digestion offers the advantage of improved biogas yield. At the East Bay Municipal Utility District in San Francisco, anaerobic co-digestion of sorted, ground food waste to wastewater sludge yielded 3.5 times more methane than digestion of sludge alone. Co-digestion offers other advantages as well, including:

- Potential increases in digester performance (improved VSR)
- Energy savings
- Potential tipping fees
- Reduced green house gas emissions
- Reduced solid waste loadings at landfill
- Sustainable organic waste management

One crucial digester characteristic for successful FOG digestion is good digester mixing, particularly at the surface. Without adequate surface mixing, the FOG will tend to collect at the surface of the digester. In addition to digesters, a food waste receiving station, grinding/pulping equipment (for food waste), and screening equipment are required.

The disadvantages associated with FOG co-digestion can be summarized as follows:

- Potential pretreatment requirements
- Potential odors
- Greater Potential for digester upset
- Significant increase in gas production can overload gas system

Food waste co-digestion is well-established overseas, but has yet to gain widespread use in the U.S. As of 2010, more than 200 municipal organic solid waste (MOSW, e.g. food waste) facilities, with a combined capacity of almost 6 million tons per year, were successfully operating in Europe. However, several barriers to food waste co-digestion implementation exist in the U.S. The regulatory environment in the U.S., combined with low energy prices, make cost recovery difficult for dedicated co-digestion facilities. Co-digestion may become more viable if excess anaerobic digester capacity were available (e.g., in the years just after construction of a facility, or in the event of lower than expected growth.)

FOG co-digestion is somewhat more common in the U.S.; however it is worth noting that a privately-owned FOG processing facility located in Raleigh would likely compete for product.

3.1.2.3 Composting

Composting produces a stable end product by facilitating the biological degradation of organic material. The City of Raleigh currently composts a portion of the sludge from NRWWTP through a third-party contractor, and also (separately) operates a composting facility for yard waste.

Co-composting of biosolids together with yard waste could offer a way to consolidate these operations. Co-composting facilities can be designed as windrows (**Figure 3-4**) or aerated static piles. In either case, the operation is much more complex than conventional yard waste composting. Since composting is an aerobic process, the pile requires a certain porosity to allow the flow of oxygen throughout, and the addition of biosolids to yard waste significantly increases the aeration requirement. Bulking agents, like yard-waste, are recommended amendments for enhancing porosity. For dewatered sludge at about 20% solids content the amendment ratio is typically 3:1 on a volume basis.

The period of time biosolids are composted at a specific temperature is important in determining the eventual use of the compost end product. Time and temperature requirements are defined in 40 CFR Part 503 (9) as follows:

- Class A: For aerated static pile composting, the temperature should be 55 degrees C for at least 3 days. For windrow composting, the temperature should be 55 degrees C for at least 15 days with 5 turns.
- Class B: The temperature should be about 40 ºC or higher for 5 days during which it should exceed 55 degrees C for at least 4 hours.

Co-composting of yard waste with biosolids has several disadvantages, including:

- Large space requirement to stockpile yard waste and sludge separately, in addition to providing other areas for the mix to compost and properly cure (typically 60 days). A storage area for the final product may also be required.
- If the composting facility is not located at the NRWWTP, transportation costs could be significant.
- High odor risk. Odor control is critical, but indoor co-composting facilities represent a highly corrosive environment.
- The final product is marketable but revenues are typically modest.
- Odor control and stormwater management requirements will require drastic changes to the existing yard waste composting facility.

Due to the above disadvantages of co-composting, the technology was not evaluated further.

Figure 3-4 Composting Windrows

3.1.2.4 Alkaline Stabilization

Alkaline or lime stabilization involves raising the pH of sludge (often by adding lime) to inactivate bacteria and other microorganisms present. Lime-stabilized biosolids are generally suitable for agricultural application or landfill disposal. Traditional lime stabilization produces Class B product; although Class A requirements can be met with advanced stabilization involving certain pH and temperature conditions. This process is currently used to stabilize a large fraction of the NRWWTP sludge into a Class A product marketed as "Raleigh Plus."

3.1.2.5 Thermal Hydrolysis

Thermal hydrolysis is a biosolids treatment option that applies pressure and temperature to residuals prior to digestion. The thermal hydrolysis pretreatment (THP) conditions sludge by fracturing cellular material and long-chain fatty acids which makes the sludge more conducive to downstream digestion and dewatering processes. Coupled with downstream mechanical dewatering (e.g., belt filter presses, centrifuges) the digested biosolids can produce a cake that typically exceeds 30% total solids concentration. Prior to entering the THP, sludge must be dewatered. Once injected into the THP, solids are treated for about 30 minutes at 330 degrees F and 90 psi. These treatment conditions exceed those required by EPA 503 for producing Class A biosolids. The final product exhibits excellent properties for soil blending and land application with low odor. There are two commercially available thermal hydrolysis processes currently, Cambi and Exelys, which are described in greater detail below.

CAMBI

The Cambi THP process consists of three basic steps: solids heating in the pulper/pre-heater tank, heating, pressurization and thermal hydrolysis in the reactor, and pressure release to the flashtank. Dewatered cake of 17% solids concentration is fed from cake bins to the pulper where solids are circulated by circulation pumps and preheated with steam. Then the cake is transferred to batch reactors where steam is added to increase both temperature and pressure within the batch reactor. The batch reactor is raised to a temperature of approximately 330 degrees F and a pressure near 90 psig. After a prescribed amount of time elapses, a pressure discharge opens and allows steam to travel to the pulper. The remaining pressure is used to transfer the solids slurry through the blow down valve to the flashtank. Excess flash steam from the flashtank is conveyed to the pulper to pre-heat the cake.

Thermally hydrolyzed sludge (THS) is continuously removed from the flashtank by digester feed pumps which convey it to a THS booster/circulation system that increases the pressure and keeps the sludge constantly moving to prevent setting. Between the flashtank and the digesters, the sludge is diluted with water from 13-15% to 8-12% percent dry solids. Without dilution, high ammonia concentrations may build-up in the digesters, high sludge temperatures may damage the digester feed pump stators and the viscosity wouldn't be conducive to digester mixing. Finally the THS is cooled by mixing with recycled digested sludge and then routed to the digester. Heat exchangers may be added upstream of each digester to cool the sludge to the proper temperature for high-rate digestion. A schematic of this process is shown in **Figure 3-5.** An example equipment installation is illustrated in **Figure 3-6.**

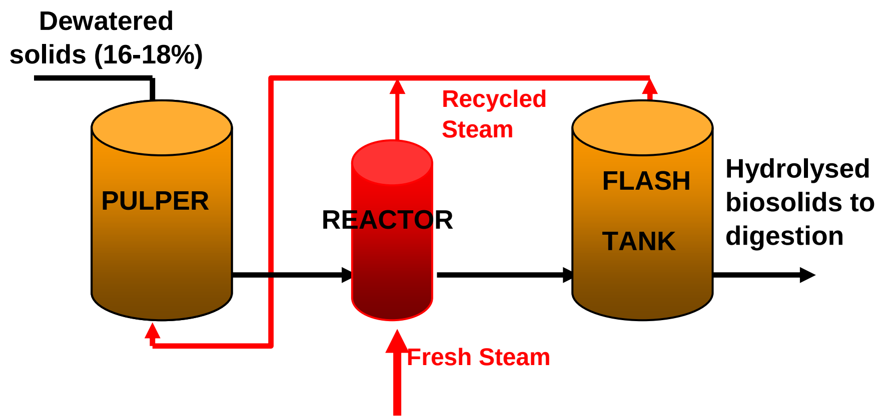


Figure 3-5 Cambi Thermal Hydrolysis Pretreatment (image courtesy CAMBI)

The gases produced in the pulper have a high moisture content and are highly odorous. A foul gas handling system is provided to mitigate the odor through carbon absorption.

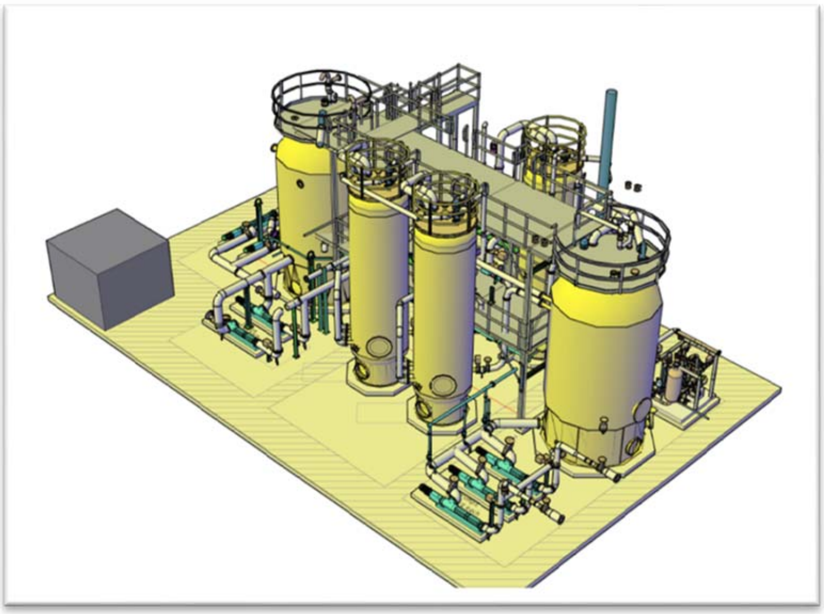


Figure 3-6 Cambi Thermal Hydrolysis System

Exelys

Exelys is another thermal hydrolysis process that is currently being developed by Kruger/Veolia. Exelys is a continuous plug flow process that treats primary and secondary sludge. Dewatered sludge from a storage silo is conveyed to the Exelys system via a progressive cavity pump. Steam is injected continuously and begins to heat the sludge up to the level at which hydrolysis can occur. The heated sludge passes through a self-cleaning static mixer before entering the reactor. The reactor operates within a temperature range of 285-330 degrees F and pressure range of 130-220 psi. After the reactor, the sludge enters a heat exchanger system where excess thermal energy can be recovered and exported from the system.

Exelys offers two configurations, the most common of which is the Exelys-LD. In the LD configuration thermal lysis (L) is followed by digestion (D), as shown in the schematic in **Figure 3-7**. The process can also be configured into a digestion - lysis – digestion configuration, called Exelys-DLD (shown in **Figure 3-8**). In the DLD configuration, sludge is digested and dewatered before entering the thermal hydrolysis reactor. Next the dewatered, hydrolyzed sludge is cooled and diluted and then sent to a second digester.

The Exelys-DLD configuration offers a number of advantages that are not available with conventional thermal hydrolysis digestion. Approximately 20-30% of the total solids entering the first digester are converted to biogas. Since digested sludge is easier to dewater than raw sludge, the Exelys system can be approximately 2/3 of the size required in an LD configuration under the same conditions.

While Exelys and Cambi both rely on thermal hydrolysis for sludge conditioning, there are a few key differences in their designs. The Exelys system does not recycle steam and therefore requires more of it than the Cambi. The Cambi process produces biosolids that meet Class A requirements of EPA Part 503, while Exelys does not. Though the Exelys process meets the Class A time and temperature requirements, there is potential for the system to short circuit since it is not a batch process. It should be noted that Veolia/Kruger also markets a batch process called Biothelys™ which is very similar to CAMBI.

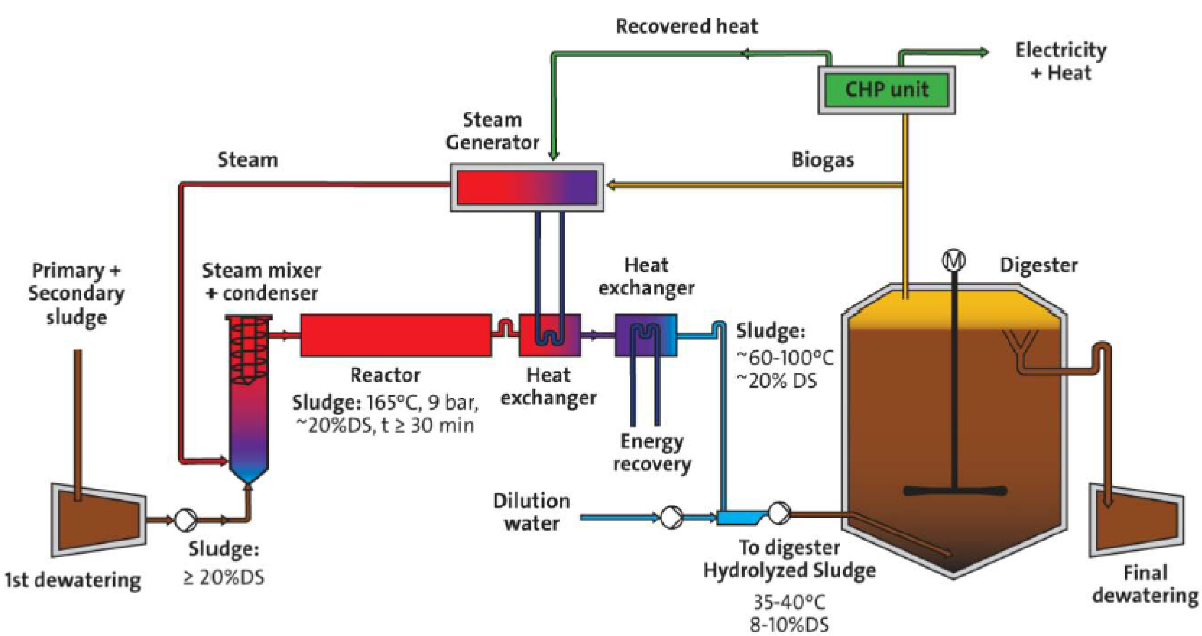


Figure 3-7 Exelys™ thermal hydrolysis LD configuration (image courtesy Kruger)

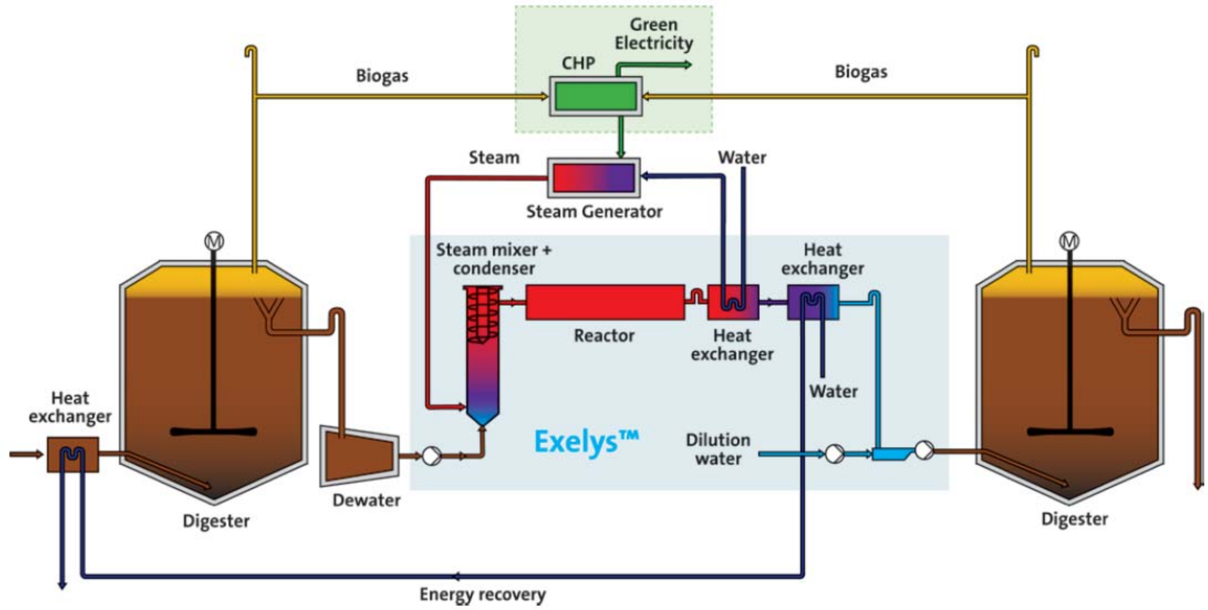


Figure 3-8 Exelys™ thermal hydrolysis DLD configuration (image courtesy Kruger)

3.1.2.6 Alternatives Screening

Anaerobic digestion was recommended in the 2008 Master Plan because it offers CORPUD the ability to capture and use energy from biosolids in the form of biogas and it facilitates the production of Class A biosolids, giving CORPUD added flexibility in disposal. Thermal hydrolysis enhances AD and may offer cost savings over the life cycle of the facility. Both technologies are evaluated in more detail in Section 5.

Although co-digestion of FOG may result in a significant increase in biogas production for a small increase in digester volume, in order to control capital costs, digesters were not sized for co-digestion. However, excess digester capacity will be available immediately after the facilities are constructed (until wastewater flows increase to 75 mgd). During this period, FOG co-digestion could be implemented with minimal additional construction. This option could be considered in more detail when anaerobic digestion is implemented.

Third-party composting of biosolids and alkaline stabilization using existing facilities at the NRWWTP will remain viable outlets for biosolids, but expansion of these facilities was not considered. For the reasons outlined above, co-digestion of biosolids with food wastes and co-composting with yard waste were not evaluated further.

3.1.3 Dewatering

3.1.3.1 Belt Filter Press

The belt filter press (BFP) is a widely used dewatering technology with a proven track record and low operating costs. Polymer-conditioned sludge is delivered onto a porous belt through which free water drains by gravity. The biosolids are then trapped between two porous belts and passed between rollers of varying diameters that further purge water from the residuals.

Belt filter presses are currently used at the NRWWTP to process the majority of its sludge.

3.1.3.2 Centrifuge

Centrifugation is the process in which a centrifugal force 500 to 3,000 times the force of gravity is applied to a slurry to accelerate the separation of the solid and liquid fractions. In 2008, CDM Smith recommended dewatering centrifuges be added to the dewatering process at NRWWTP, due to their ability to achieve a drier cake. One centrifuge was added and is used primarily to dewater sludge for third-party composting.

Compared to BFPs, Centrifuges typically produce a 3-5% drier cake. This reduced volume of dewatered material is beneficial if drying is used downstream. Centrifuges also offer a smaller footprint, require less water, and are totally enclosed, which facilitates odor control. However, centrifuges typically have a higher capital cost, require more energy, and more polymer. Centrifuges require skilled maintenance personnel but do not need continuous operator attention.

3.1.3.3 Alternatives Screening

Both BFPs and centrifuges are being operated successfully at the NRWWTP, and both technologies were considered for use in the recommended strategy.

3.1.4 Drying and Thermal Processing

3.1.4.1 Solar Dryer

Solar drying systems are similar to greenhouses, concentrating solar radiation inside a climate controlled building. In the case of solar dryers, however, the solar energy is harnessed to evaporate moisture from dewatered biosolids. To facilitate evaporation, the solids are turned regularly by an automated mechanical device. The air quality control system is also automated, moving air to maintain low humidity levels for drying. In some cases, the moist air removed from the system requires treatment for odors before discharge to the atmosphere. A solar drying facility is shown in **Figure 3-9.**

The solar drying system is composed of a number of drying chambers. Chambers are constructed atop concrete slabs with short side walls (3 feet), and transparent roofs. The dried biosolids typically emerge with total solids content of approximately 80%. Solar drying is not identified among the "processes for removing pathogens" (PFRPs) in US EPA 40 CFR 503, although site-specific permitting is available for facilities that demonstrate production of Class A biosolids. Solar drying may be capable of producing Class A biosolids whether or not the material has undergone thermal hydrolysis.

Drying costs and energy consumption are less than half as much in solar drying facilities when compared with traditional thermal dryers. According to information furnished by Parkson, solar dryers release one seventh as much carbon dioxide (CO_2) emissions as conventional thermal dryers. Operation is automated and maintenance requirements are low.

There are two main disadvantages of solar drying facilities. One is that the drying performance varies with climate, seasonally and regionally, making the system less predictable. The land area requirement is also dependent on climatic conditions and can be extensive.

Parkson is the leading manufacturer of solar drying systems; while Kruger is a second major supplier. The systems are substantially similar, achieving similar drying performance using fundamentally the same mechanisms. There are differences, however. For example, in the Kruger greenhouse, the sludge is stacked in a series of separate windrows, which help to retain heat but make aeration more difficult. The Kruger system also includes a means of conveying the sludge into the greenhouse via progressive cavity pumps, while a mechanical windrow turner disperses the sludge. In contrast, the Parkson system requires dewatered material to be transported to each greenhouse by front-end loader. Cost estimates will be based on the Parkson system, and will assume the inclusion of a roof made from twin-wall polycarbonate and corrugated polycarbonate sheets, though glass roofs are also available.

3.1.4.2 Solar + Thermal Drying

Parkson also produces a hybrid drying system that combines the strengths of both solar and thermal drying systems. (i.e., it requires half as much energy as a conventional thermal dryer and significantly less land area than solar dryers). The dried biosolids product is at least 90% TS and because of the heat-addition option, drying performance isn't as dependent on climatic conditions. Unlike the solar-only drying system, the Solar + Thermal system has a separate dewatered sludge loading area. Dewatered sludge is conveyed to a covered sludge bunker prior to a front-end loader loading it into a drying chamber, preventing wet sludge from being tracked outside the drying system. The control system and ventilation system are identical between the Solar and Solar + Thermal drying systems.

Figure 3-9: Solar Dryers

3.1.4.3 Thermal Dryer

Thermal drying was presented in the 2008 MP as the recommended strategy and remains a viable option. Thermal drying would be suitable downstream of digestion and dewatering unit processes. Thermal drying catalyzes the evaporation of water contained in the dewatered product which results in a finished product with at least 90 percent solids content. This reduction in volume facilitates the transport of the dried product to distant locations where it can be reused. Since the dried product of thermal hydrolysis meets the Class A biosolids requirements for pathogen reduction there are a range of reuse and disposal options.

Thermal drying is well in line with the City's interest in providing diversified disposal strategies. It is recommended to evaluate this alternative further, the details of which are included in section 5.

3.1.4.4 Incineration

Thermal oxidation of residuals is currently practiced in the United States using either multiple hearth furnace (MHF) or fluidized bed (FB) oxidation processes. Recently constructed thermal oxidation processes have typically utilized FB technology due to higher thermal destruction efficiencies, increased process control and process flexibility, high system reliability, and reduced air emissions rates when compared to the multiple hearth processes.

Fluidized Bed Thermal Oxidation Process

FB oxidation processes include the following subsystems: a fluidized bed reactor; a primary heat exchanger utilized to preheat the combustion and fluidizing air to an operating temperature of approximately 1200 degrees F; a secondary heat exchanger to further reduce the gas stream heat and capture heat that can be utilized to raise the exhaust stack exit temperature for plume suppression; air pollution control equipment; fluidizing sand storage and feed systems are required to provide make-up sand to the fluidized bed to replace sand lost during normal operations. The advantages and disadvantages of this system are summarized in **Table 3-1.**

Table 3-1 Advantages and Disadvantages of Fluidized Bed Thermal Oxidation

Advantages	Disadvantages
▪ Fuel efficiency ▪ Electrical power requirements of FBI are 50% of MHF ▪ Improved heat recovery ▪ Reduced emissions ▪ Dewatering improvements ▪ Can achieve ≥28% cake solids ▪ Autogenous operations that require no supplemental fuel	▪ High capital cost ▪ Complex permitting process ▪ Adverse public perception ▪ Typically, requires 30-40 dry tons per day of biomass production.

3.1.4.5 Advanced Thermal Technologies

Use of thermal technologies has often been foregone in the U.S. in favor of land-application methods that utilize the nutrient content of sludge. In European countries, however, interest has shifted toward another form of beneficial reuse: energy extraction. Generation and treatment of incineration byproducts, such as ash and flue gas, were significant challenges in the past. Alternatives to incineration have evolved, however, that reduce the amount of ash and flue gas generated while also recovering energy. With persistent concerns of land-application threatening public health, thermal technologies like pyrolysis, gasification and fertilizer production are gaining momentum.

Pyrolysis

Pyrolysis achieves decomposition of organic substances by subjecting them to an environment of high heat and low oxygen. Typical operating temperatures range from 300 to 900 degrees Celsius. Ash, oil, and gas are the final products of pyrolysis, all of which can be burned as fuel. The technology is composed of two rotary reactor chambers; Pyrolysis takes place in the first, while the pyrolysis products are combusted in the second.

Gasification

Gasification is similar to pyrolysis, though, it incorporates oxygen, making it an incomplete thermal oxidation process. The only by-products of gasification are ash and syngas (primarily carbon monoxide and hydrogen). Syngas, once cleaned, could be used as an energy source. Gasification has the potential advantages of incineration including a sterilized final product of dramatically reduced mass. Though the ash is not generally considered a hazardous waste, there are limited markets for its use. Gasification has been used for fuel sources such as coal and biomass but never wastewater sludge on a full-scale basis. Capital costs, as well as operation and maintenance costs associated with gasification are expected to be high. This technology is not sufficiently mature to be a viable option in the near future and therefore will not be evaluated further.

Commercial Fertilizer Production

Fertilizer production is a relatively new management strategy. There are a limited number of commercially available systems that are designed to produce ammonium sulfate fertilizer that meets "Class A-Exceptional Quality" USEPA standards. Ammonium sulfate fertilizer is a common type that is used with alkaline soils and sold in granulated form. Influent biosolids may be either digested or undigested and have solids content of 18 to 30%. The resulting product is very dry (greater than 99%), sterile, and enriched with nutrients.

Generally, the process focuses on odor removal, pathogen destruction, and moisture reduction. **Figure 3-10** below is a schematic of the VitAG process—one of the most well-established commercial processes in this market. Dewatered biosolids are stored in live-bottom bins with a detention time of 12-24 hours. Solids then enter the first pugmill, which grinds the cake into a paste and oxidizes the mixture to remove odors. In the hydrolysis vessel that follows, the biosolids are combined with a strong acid and ammonia under high pressure and temperature conditions to destroy pathogens and produce ammonium sulfate. The conditioning pugmill and hydrolysis vessel are unique to the VitAG system, while the rest of the equipment is standard for fertilizer manufacturing. The process includes an emissions treatment and odor control system that includes a venture scrubber, three packed bed scrubbers and biofilters.

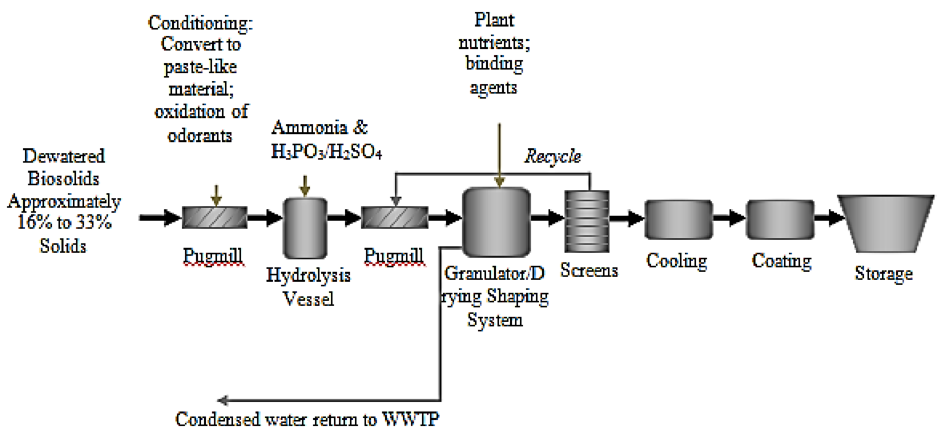


Figure 3-10 VitAG process schematic (courtesy VitAG)

Once biosolids are dewatered and transferred to the VitAG system, the biosolids are no longer the responsibility of the biosolids producer (CORPUD). VitAG charges a tipping fee to receive the biosolids and assumes responsibility for the construction, operation and permitting of the facility.

3.1.4.6 Alternatives Screening

Solar drying and combination solar/thermal drying were evaluated in more detail (see Section 5). Thermal drying was evaluation in the previous master plan. Incineration was eliminated from consideration due to vulnerability to future regulatory changes. Due to the complexity of the operations, the limited number of existing installations, and high costs, the advanced thermal technologies described above (pyrolysis, gasification, fertilizer production) were not evaluated further. However, the costs of commercial fertilizer production are decreasing at a rapid rate. CORPUD may wish to reevaluate this technology in the future in case it becomes more viable, as it would provide yet another outlet for biosolids.

3.1.5 Disposal

3.1.5.1 Land Application

Class B Biosolids may be spread on agricultural, forested, or disturbed land, as well as dedicated land disposal sites. Land application is a form of beneficial use because biosolids improve the soil's structure and water holding capacity while also providing nutrients and aeration. Pathogens and toxic organic substances are reduced in the presence of sunlight, soil microorganisms and desiccation.

3.1.5.2 Landfill

Dewatered solids can be hauled off site for disposal in a municipal solid waste landfill that has been permitted to receive wastewater solids. Landfill disposal was evaluated in the 2008 Master Plan, but not recommended for further investigation as a long-term management solution. Landfill disposal may still remain an option during emergency situations.

3.1.5.3 Product Marketing

Distribution and marketing of wastewater residuals to users such as homeowners, landscape contractors, agricultural and horticultural industries is a common practice. EPA's 40 CFR Part 503 presents the requirements for Class A pathogen reduction alternatives and vector attraction reduction which are required for any product to be distributed and/or marketed to the general public. Additionally, metal concentrations must meet maximum concentrations listed in the regulations, Part 503.13.

Typically, heat dried or composted biosolids can be marketed. There are several long standing examples including Milwaukee's Milorganite (heat-dried) and Kellog Supply's Los Angeles County program (composted). In Georgia, Clayton County Water Authority produces pellets by heat drying and sells to a distributor under the trademark AGRI-PLUS 650.

It should be noted that a successful marketing implementation requires ensuring that the final product meets all EPA and state standards before it is marketed, finding high-end users who will be loyal to the program over a long term, and educating potential users on how the product is produced and how it can benefit their application.

3.1.5.4 Alternatives Screening

The ability to maintain diverse outlets for biosolids is a key objective for CORPUD. All of the above disposal options were evaluated. However, landfill disposal was considered available only for emergency use, because it does not contribute to CORPUD's sustainability objectives.

3.1.6 Nutrient Management

Wastewater treatment plants concentrate nitrogen and phosphorus in the sludge dewatering sidestreams. Large quantities of metal salts such as alum are typically added to precipitate and remove the phosphorus. Further, the dissolved nutrients promote the formation of struvite affecting pipes, valves and pumps efficiency and operations.

To avoid chemicals purchase and sludge disposal costs, in addition to taking advantage of potential revenues from fertilizer sales, nutrient management technologies have been implemented in recent years. These processes, such as Pearl by Ostara, provide chemical precipitation in a fluidized bed reactor, removing the phosphorus load in the sludge dewatering liquid. Nutrients from the system feed streams are mixed with magnesium chloride. Sodium hydroxide is also added when needed to increase alkalinity and pH, and enhance nutrient removal. They are then fed into a fluidized bed reactor where struvite precipitates forming particles that are recovered in the form of crystalline pellets. The liquid process runs continuously. The fertilizer is removed periodically in batches and the bagged product can be potentially marketed as a commercial fertilizer.

Nitrogen in the recycled stream also required to be managed. While a side-stream treatment system can be considered, it is assumed that the main plant can handle this stream through equalization and managed feeding.

3.2 Selection of Alternatives for Further Evaluation

The objective of CORPUD's biosolids management strategy is to allow the City to produce a final product that can be readily marketed and/or distributed for beneficial use. In addition, the City wishes to enhance the sustainability of its operations by taking advantage of waste-to-energy opportunities. With these goals in mind, the following technologies were considered for detailed evaluation:

- Gravity Belt Thickening
- Anaerobic Digestion
- Thermal Hydrolysis
- Centrifuge Dewatering
- Belt Filter Press Dewatering
- Solar Drying
- Solar+Thermal Drying
- Third-party composting
- Land Application
- Alkaline Stabilization / Product Marketing
- Nutrient Management

Two comprehensive biosolids management strategies (plus several variations) employing these technologies were developed for comparison to the current solids management strategy. A detailed evaluation of these alternatives is presented in Section 5.

Section 4

Biosolids and Residuals Management Alternatives Evaluation Criteria

This section presents the methodology that was used to evaluate biosolids management alternatives at NRWWTP, including proposed cost and non-cost criteria.

4.1 Design Basis and Equipment Sizing Criteria

4.1.1 Mass Balance

A mass balance was developed for each biosolids management alternative to determine solids loadings at each step in the process train. The equipment was sized based on the results of the mass balance for maximum month solids production, with the exception of the solar dryers. Solar dryers were sized based on average day solids production.

4.1.2 Phased Implementation

The equipment requirements (e.g., number of units, capacity and operating time) for future conditions up to 75 mgd (approximately year 2035) were evaluated. When feasible and cost effective, phased implementation was considered for the selected management strategy. Phased implementation would allow the timing of capital expenditures to be adjusted based on changes in sludge loading rates, economic conditions, or the availability of funds.

4.1.3 Equipment Operating Time and Redundancy

In general, mechanical equipment was sized based on a 6 day work week, with two operating shifts (16 hours) per day under maximum month conditions at ultimate capacity (year 2035). Therefore, under average daily conditions, the operating time would be less. Provisions were made for a standby unit, which could be brought into service to reduce the daily operating time. Treatment processes that require minimal operator attention (digestion, thermal hydrolysis, solar drying) were assumed to run continuously, 24-hours per day, 7 days per week.

A few exceptions are noted in the following. For example, thermal dryers are generally operated 24 hours a day to maximize efficiency. 24-hour operation over a 5-day work week was assumed for this equipment. No redundancy was provided for the thermal dryer, since the cost of providing a redundant train is substantial, and biosolids could be diverted to other outlets in the event of a shutdown.

4.2 Basis of Cost Analysis

The cost analysis of each alternative includes the development of total present worth costs based on conceptual construction and annual O&M costs. The cost figures developed not only facilitate the comparison between alternatives but also indicate the order-of-magnitude of the cost for implementing each biosolids management strategy.

The opinions of probable cost are based on the conceptual design of each alternative to determine the equipment, land area, process building, storage, utility, maintenance and staffing requirements. The conceptual construction costs were prepared using quotations from qualified equipment vendors, recent bid tabs, and recent cost estimates prepared for similar projects. Construction of electrical structures and instrumentation costs were calculated as percent of the equipment cost.

4.2.1 Conceptual Capital Cost Development

The conceptual opinion of probable construction cost was developed to compare alternatives relative to one another. In addition to direct construction costs (equipment, labor, and materials), capital cost estimates include a number of indirect costs, as illustrated in **Table 4-1.** These costs follow the framework described in the 2008 *Master Plan.* Capital costs are reported in December 2012 dollars (ENR CCI = 9412.25).

Table 4-1 Summary of Indirect Construction Cost Assumptions

Item	Percentage	Basis	
Subtotal Direct Construction Costs (Equipment, Labor, Materials)			**TOTAL A**
Sales Tax	6.75%	Equipment Only	↓
Building Permits	0.25%	of A	
Builders Risk and Liability Insurance	2%	of C	
Performance and Payment Bonds	1.50%	of C	
Subtotal Direct Construction Cost and Fees			**TOTAL B**
Contractor General Conditions	8%	of B	↓
Contactor General Overhead	5%	of B	
Contractor Profit	5%	of B	
Subtotal Direct Construction Cost + Contractor OH&P			**TOTAL C**
Construction Contingency	25%	of C	↓
Design Engineering Services	10%	of C	
Engineering Services During Construction	5%	of C	
Owners Administration, Legal and Bonding	3%	of C	
Total Project Cost			**TOTAL D**

The intended use of this opinion of probable costs is to compare alternatives relative to one another. The final cost of any project described in this report will depend on project complexity, actual labor and material costs, competitive market conditions, actual site conditions, final scope of work, implementation schedule, and engineering. The cost of buffer zones to reduce visual, odor, traffic and noise impacts was not included in this analysis.

4.2.2 Operations and Maintenance Costs Development

In addition to capital costs, total project life cycle costs are influenced by the ongoing O&M costs associated with the selected treatment technologies and the sequence in which these processes are deployed in the overall management of residuals from the system. O&M unit costs ($/dry ton) for each residuals unit process were developed based on the mass of material entering the specific unit process. These costs were estimated using the assumptions for power, labor, chemicals and other cost components shown in **Table 4-2**. These unit costs were reviewed by CORPUD staff to verify consistency with current operations.

Table 4-2 Unit O&M Cost Assumptions

O&M Parameter	Unit Cost
Labor and Utilities	
Labor cost (including fringe benefits)	$34.09 per hour
Electricity cost	$0.076 per KWH
Natural gas cost	$8.00 per MMBTU
Polymer cost	$1.59 per pound (active) of polymer
Thickening	
Thickening polymer dose	10 lb per dry ton (active)
Dewatering	
Dewatering schedule	16hr/day, 6 days/week
BFP Dewatering polymer dose	12.5 lb per dry ton (active)
Centrifuge Dewatering polymer dose	25 lb per dry ton (active)
Centrifuge Pre-dewatering polymer dose	5 lb per dry ton (active)
Disposal	
LKD Admixture blending ratio	2 tons admixture per dry ton solids
Raleigh Plus average hauling distance	36-55 miles
Raleigh Plus sale price	$4.70/product ton[a]
Liquid Land Application Cost	$0.0525/gallon sludge
Liquid Land Application average hauling distance	31-60 miles
Contract Composting Fee (<16 dry ton/day)	$37.22 per wet ton
Contract Composting Fee (>16 dry ton/day)	$43.22 per wet ton

[a] Assumes 90% of Raleigh Plus is sold with spreader rental at $5/ton. The remainder is sold at $2/ton

O&M unit costs for each residuals unit process and cost category (i.e., labor, power, polymer, natural gas, maintenance) were developed and are presented in detail in **Appendix A**. These unit process costs were combined to develop overall management strategy operations and maintenance unit costs (e.g., $/dry ton raw material) for each management option. Solids loading rates for this analysis were based on annual average day solids production.

Annual O&M costs were projected up to year 2035, assuming that all facilities for each alternative were constructed at the beginning of the study period, without phased implementation. O&M costs are shown for each alternative in Section 5 of this report.

As an update to Table 4-1 in the 2008 Biosolids Management Master Plan, **Table 4-3** summarizes the O&M costs developed for each process, based on current operating costs for power, labor, and chemicals. For equipment not currently installed at NRWWTP, information provided by manufacturers and observed at similar facilities was also utilized for this analysis. Each value in Table 4-3 represents the unit cost to treat 1 dry ton of solids entering that specific process.

Table 4-3 Unit Operating Cost Summary

Process	Unit Cost Per Dry Ton Entering the Process		
	Alternative* 1: Existing Process	Alternative* 2: Anaerobic Digestion	Alternative* 3: Anaerobic Digestion with Thermal Hydrolysis
Gravity Belt Thickening	$74	$40	-
Aerobic Stabilization	$118	-	-
Anaerobic Stabilization	-	$6	$3
Dewatering (Belt Filter Press)	$37	-	$41
Dewatering (Centrifuge)	$90	$67	-
Pre-Dewatering (Centrifuge)	-	-	$25.29
Solar Drying	-	$25	$15
Solar/Thermal Drying	-	$85	-
Thermal Drying	-	$143	$106
Thermal Hydrolysis Process	-	-	$9
Alkaline Stabilization	$187	$188	$177
Off-Site Composting (<16 DTPD)	$177	$162	$124
Off-Site Composting (>16 DTPD)	$206	$188	$144
Liquid Land Application	$350	$468	$225
Dewatered Material Land Application	$144	$132	$101

* See Section 5 for a detailed description of each alternative.

As shown in the table, the costs of final disposal (via alkaline stabilization, composting, liquid or cake land application) vary between the alternatives. This is due to the different degrees of dewatering achieved: existing equipment dewaters cake to approximately 21% solids. Anaerobic digestion improves the dewaterability of the sludge, so 23% solids are assumed under Alternative 2; while under Alternative 3, 30% cake is expected due to the impact of hydrolysis. In the case of liquid land application, the post-digestion solids content of the sludge is expected to be higher for hydrolyzed, digested sludge (Alternative 3) than for aerobically or anaerobically digested sludge alone. More detail concerning these assumptions can be found in Appendix A.

4.2.3 Net Present Worth Cost Development

Net present operating costs were developed to assess the life-cycle operations and maintenance expense associated with each management strategy. Assumed rates of cost escalation, bond issue rate, and discount rate were coordinated with those presented in the *Falls Lake Dam Hydroelectric Project Pre-Feasibility Study* (2011*).* **Table 4-4** summarizes the parameters used. For analysis of the combined heat and power system, discussed in Section 6, avoided-cost electricity prices were escalated separately using the base scenario from the schedule of projected prices presented in the above report. This schedule is provided in **Appendix B**.

Table 4-4 Net Present Value Cost Assumptions

Parameter	Rate
Escalation of capital and major maintenance costs	4.5%
Escalation of Operations Costs	3.0%
Bond Issue Rate	4.7%
Discount Rate	4.7%

Present worth costs are reported in December 2012 dollars. Construction of the proposed facilities was assumed to be completed by 2016, which would be the first year of operation. Life cycle operating costs were developed for each of the management strategies from 2016 through 2035.

4.2.4 Sensitivity Analysis

Certain unit costs, particularly energy prices, are quite volatile and difficult to predict far into the future. As such, a sensitivity analysis was performed for the lifecycle O&M costs in which the price of electricity was increased and decreased by 20%. The impact of this change on NPV O&M costs was negligible, at approximately 3%. Biosolids O&M costs are driven much more strongly by labor and chemical expenses than energy prices.

4.3 Framework for Non-Monetary Evaluation of Alternatives

4.3.1 Evaluation Criteria and Performance Measures

Cost is only one of many factors that must be considered in the selection of a biosolids management strategy. Equally important are factors such as public health, long-term sustainability, the number and variety of distribution outlets, ability to react to future changes in environmental regulations, public perception of treatment processes and biosolids products, and adaptability of the program to growth and other changes in the area.

The following non-cost evaluation criteria were developed through discussions with CORPUD staff:

- **Regulatory Requirements**: This criterion rates the ability to meet both the current and anticipated future federal, state, and local regulations.
- **Reliability:** The ability of a given treatment process to consistently perform in accordance with the intended design with minimal down time. Systems that require extensive equipment or incorporate newer technologies may be considered less reliable than other systems using simpler, proven technologies with a long history of success.
- **Sustainability**: The extent to which a treatment alternative contributes to achieving the City's stated sustainability goals related to energy efficiency and greenhouse gas emissions reduction. It also considers the extent to which an alternative uses all potential resource recovery opportunities.
- **Constructability**: The ability to modify and/or expand the existing treatment facility to accommodate each alternative, and to make best use of existing facilities. It will consider the impacts on existing layout and the ability to integrate new equipment to the existing facility.

- **Operator Friendliness**: Considers exposure to potential safety hazards, the amount and type of operator attention required, the degree of automation, and accessibility of equipment.
- **Ease of Maintenance:** Considers the amount and complexity of routine maintenance requirements, required spare parts inventory, availability of parts, and special tools or skill requirements.
- **Flexibility/Adaptability**: Flexibility/adaptability is defined as the ability of a treatment process to accommodate variations in flow, waste load, maintenance service needs (down time), and permit requirements.
- **Outlet Diversification:** The diversity of available outlets for the final product(s) (e.g., Raleigh Plus or Class B biosolids). Multiple outlets allow the treatment system to adapt to changing market conditions.
- **Side Stream Impacts**: Concentrated return flows from biosolids treatment may upset the liquid treatment and result in high levels of nitrogen and phosphorous in the effluent. This criterion measures the potential impact of the solids treatment system on liquid treatment.
- **Public Acceptance**: Includes the positive or negative impact each alternative has on the surrounding community including residents and businesses near the WWTP and at biosolids land application locations. Public acceptance includes aesthetic and ergonomic factors such as traffic, noise, odor, and visual appeal.
- **Public Health and Environmental Impacts:** The ability to meet the Biosolids EMS goal of protecting the environment and public health. Treatment alternatives which minimize impacts such as potential for groundwater contamination, odors, pathogen/vector attraction, and destruction of plant and wildlife habitat will score highly. Treatment alternatives that achieve Class A pathogen reduction will score more highly than those that achieve Class B.

4.3.2 Alternatives Ranking

A simple ranking process was used to rate alternatives based on non-cost factors. This method consisted of developing weighting factors to be assigned to each criterion, and rating the performance of each alternative in meeting each criterion on a 1-5 scale. For each criterion, the weight factor was multiplied by the 1-5 rating to generate a score, which was summed over all the criteria to establish an overall score for the alternative.

Weighting factors for each criteria were established by surveying a cross-section of CORPUD staff, including management, operations, maintenance, and other functional roles within the organization. The survey used to solicit the weight factors is provided in **Appendix C.** A total of 100 weighting points were distributed across all evaluation criteria. **Table 4-5** summarizes the results of the weighting exercise. As shown, regulatory requirements, public health and environmental impacts, and outlet diversification received the highest weights.

CDM Smith staff, in collaboration with CORPUD, rated the performance of each management strategy by assigning a 1 to 5 score to each criterion. A “1” signifies that the alternative performs poorly, while a “5” signifies excellent performance.

Table 4-5 Summary of Non-Cost Weight Factors

Performance Criterion	Weight Factor
Regulatory Requirements	12
Public Health and Environmental Impacts	12
Outlet Diversification	11
Reliability	9
Operator Friendliness	9
Ease of Maintenance	9
Constructability	8
Flexibility/Adaptability	8
Side Stream Impacts	8
Public Acceptance	7
Sustainability	7
TOTAL	**100**

The following equation summarizes the scoring methodology:

$$\text{Overall Non-Monetary Score} = \Sigma\, w_i\, R_i$$

In this equation, the overall non-monetary score is the total number of rating points received from each criterion. The higher overall scores represent the most favorable alternatives. w_i represents the weight assigned to each criterion "i", and R_i represents the individual 1-5 rating score assigned to the alternative for the criteria "i". The multiplication was carried out for each individual criterion, and then the scores were added together. The summed results were then ranked highest to lowest with the highest ranked alternative being the most favorable alternative. The maximum possible score using this system is 500 points.

The results of the non-cost evaluation are presented in Section 5.

4.3.3 Greenhouse Gas Emissions

The life cycle greenhouse gas (GHG) emissions associated with each management alternative were estimated using nominal assumptions about the treatment processes and disposal outlets involved. GHG emissions are reported in metric tons of CO2 equivalents (CO2e). A typical passenger vehicle will generate approximately 5 metric tons CO2e of emissions during the course of a year (U.S. EPA, 2012).

It is common practice to classify GHG emissions into "scopes" representing different sources of emissions. The scopes are listed below, with elements of each that are applicable to this project.

- Scope 1 – Includes all emissions generated inside the plant, consisting primarily of fugitive methane and N_2O emissions.
- Scope 2 – Accounts for off-site emissions associated with electricity usage.
- Scope 3 – All emissions generated outside the plant are included in Scope 3. The principal component of scope 3 emissions in this study is transportation of biosolids to final disposal.

- Scope 3 offsets – Offsets represent processes that effectively remove carbon from the atmosphere. The majority of the organic carbon in wastewater originated in the atmosphere, was incorporated into plants through photosynthesis, and consumed by animals and people. Some biosolids disposal outlets, such as land application and composting, render this carbon unavailable for an extended period of time, effectively sequestering it in the soil. As such, final disposal of biosolids may offset some or all of the GHG emissions associated with processing.

Estimated GHG emissions for each alternative are included in Section 5. A summary of the assumptions used in the calculations is provided in **Appendix E.**

Reference

U.S. EPA. *Greenhouse Gas Equivalencies Calculator.* Updated October 2012. http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Section 5

Evaluation of Selected Biosolids Management Alternatives

This section identifies several alternatives for biosolids processing and beneficial use that aim at improving the sustainability of CORPUD's current operations. Each alternative consists of a series of management strategies that are based on the technologies presented in Section 3. A preliminary screening of all available technologies resulted in the selection of those below, which were deemed most compatible with CORPUD's evaluation criteria, current biosolids practices, and future conditions.

5.1 Wastewater Biosolids Management Strategies

The following management strategies were developed in collaboration with CORPUD staff.

- **Anaerobic Digestion** - Mesophilic anaerobic digestion characterizes this management strategy. Primary sludge and thickened WAS are sent to the digesters, which are maintained at a temperature of 95 degrees F with a minimum solids retention time (SRT) of 17 days (at two week max solids loading rates). This treatment is expected to achieve a volatile solids reduction (VSR) of 50 percent, offering superior performance compared to the 40 percent VSR achieved in the existing aerobic digesters. Stabilized cake can typically be dewatered to 20 percent solids.
- **Thermal Hydrolysis Process with Anaerobic Digestion** – Prior to anaerobic digestion, sludge is fed through a thermal hydrolysis process (THP) in which the reactors are heated with steam to 320 degrees F and pressurized to 100 psi, achieving pathogen reduction and biomass cell lysis. Following hydrolysis, sludge is diluted with effluent water and is fed to anaerobic digesters at 10 to 11%total solids, which yields a higher VSR (65%) and proportionally increased gas production compared to anaerobic digestion alone. Dewatering capabilities are also improved, with dewatered cake at 30% solids concentration.
- **Existing Disposal Management Strategies** – CORPUD's current practices for disposal of biosolids remain viable management strategies for the future. Class A alkaline stabilization (aka RaleighPlus) and contract Class A composting at NRWWTP and Class B liquid land application at NRWWTP and LCWWTP provide a diversified set of outlets for this material.
- **Drying** – drying is a potentially cost-effective solution to solids disposal, as it reduces the volume of material that must be transported and generates a Class A product. Three drying technologies were evaluated:
  - ***Solar Drying*** - Dewatered sludge cake is spread in a layer across the floor of several solar modules, and agitated by an automated roving machine. The combination of solar heat and constant agitation work together to speed the drying process, and solids content of 75 percent or higher may be achieved. Class A is a potential outlet, although this technology is not currently classified by EPA as a Process to Further Reduce Pathogens. A list of installations in the U.S. by Parkson (the market leader) is provided in **Appendix D.**

- ***Thermal Drying*** – The 2008 Biosolids Management Master Plan (MP) recommended rotary drum drying, in which dewatered sludge cake is dried by direct contact with hot gases in a drum dryer to a solids content above 90%. Fuel for heat drying may be natural gas or biogas. The results of the 2008 MP for thermal drying are compared against those obtained for other technologies evaluated in this report.
- ***Solar Drying + Thermal Drying*** – This recent development in heat drying consists of a combination of solar drying for pre-drying followed by thermal drying. The dewatered cake at 20% solids is fed to the solar dryer, which delivers solids with a solids content above 30% to the thermal dryer. The final output achieves Class A characteristics with solids content from 75- 90%.

- **Energy Recovery** – A combined heat and power (CHP) engine fueled by biogas from the anaerobic digesters produces electrical and thermal energy. The thermal output can be used by the digester heat exchangers or to generate steam for the thermal hydrolysis system, while the electrical power can be either used on site or distributed to the electrical grid.

The above management strategies were combined into alternatives that are evaluated below for comparison to NRWWTP's current operations. A detailed evaluation including design characteristics, non-monetary factors, and a present worth cost analysis based on conceptual construction and annual O&M costs is presented for each alternative. This evaluation assumes that construction will be completed in year 2016. O&M costs are projected for the 20-year period between 2016 and 2035. The methodology for this analysis is further discussed in Section 4.

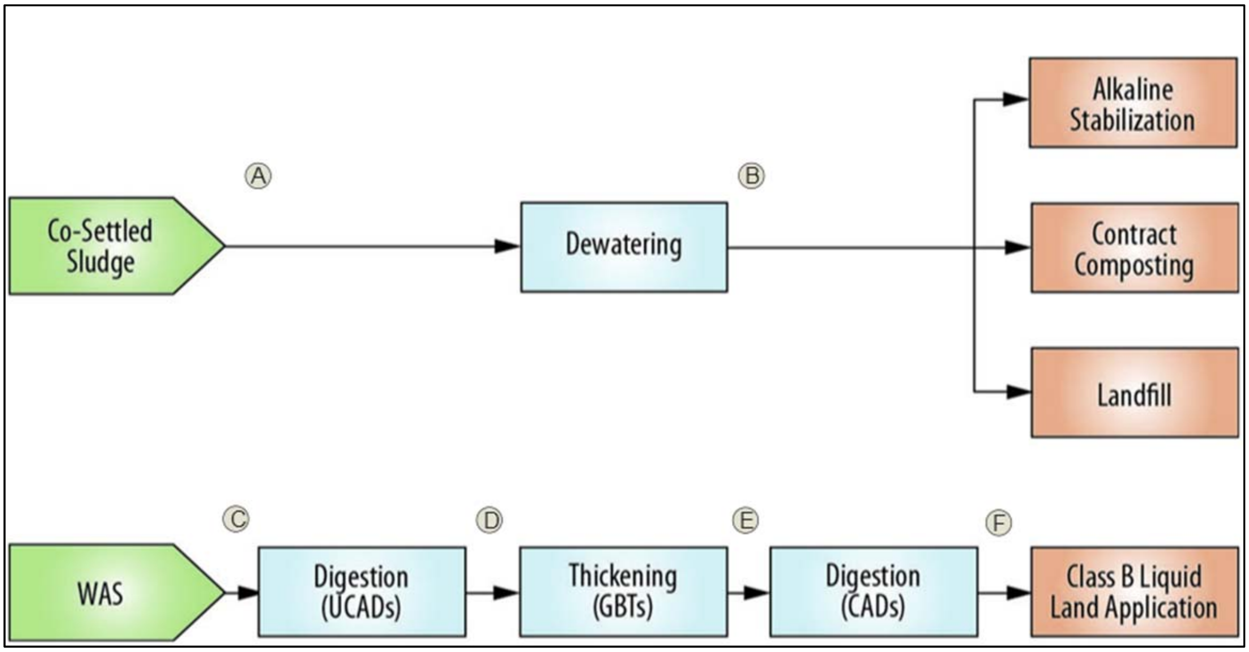
At LCWWTP, the existing practice of land applying digested biosolids as a Class B liquid is expected to be sufficient for the duration of the planning period. As noted in Section 2, influent flows to LCWWTP have decreased in recent years and the projected growth will not occur within this plant's service area. Due to its distance from NRWWTP, hauling or conveying the sludge to NRWWTP for further process would not be cost-effective.

5.2 Wastewater Biosolids Alternative 1 – Base Case

5.2.1 Process Description

The Base Case alternative represents continued use of the existing facilities and operational practices. It serves as a point of reference for the remaining alternatives, which involve capital improvements and modifications to the biosolids treatment process.

The current practice at NRWWTP involves co-settling a large fraction of the waste activated sludge (WAS) with the primary sludge. The remaining WAS is thickened with gravity belt thickeners (GBTs), and then aerobically digested. Multiple outlets are available for biosolids under this alternative. Dewatered cake can undergo alkaline stabilization to Class A quality and be marketed as "Raleigh Plus," or hauled away for composting by a third party. Landfill disposal is available if necessary. Biosolids can also be removed directly from the CADs for land application as a Class B liquid. **Figure 5-1** shows a process schematic and mass balance for this alternative.



Process Step	A	B	C	D	E	F
	Co-Settled Sludge	Dewatered Cake	WAS	UCAD Effluent	Thickener Effluent	CAD Effluent
Average Solids loading (DT/day)	59.6	56.7	9.8	9.8	9.3	6.7
Average Solids loading (WT/day)	n/a	266	n/a	n/a	n/a	n/a
Solids Concentration (%)	2.6%	21.3%	0.9%	0.9%	5.0%	3.6%
Average hydraulic loading (gal/day)	550,000	n/a	262,000	262,000	45,000	45,000

Figure 5-1 Process Flow Diagram and Mass Balance at average day 2035 conditions for Alternative 1

5.2.2 Facilities Required

A detailed description of the existing facilities is provided in Section 2 of the 2008 MP. Detailed assessment of the existing facilities was not performed as part of this project. However, several capital improvements are assumed to be needed in order for these facilities to remain in operation for the duration of the planning period. These are described below.

5.2.2.1 Aerobic Digester Rehabilitation

Numerous improvements to the existing anaerobic digestion system will be needed in the next 20 years. The following improvements are included in Alternative 1:

- **Aerobic Digester Tanks:** According to CORPUD, the two pre-stressed aerobic digesters built in the early 80s (Digesters 1 and 2) and the two poured in place digesters built in 1991 (Digesters 3 and 4) were recently inspected and appear to be in acceptable condition. Some repairs were performed on Digester 4. The capital costs for Alternative 1 assumes an allowance for limited repair of the concrete tanks during the planning period. However, no replacement of the tanks was assumed, given that typically wastewater infrastructure is designed with a 50-year life expectancy. Since these tanks are 20 to 30 years old, they fall within that life for the planning period.

- **Aerobic Digester Equipment:** Replacement of the jet mixing system, covers, and odor control is included in the opinion of probable costs. It is also anticipated that new blowers similar to the existing 800 hp single stage Roots blowers in the Thickening Building may be used to aerate the digesters in the future. Two new units are included in the costs.
- **Electrical and Instrumentation Upgrades:** While it is anticipated that fairly extensive upgrades will be required in the future, the specifics have not been identified by CORPUD at this time. An allowance was included in the costs to capture these improvements.

5.2.2.2 Dewatering Improvements

CDM Smith conducted a preliminary structural inspection of the existing Dewatering Building, constructed in 1993, and concluded that it appears to be in sound condition. However, most of the metallic equipment inside is corroded and in need of replacement, and minor structural modifications may be necessary to accommodate changes in the building HVAC requested by plant staff. For the purposes of this evaluation, it was assumed that the existing facility would be modified or rehabilitated as needed, and the existing belt filter presses replaced. The high solids centrifuge installed in the existing Dewatering Building is assumed to remain in service as well. **Table 5-1** provides a summary of the belt filter press characteristics.

Table 5-1 Replacement Belt Filter Press Design Criteria

Parameter	Design Criteria
Number of Units	3
Belt Width	2m
Design Solids Loading Rate	750 dry lb/hr/m
Design Hydraulic Loading Rate	30 gpm/m
Design Outlet Solids Concentration	22 %
Solids Capture Efficiency	95 %

5.2.2.3 Truck Loading Improvements

The dewatered cake conveyance system and truck loading station will reach the end of their design life in 2028. Both facilities will be replaced.

5.2.3 Evaluation

5.2.3.1 Cost

Table 5-2 provides an opinion of probable capital costs and net present O&M costs over the 2016-2035 period based for the facilities described above.

5.2.3.2 Non-Cost Factors

When considering the non-cost factors, Alternative 1 scored 58% in terms of meeting the City's goals, as illustrated in **Table 5-3**. While this alternative does represent a viable strategy for managing biosolids, compared to the others considered, it offers fewer opportunities for outlet diversification and has fewer sustainable features.

Finally, the greenhouse gas emissions offset associated with this alternative were estimated at 1,000 metric tons CO2 equivalents (CO2e) per year, which is roughly equivalent to the emissions from 200 passenger cars. Although treatment and hauling of residuals use energy and generate CO2 emissions, final disposal of biosolids actually prevents CO2 emissions by 1) sequestering carbon in the ground for a long period and 2) replacing the use of synthetic fertilizers, and the emissions associated with their production and application. As such, the net greenhouse gas impact of Alternative 1 is to remove CO2 from the atmosphere. While this fact is certainly positive from a sustainability standpoint, the offset for Alternative 1 is considerably less than for the other alternatives.

Table 5-2 Opinion of Probable Capital and O&M Costs for Alternative 1

Capital Cost ($M)[1]	Equipment	Labor & Material	Total
Aerobic Digester Rehabilitation	$6.8 M	$3.1 M	$9.9 M
Replace Existing BFPs	$1.6 M	$1.4 M	$3.0 M
Replace Conveyors (2028)	$0.8M	$0.3 M	$1.1 M
Replace Truck Loading Station (2028)	$0.9 M	$0.3M	$1.2 M
Subtotal Direct Construction Costs	**$10.1 M**	**$5.1 M**	**$15.2 M**
Total Capital Cost[2]			**$28.3 M**
O&M Cost ($M)		**Unit Cost ($/MG)[3]**	**NPV**
WAS Thickening		$9.65	$3.5 M
Aerobic Digestion		$14.70	$5.4 M
Liquid Land Application[4]		$31.16	$11.4 M
Dewatering		$29.68	$10.9 M
Alkaline Stabilization[4]		$105.80	$38.7 M
Composting[4]		$33.42	$12.2 M
Total Net Present O&M Cost[5]			**$82.1 M**
Total Net Present O&M Cost per Dry Ton Biosolids Disposed			**$237**

[1] All capital costs are reported in December 2012 dollars (ENR CCI = 9412.25), with the exception of Conveyance and Truck Loading replacement, which are assumed installed in 2028, at the end of the current facility design life. These costs are escalated and discounted as described below.

[2] Includes markups for taxes, permits, bonds, insurance, contractor's general conditions, overhead and profit, engineering services during design and construction, administrative costs, and contingency. A detailed description of these markups is provided in Section 4.

[3] Unit cost per million gallons treated by the WWTP

[4] Unit cost per MG treated assumes that the contracted amount of biosolids continue to be sent to composting, while the remainder is processed by alkaline stabilization.

[5] Net present cost for the period 2016-2035, assuming annual inflation of 4.5% for capital costs, 3.0% for labor costs, and a 4.7% nominal discount rate.

Table 5-3 Summary of Non-Cost Performance for Alternative 1

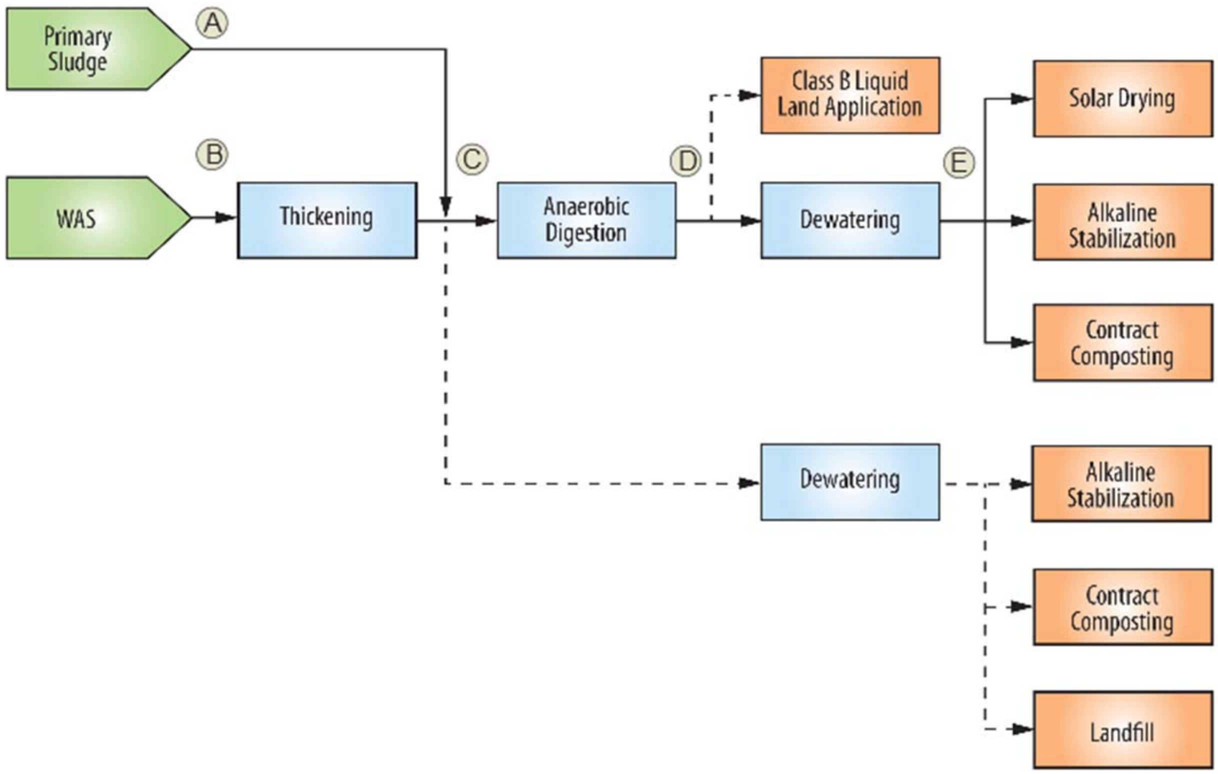
Performance Criterion	CORPUD Weight	CDM Smith Rating (0-5)	Criterion Score
Regulatory Requirements	12	3	36
Reliability	9	3	27
Sustainability	7	1	7
Constructability	8	0	0
Operator Friendliness	9	4	36
Ease of Maintenance	9	4	36
Flexibility/Adaptability	8	3	24
Outlet Diversification	11	3	33
Side Stream Impacts	8	4	32
Public Acceptance	7	3	21
Public Health and Environmental Impacts	12	3	36
		Overall Score:	**288**
		Percent Score (out of 500):	58%
Annual Greenhouse Gas Emissions Offset (2016-2035), metric tons CO2 equivalents/yr			**1,000**

5.3 Wastewater Biosolids Alternative 2 – Anaerobic Digestion with Solar Drying

5.3.1 Process Description

Anaerobic digestion forms the backbone of the residuals treatment train in this alternative, allowing a more stable product than aerobic digestion and higher VSR resulting in lower volume of solids. The portion of solids not processed by solar drying would continue to be disposed with current methods such as land application, improving the diversification of end uses. In addition, the production of biogas creates opportunities for energy recovery.

Figure 5-2 shows a process flow diagram for this alternative. Dashed lines indicate alternative, optional modes of operating the facilities that not considered part of the “normal” process.

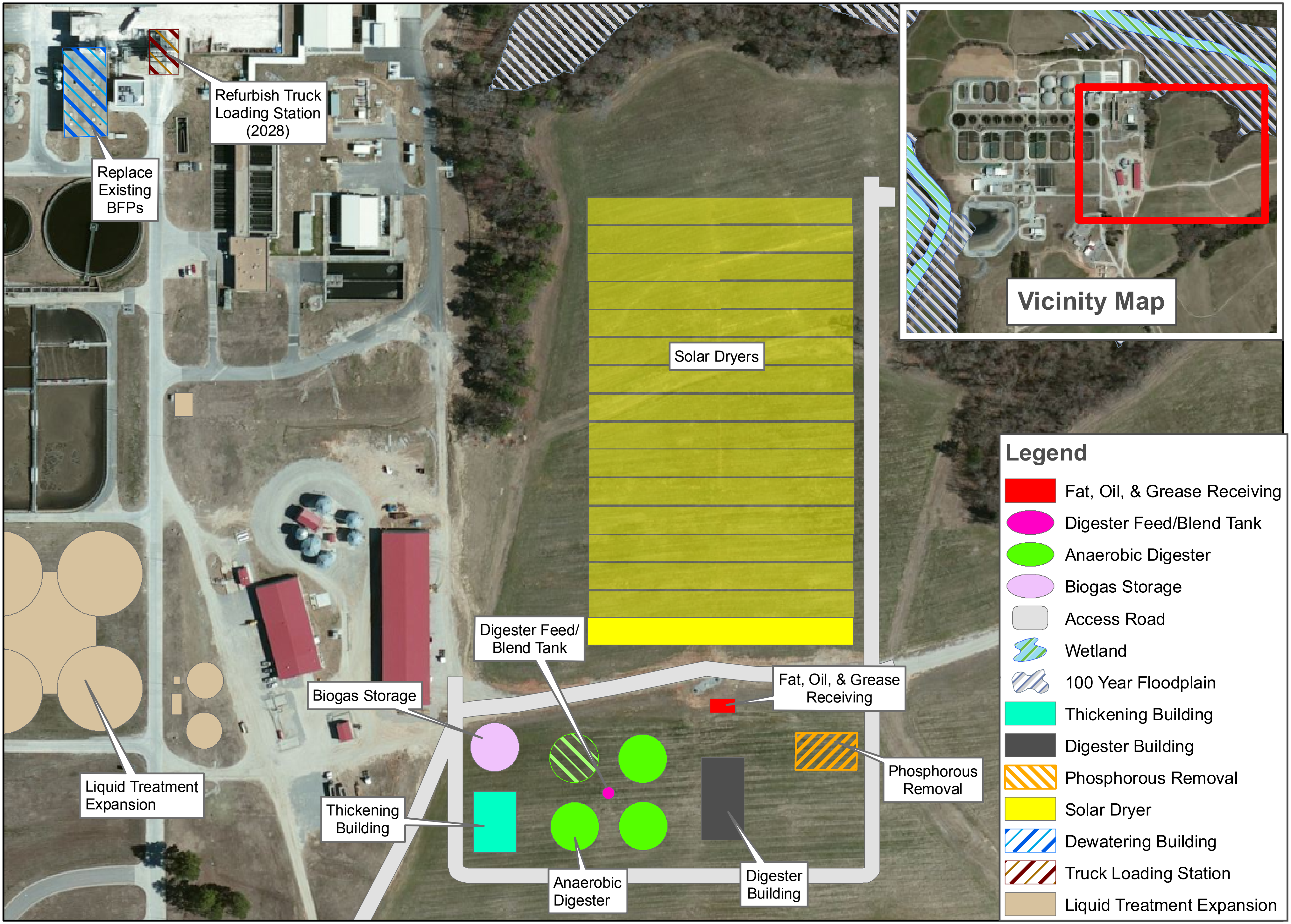


Process Step	A Primary Sludge	B WAS	C Thickener Effluent	D Anaerobic Digester Effluent	E Dewatered Cake
Average Solids loading (DT/day)	42.0	27.4	26.0	42.2	40.1
Average Solids loading (WT/day)	n/a	n/a	n/a	n/a	174
Solids Concentration (%)	4.0%	0.9%	5.0%	2.7%	23%
Average hydraulic loading (gal/day)	252,000	729,000	377,000	377,000	n/a

Figure 5-2 Process Flow Diagram and Mass Balance at average day 2035 conditions for Alternative 2

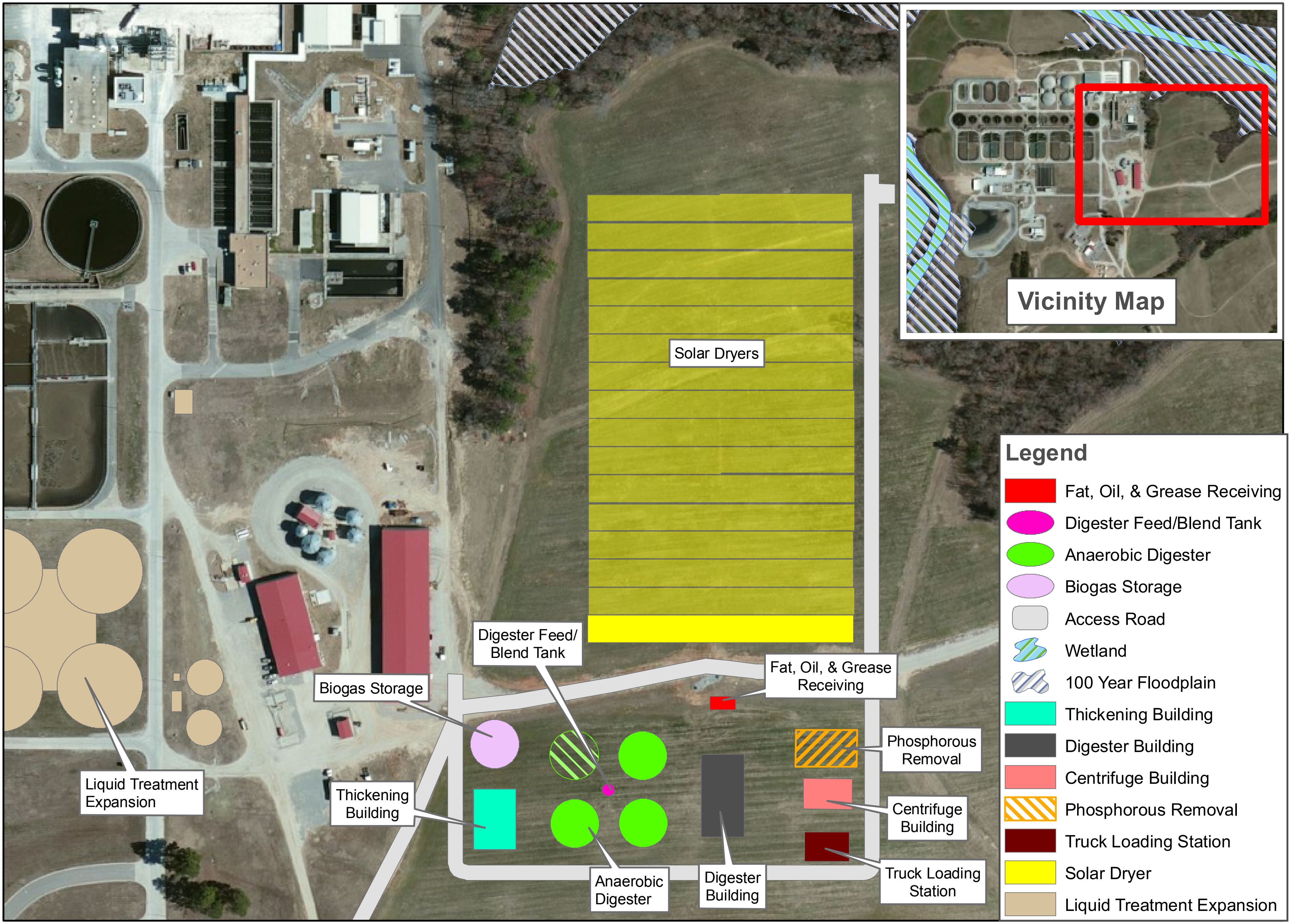
5.3.2 Facilities Required

Two implementation options are proposed for this alternative. Under option A (shown in **Figure 5-3**), the existing dewatering facility would remain in use similar to Alternative 1. The proposed new facilities are located south of the current plant. Under option B, shown in **Figure 5-4**, a new centrifuge dewatering building and the other proposed solids processing facilities are located east of the administration building. CORPUD identified this area as the most suitable for these processes, allowing continuation of current operations during construction as well as placing potential sources of odor away from neighboring communities. However, its distance from the existing dewatering facilities would make it difficult to incorporate them into the biosolids treatment process.



CDM Smith

Figure 5-3
Alternative 2A - Anaerobic Digestion and Solar Drying



CDM Smith

Figure 5-4
Alternative 2B - Anaerobic Digestion and Solar Drying

5.3.2.1 Gravity Belt Thickening

WAS is thickened through three 3m GBTs, similar to but larger than the existing units at NRWWTP. These will be located in a new thickening building located to the southeast of the main liquid treatment train, near the other biosolids processing facilities. **Table 5-4** summarizes the thickener design criteria.

Table 5-4 Gravity Belt Thickener Design Criteria

Parameter	Design Criteria
Number of Units	3
Belt Width	3m
Design Solids Loading Rate	900 dry lb/hr/m
Design Hydraulic Loading Rate	250 gpm/m
Design Outlet Solids Concentration	5.0 %
Solids Capture Efficiency	95 %

5.3.2.2 Anaerobic Digesters

Digester Tanks

Primary sludge and thickened WAS are blended prior to anaerobic digestion, which takes place in three 2.75-MG concrete digesters. Space is provided for a future fourth digester of the same size to accommodate expansion beyond 2035. Each digester is equipped with draft tube mixers to keep solids in suspension and enable the process to operate at a high rate, as discussed in Section 3. **Table 5-5** presents the design criteria for the digesters. These vessels are sized to treat all sludge produced by the NRWWTP. Therefore, once they are implemented, it would not be necessary to maintain the aerobic digestion or direct dewatering treatment trains.

Table 5-5 Anaerobic Digester Design Criteria for Alternative 2

Parameter	Design Criteria
Number of Units	3
Volume (each)	2.75 MG
Solids Retention Time (at 14-day peak rate)	17 days
Volatile Solids Reduction	50%
Design Outlet Solids Concentration	2.7 %

Digester Building

A Digester Building located adjacent to the digesters will house heat exchangers, boilers, and feed pumps that are required to heat incoming sludge and maintain the appropriate temperature for high-rate digestion within each vessel.

Biogas Storage

A biogas storage vessel, consisting of a domed membrane cover and a concrete slab, is located near the dewatering building. This facility will equalize the flow of biogas from the digesters to downstream processes such as CHP engines, and will provide limited biogas storage. Biogas can be saved for use during periods of peak electrical demand to reduce power costs. Energy utilization options for biogas are discussed further in Section 6.

5.3.2.3 Dewatering

The recommended option (Option A) for dewatering is to refurbish the existing dewatering facility and replace the belt filter presses. This will allow CORPUD to realize more of the useful life of the existing conveyance and truck loading facilities by keeping them in service. This option will also preserve the ability to use the alkaline stabilization facilities to treat biosolids.

Under Option A, a pipeline would be constructed to convey digested solids from the new biosolids management area back to the existing biosolids day tanks. Pumps in the digester building would provide the head needed to convey this material. Once in the day tanks, the biosolids could be treated in the same way they are now.

Option B is proposed in response to CORPUD's concerns regarding the condition of the existing dewatering building and a desire to co-locate as many biosolids processing facilities as possible. Under this option, a new dewatering facility will be constructed in close proximity to the digesters and solar dryers. It will be substantially similar to that proposed in the 2008 MP, housing three centrifugal dewatering units. The existing centrifuge will be relocated to this new building, and two additional units of the same size will be added. Dewatered material will be conveyed to a new truck loading station, where it can be transported to the solar dryers, off-site composting, or landfill disposal. Design criteria for the centrifuges are shown in **Table 5-6.**

Table 5-6 Final Dewatering Centrifuge Design Criteria for Alternative 2

Parameter	Design Criteria
Number of Units	3
Manufacturer/Model	Alfa Laval G2 115
Design Solids Loading Rate	3,150 dry lb/hr
Design Hydraulic Loading Rate	250 gpm
Design Outlet Solids Concentration	23 %
Solids Capture Efficiency	95 %

5.3.2.4 Solar Dryers

Dewatered cake is transported by truck from the new dewatering facility to the solar drying modules. While some manufacturers supply pumping or conveyance systems to transport the cake, to control costs the solar dryers were assumed not to include these additional facilities. The solar drying process consists of 16 individual solar modules (greenhouses) equipped with automated climate control and autonomous rototilling devices that mix, aerate and distribute the sludge unloaded to each module with front end loaders. The facilities are capable of drying biosolids from 23% to 75% solids or beyond, based upon average climatic conditions for Raleigh. Each module is approximately 42-ft wide by 450-ft long.

In sizing these facilties, it was assumed that the 80 DT/week composting contract remains in effect throughout the planning period, and that solar drying is used to process all the remaining biosolids. However, due to the modular nature of the solar system, construction can be phased and a different number of modules can be selected by CORPUD to align with future disposal and capital improvement requirements. 8 modules would be required to process the biosolids currently sent to composting. The City may wish to install a limited number of modules at first, in order to evaluate their performance under local conditions and gain experience with the process.

5.3.2.5 End Use of Biosolids

Alternative 2 provides flexibility to divert biosolids to multiple end use outlets.

- Solar drying produces a product that can potentially achieve Class A and be distributed and marketed, or simply land applied.
- The portion of solids not processed by the solar dryers can continue to be composted.
- If desired, thickened WAS and primary sludge can be sent directly to dewatering (either at the new facility or the existing BFP facility). From there, alkaline stabilization, off-site composting, or landfill disposal remain viable outlets. The stabilized biosolids can also be withdrawn directly from the anaerobic digesters for Class B liquid land application.

5.3.3 Evaluation

5.3.3.1 Cost

An opinion of probable capital costs and net present O&M costs for the facilities described above are presented in **Table 5-7**.

5.3.3.2 Non-Cost Factors

Anaerobic digestion contributes to meeting a number of the City's stated non-cost performance goals, earning this alternative an 83% score, as shown in **Table 5-8.** In particular, anaerobic digestion offers the ability to produce and use biogas, while its higher VSR reduces the quantity of biosolids that must be disposed. Solar drying provides CORPUD an alternative pathway to achieving Class A that is much less energy-intensive than the current Alkaline Stabilization process.

For these reasons, the greenhouse gas emissions offset for Alternative 2 is considerably higher than that for Alternative 1, at 5,000 metric tons CO_2e per year (equivalent to 1,000 passenger cars).

Table 5-7 Opinion of Probable Capital and O&M Costs for Alternative 2

Capital Cost ($M)1	Equipment	Labor & Material	Total
Gravity Belt Thickeners	$0.8 M	$2.6 M	$3.4 M
Anaerobic Digesters	$6.2 M	$16.7 M	$22.9 M
Replace Existing Belt Filter Presses	$1.6 M	$1.4 M	$3.0 M
Replace Conveyors (2028)	$0.8 M	$0.3 M	$1.1 M
Replace Truck Loading Station (2028)	$0.9 M	$0.3 M	$1.2 M
Solar Dryers	$13.8 M	$9.9 M	$23.7 M
Subtotal Direct Construction Costs	**$24.1 M**	**$31.2 M**	**$55.3 M**
Total Capital Cost[2]			**$97.5 M**
Costs for Option B (new dewatering building)	**Equipment**	**Labor & Material**	**Total**
Deduct replacement of existing facilities	-$3.3 M	-$2.0 M	-$5.3 M
Centrifuge Dewatering Building	$2.0 M	$3.9 M	$5.9 M
Truck Loading Station	$1.0 M	$0.3 M	$1.3 M
Subtotal Additional Direct Construction Costs	**-$0.3 M**	**$2.2 M**	**$1.9 M**
Total Additional Change in Capital Cost[2,5]			**$3.2 M**
O&M Cost ($M)		**Unit Cost ($/MG)3**	**NPV**
Gravity Belt Thickening		$14.63	$5.4 M
Anaerobic Digestion		$5.89	$2.1 M
Centrifuge Dewatering		$37.90	$13.9 M
Solar Drying		$9.65	$3.5 M
Composting		$25.10	$9.2 M
Total Net Present O&M Cost[4]			**$34.1 M**
Total Net Present O&M Cost per Dry Ton Biosolids Disposed			**$144**

1 All capital costs are reported in December 2012 dollars (ENR CCI = 9412.25), with the exception of Conveyance and Truck Loading replacement, which are assumed installed in 2028, at the end of the current facility design life. These costs are escalated and discounted as described below.

2 Includes markups for taxes, permits, bonds, insurance, contractor's general conditions, overhead and profit, engineering services during design and construction, administrative costs, and contingency. A detailed description of these markups is provided in Section 4.

3 Unit cost per million gallons treated by the WWTP

4 Net present cost for the period 2016-2035, assuming annual inflation of 4.5% for capital costs, 3.0% for labor costs, and a 4.7% nominal discount rate.

5 Costs for the new dewatering building assume that existing conveyance and truck loading facilities are not replaced at the end of their design life. If the replacement costs are to be included, the differential cost of the new dewatering building increases from $3.2 M to $7.5 M. Continued use of the existing building (Option A) is elected in order to save this cost.

Table 5-8 Summary of Non-Cost Performance for Alternative 2

Performance Criterion	CORPUD Weight	CDM Smith Rating (0-5)	Criterion Score
Regulatory Requirements	12	4	48
Reliability	9	4	36
Sustainability	7	5	35
Constructability	8	4	32
Operator Friendliness	9	5	45
Ease of Maintenance	9	4	36
Flexibility/Adaptability	8	4	32
Outlet Diversification	11	4	44
Side Stream Impacts	8	4	32
Public Acceptance	7	4	28
Public Health and Environmental Impacts	12	4	48
		Overall Score:	**416**
		Percent Score (out of 500):	83%
Annual Greenhouse Gas Emissions Offset (2016-2035), metric tons CO2 equivalents/yr			**5,000**

5.3.4 Solar pre-Drying and Thermal Drying Option

As a variation to Alternative 2, solar drying coupled with thermal drying was evaluated. This alternative also includes thickening, anaerobic stabilization and dewatering, with similar characteristics to those discussed for Alternative 2.

The solar dryer is sized to dewater the cake from 20 to 35 percent solids. The solids from the solar dryer are then transferred using a front wheel loaders or trucks to a belt dryer for further processing to 90 percent solids. The system performance depends on heat recovery from the thermal dryer that is used to increase the performance of the solar dryer and reduce the number of required solar modules. Twelve modules (as opposed to 16) would be required to treat all biosolids that are not sent to composting.

This alternative is being marketed by Parkson, and aims at providing a cost effective operation with the highest drying performance by combining solar and thermal drying technology. No facilities of this kind are currently present in the United States.

While the combination of solar and thermal drying is promising, it is not well-established in the United States and appears to be more costly than other options evaluated in this report. The capital cost and the O&M costs amount to **$106 M** and **$45.9 M**, respectively. Therefore, it will not be presented in further detail here.

5.4 Wastewater Biosolids Alternative 3 – Anaerobic Digestion with Thermal Hydrolysis and Solar Drying

5.4.1 Process Description

Alternative 3 maintains anaerobic digestion and solar drying as in Alternative 2, and incorporates a pretreatment step before digestion. The THP 'pressure cooks' the sludge at high temperatures and pressure (approximately 100 - 150 psi), and further improves the process with the following benefits:

- Class A product, no fecal regrowth issues
- Odorless product
- Improved dewatering performance with drier cake at about 30% solids
- Increased digester solids loading at 10 to 11% solids.
- Higher VSR, estimated at 65 percent, resulting in fewer residual solids and greater biogas production.

While this technology is becoming increasingly established, with approximately 30 installations worldwide and the world's largest facility being constructed at the DC Water Blue Plains facility, it requires additional processes:

- Pre-screening of the co-settled primary solids and WAS, prior to pre-dewatering
- Pre-dewatering to produce dewatered cake with 17 percent solids discharged directly into solids cake bins prior to THP

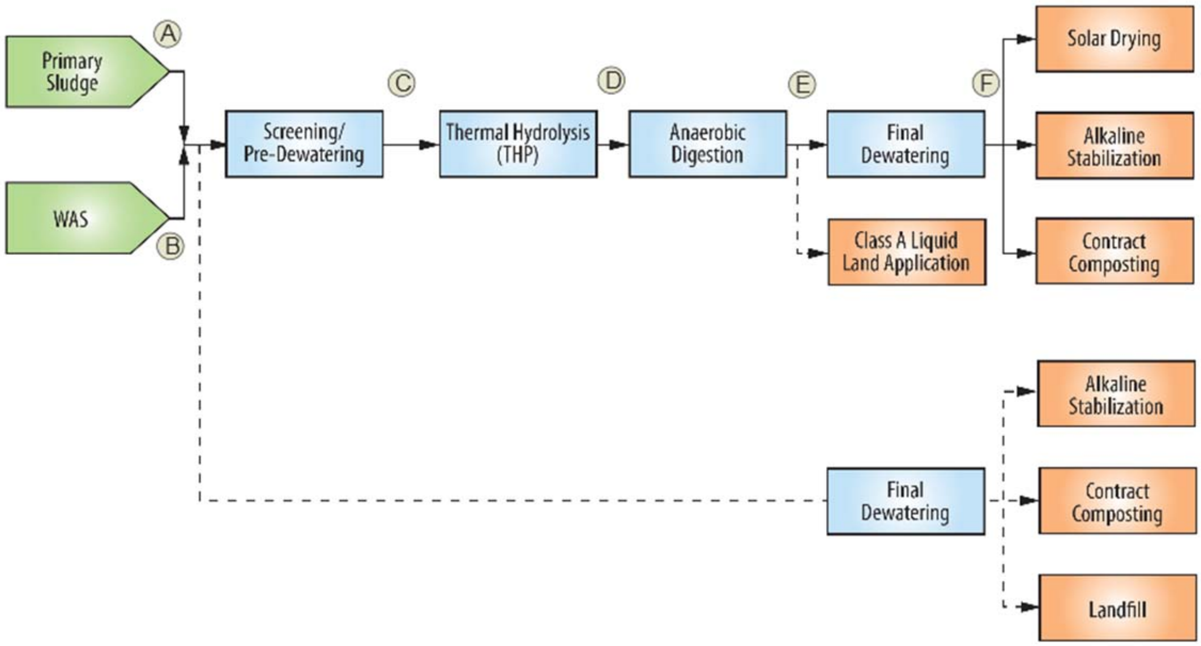
These processes are illustrated on the process flow diagram and mass balance in **Figure 5-5.** Dashed lines indicate alternative, optional modes of operating the facilities that are not considered part of the "normal" process.

This process is sized to replace the current biosolids treatment equipment with all new facilities, with the exception of the final dewatering building. As with Alternative 2, two implementation options are proposed. Option A reuses the existing dewatering facilities, while Option B contains a new dewatering building located adjacent to the proposed facilities. Site layouts for the two options are provided in **Figure 5-6** and **5-7,** respectively.

5.4.2 Facilities Required

5.4.2.1 Pre-Screening

Two horizontal in-line coarse solids screens will be installed on an elevated platform. These units remove grit and large solids from the co-settled sludge. A pre-engineered metal enclosure and odor control system will be provided for this facility.



Process Step	A Primary Sludge	B WAS	C Pre-Dewatering Effluent	D THP Effluent	E Anaerobic Digestion Effluent	F Dewatered Cake
Average Solids loading (DT/day)	42.0	27.4	65.9	65.9	33.4	31.7
Average Solids loading (WT/day)	n/a	n/a	n/a	n/a	n/a	106
Solids Concentration (%)	4.0%	0.9%	17.0%	11.0%	5.6%	30.0%
Average hydraulic loading (gal/day)	252,000	729,000	93,000	144,000	144,000	n/a

Figure 5-5 Process Flow Diagram and Mass Balance at average day 2035 conditions for Alternative 3

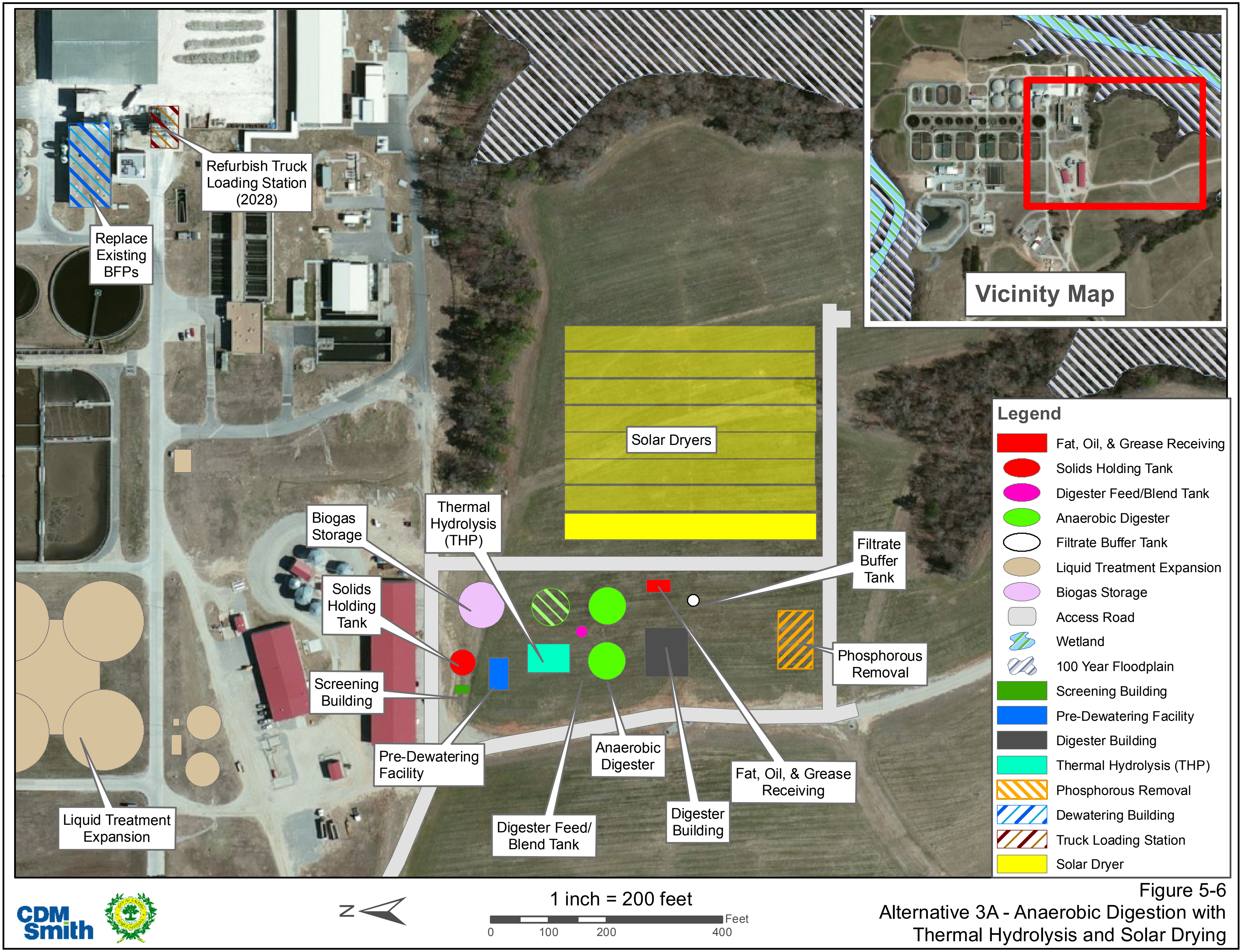
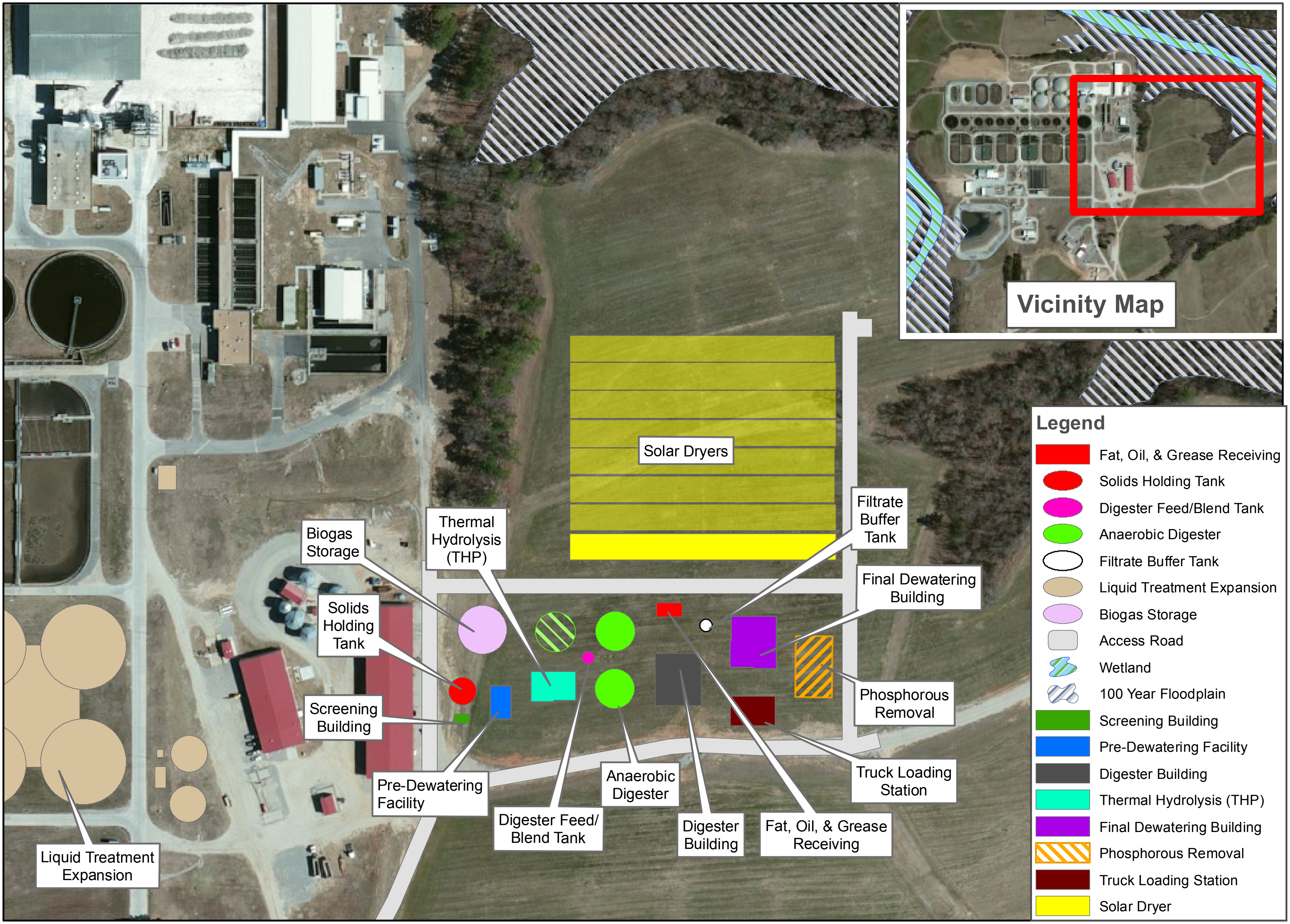


Figure 5-6
Alternative 3A - Anaerobic Digestion with Thermal Hydrolysis and Solar Drying



CDM Smith

Figure 5-7
Alternative 3B - Anaerobic Digestion with Thermal Hydrolysis and Solar Drying

5.4.2.2 Pre-Dewatering

Four centrifuges are located in a new dewatering facility to pre-dewater the solids feeding the THP system to approximately 17% solids. These units operate 24x7. **Table 5-9** summarizes the design criteria for this equipment.

Table 5-9 Pre-Dewatering Centrifuge Design Criteria for Alternative 3

Parameter	Design Criteria
Number of Units	4
Manufacturer/Model	Alfa Laval G2 115
Design Solids Loading Rate	4,000 dry lb/hr
Design Hydraulic Loading Rate	270 gpm
Design Outlet Solids Concentration	17 %
Solids Capture Efficiency	95 %

5.4.2.3 Thermal Hydrolysis

Pre-dewatered cake is fed to the THP system. The equipment will include a pulper, feed pumps for each reactor, three reactors (plus space for a fourth), a flash tank where steam is recovered, and digester feed pumps to convey treated sludge into the anaerobic digesters.

5.4.2.4 Anaerobic Digesters

Digester Tanks

The hydrolyzed sludge is digested in two 1.6 MG concrete digesters with characteristics similar to those discussed for Alternative 2. Space is provided for an additional digester to accommodate future expansion. **Table 5-10** summarizes the design characteristics of these digesters.

Table 5-10 Anaerobic Digester Design Criteria for Alternative 3

Parameter	Design Criteria
Number of Units	2
Volume (each)	1.6 MG
Solids Retention Time (at 14-day peak rate)	17 days
Volatile Solids Reduction	65%
Design Outlet Solids Concentration	5.6 %
Solids Capture Efficiency	95 %

Digester Building

The Digester Building located adjacent to the digesters will house steam boiler, recirculation pumps and solids withdrawal pumps.

Biogas Storage

Biogas storage will be provided similarly to Alternative 2.

5.4.2.5 Final Dewatering

Under Option A, the existing belt filter presses will be replaced, and the facility refurbished, as described for Alternative 1. The existing centrifuge will remain in service as well. A pipeline would be constructed to convey thickened solids from the new biosolids management area back to the existing biosolids day tanks. Pumps in the thickening building would provide the head needed to convey this material. Once in the day tanks, the biosolids could be treated in the same way they are now.

Under Option B, a new post-dewatering facility and truck loading station will be constructed. It will include four 3m BFPs on the second level and a polymer system and feed equipment on the bottom level. The dewatered material will be conveyed to the truck loading station for land application or further processing with solar dryers. BFP design criteria are summarized in **Table 5-11.**

Table 5-11 Belt Filter Press Design Criteria

Parameter	Design Criteria
Number of Units	4
Belt Width	3m
Design Solids Loading Rate	750 dry lb/hr/m
Design Hydraulic Loading Rate	100 gpm/m
Design Outlet Solids Concentration	30 %
Solids Capture Efficiency	95 %

5.4.2.6 Solar Dryers

Solar dryers with similar characteristics to those discussed for Alternative 2 will dry a portion of the hydrolyzed dewatered cake from 30 to 75 percent solids. The feed concentration is higher due to the improved dewatering characteristics of hydrolyzed sludge.

Solar drying for Alternative 3 consists of 8 modules sized to process an annual average loading rate of 20.3 DT/d of dewatered cake (all of the NRWWTP biosolids not sent to composting). Five modules would be required to treat only the biosolids currently sent to composting.

5.4.2.7 End Use of Biosolids

Potential disposal outlets for biosolids are identical to those described in Alternative 2.

5.4.3 Evaluation

5.4.3.1 Cost

Table 5-12 provides an opinion of probable construction and O&M cost for the above facilities.

Table 5-12 Summary of Capital and O&M Costs for Alternative 3

Capital Cost ($M)[1]	Equipment	Labor & Material	Total
Pre-Screening Building	$0.6 M	$1.1 M	$1.7 M
Pre-Dewatering Centrifuges	$3.8 M	$3.1 M	$6.9 M
Thermal Hydrolysis	$7.3 M	$1.6 M	$8.9 M
Anaerobic Digesters	$3.5 M	$7.2 M	$10.7 M
Replace Existing Belt Filter Presses	$1.6 M	$1.4 M	$3.0 M
Replace Conveyors (2028)	$0.8 M	$0.3 M	$1.1 M
Replace Truck Loading Station (2028)	$0.9 M	$0.3M	$1.2 M
Solar Dryers	$7.5 M	$5.2 M	$12.7 M
Subtotal Direct Construction Costs	**$26.0 M**	**$20.2 M**	**$46.2 M**
Total Capital Cost[2]			**$81.2 M**
Costs for Option B (new dewatering building)	**Equipment**	**Labor & Material**	**Total**
Deduct replacement of existing facilities	-$3.3 M	-$2.0 M	-$5.3 M
Final Dewatering Building (Belt Filter Presses)	$2.2 M	$2.7 M	$4.9 M
Truck Loading Station	$1.0 M	$0.3 M	$1.3 M
Subtotal Additional Direct Construction Costs	**-$0.1 M**	**$1.0 M**	**$0.9 M**
Total Additional Capital Cost[2,5]			**$1.4 M**
O&M Cost ($M)		**Unit Cost ($/MG)[3]**	**NPV**
Centrifuge Pre-Dewatering		$23.40	$8.6 M
Thermal Hydrolysis		$7.79	$2.8 M
Anaerobic Digestion		$2.43	$0.9 M
Belt Filter Press Dewatering		$18.18	$6.7 M
Solar Drying		$4.77	$1.7 M
Composting		$18.89	$6.9 M
Total Net Present O&M Cost[4]			**$27.6 M**
Total Net Present O&M Cost per Dry Ton Biosolids Disposed			**$140**

[1] All capital costs are reported in December 2012 dollars (ENR CCI = 9412.25), with the exception of Conveyance and Truck Loading replacement, which are assumed installed in 2028, at the end of the current facility design life. These costs are escalated and discounted as described below.

[2] Includes markups for taxes, permits, bonds, insurance, contractor's general conditions, overhead and profit, engineering services during design and construction, administrative costs, and contingency. A detailed description of these markups is provided in Section 4.

[3] Unit cost per million gallons treated by the WWTP

[4] Net present cost for the period 2016-2035, assuming annual inflation of 4.5% for capital costs, 3.0% for labor costs, and a 4.7% nominal discount rate.

[5] Costs for the new dewatering building assume that existing conveyance and truck loading facilities are not replaced at the end of their design life. If the replacement costs are to be included, the differential cost of the new dewatering building increases from $1.4M to $5.7M. Continued use of the existing building (Option A) is elected in order to save this cost.

5.4.3.1 Non-Cost Factors

Much like Alternative 2, Alternative 3 contains several features that align well with CORPUD's stated performance goals, earning a score of 82%. The enhanced VSR achieved with hydrolysis and improved dewaterability of the sludge dramatically reduce the quantity of material that must be hauled. Biogas production is also enhanced relative to Alternative 2. However, the THP process and associated equipment is somewhat more maintenance-intensive than conventional anaerobic digestion.

Primarily as a result of the reduced volume of biosolids that must be hauled, the greenhouse gas emissions offset for this alternative is three times greater than that of Alternative 2, at 14,000 metric tons CO_2e per year. This offset is equivalent to the annual emissions of 2,900 passenger cars.

Table 5-13 Summary of Non-Cost Performance for Alternative 3

Performance Criterion	CORPUD Weight	CDM Smith Rating (0-5)	Criterion Score
Regulatory Requirements	12	5	60
Reliability	9	4	36
Sustainability	7	5	35
Constructability	8	4	32
Operator Friendliness	9	3	27
Ease of Maintenance	9	3	27
Flexibility/Adaptability	8	4	32
Outlet Diversification	11	5	55
Side Stream Impacts	8	3	24
Public Acceptance	7	3	21
Public Health and Environmental Impacts	12	5	60
		Overall Score:	**416**
		Percent Score (out of 500):	82%
Annual Greenhouse Gas Emissions Offset (2016-2035), metric tons CO2 equivalents/yr			**14,000**

5.5 Wastewater Biosolids Alternatives Summary and Comparison

Table 5-14 summarizes the capital cost, O&M cost, non-cost rating, and greenhouse gas impact of the alternatives discussed above. As expected, Alternative1 (the base case) has a significantly lower capital cost than either Alternative 2 or Alternative 3. However, O&M costs are considerably higher, such that the 20-year life cycle cost of continuing the current management strategy is comparable to that of implementing anaerobic digestion. Alternative 3, which includes thermal hydrolysis, has the lowest life cycle cost, which a result of savings in both capital and operating costs. Under this alternative the digesters and solar dryers are both smaller than in Alternative 2. Although thermal hydrolysis plus anaerobic digestion are more costly to operate, per unit of solids, than conventional anaerobic digestion (see Section 4), the volume of solids requiring dewatering and disposal is significantly reduced. This fact results in substantial cost savings in operating and disposal costs.

Both Alternative 2 and 3 come significantly closer to achieving CORPUD's performance goals than Alternative 1, as evidenced by the non-cost performance ratings. In addition, Alternative 2 offers a significantly greater GHG offset than the base case (a fivefold increase), while Alternative 3 offers an even larger offset (fourteen times greater than the base case).

Table 5-14 Comparison of biosolids management alternative performance

Evaluation Factor	Alternative 1	Alternative 2	Alternative 3
Capital Cost	\$28.3 M	\$97.5 M	\$81.2 M
NPV O&M Cost for Treatment	\$8.9 M	\$7.5 M	\$12.3 M
NPV O&M Cost for Dewatering	\$10.9 M	\$13.9 M	\$6.7 M
NPV O&M Cost for End Use	\$62.3 M	\$12.7 M	\$8.6 M
Total Lifecycle Cost	**\$110.4 M**	**\$131.6 M**	**\$108.8 M**
NPV O&M Cost per DT Biosolids Disposed	\$237	\$144	\$140
Non-Cost Rating (%)	53%	83%	82%
GHG Emissions Offset (metric tons CO_2e/yr)	1,000	5,000	14,000

5.6 Water Treatment Residuals Management Strategies

5.6.1 E.M. Johnson WTP

At EMJ, residuals are dewatered using one of three 2m belt filter presses. At present, a single press running 20-22 hours/day is adequate to process all the residuals. During peak periods, two presses must be operated for 20 hours per day. As discussed in Section 2, peak 30-day residuals production at EMJ is projected to increase from 26,700 lb/day today to 51,500 lb/day in 2040. At this higher rate, the existing three presses may not be adequate to process the peak 30-day residuals. However, the current hydraulic loading rate of 65 gpm at which the presses are operated is somewhat lower than typical. The City may wish to consider an optimization study to investigate whether a higher loading rate can be used. Alternatively, a fourth belt filter press should be incorporated into the next plant expansion.

Dewatered residuals are stored on an uncovered concrete pad then hauled to Harnett County for land application. These residuals can be permitted as Class A material for reuse. Based on information from City staff, the cake storage pad appears to have ample space to store residuals now and in the future. However, it is recommended that a cover for the storage pad be considered in order to prevent re-wetting of the sludge and thereby reduce hauling costs.

In addition to the storage pad, EMJ has a lagoon that can be used to store residuals in an emergency. It is recommended that this lagoon remain available to maintain additional flexibility in handling residuals.

5.6.2 D.E. Benton WTP

Residuals and backwash water generated at Benton WTP are currently pumped to the sanitary sewer via the new Highway 55 pump station. They are ultimately treated at the City's Neuse River Wastewater Treatment Plant (NRWWTP).

The City is developing plans to dewater residuals from Benton WTP at a new facility at Wrenn Road, a 600-acre former treatment plant site. Residuals would be pumped to the facility via the Old Highway 55 pump station and force main. Provisions for recycling of backwash water are being added to Benton WTP, so that backwash waste will not need to be pumped to the Wrenn Road facility or the sewer. Once on site, the residuals would likely be thickened and dewatered. Liquid from thickening and dewatering may be sprayed onto the site, which has been permitted for spray irrigation. It is possible that all the residuals from Benton WTP could be land applied at the Wrenn Road site, but additional permits will need to be acquired. Further study would be required to determine whether the manganese levels in the residuals are within an acceptable range for land application.

If the Wrenn Road facility is offline, continuing to discharge residuals from Benton WTP to the sanitary sewer will remain a viable option. At present, NRWWTP produces roughly 35 dry tons per day of biosolids, and this is projected to double to 70 dry tons per day in 2035, as discussed in Section 2. In contrast, Benton WTP is projected to generate a maximum of 8 dry tons of residuals per day by 2040. This relatively small additional solids loading is not expected to adversely impact the NRWWTP treatment process.

The relative distances between E.M. Johnson WTP, D.E. Benton WTP, and NRWWTP will make hauling of residuals from one facility to another impractical. Furthermore, the addition of a significant quantity of WTP residuals to the NRWWTP will not offer any benefits to the end products currently produced. As such, maintaining separate outlets for the residuals from each facility is recommended.

Section 6

Energy Recovery and Utilization

The use of combined heat and power (CHP) systems to recover the energy in biogas are discussed in this section.

6.1 Introduction

Use of a Combined Heat and Power (CHP) system in conjunction with anaerobic digestion (Alternatives 2 and 3) is evaluated in this Section. CHP systems harness the biogas produced from anaerobic digestion to produce both heat and electricity. A typical CHP system requires digester gas piping connections, hot water supply and return piping, and electrical connections to the grid or to mechanical equipment.

CHP equipment fueled by digester gas enables the use of energy that might otherwise be wasted in a gas burner. A CHP system can achieve an overall system efficiency of up to 80% with the use of heat recovery, composed of approximately 40% for power production and 40% for thermal energy. Both high- and low-temperature thermal energy is often recovered, depending on the type of engine. High-temperature heat is suitable for digester heating or other process uses (such as thermal hydrolysis), while the low-temperature heat is only suitable for utility services such as building hot water heating or HVAC. If the low-temperature heat is not used, the overall system efficiency drops to approximately 60%.

Figure 6-1 shows a generalized schematic of a CHP system used in conjunction with anaerobic digesters. Note *that* if thermal hydrolysis were part of the process, heat energy from the engine would be used to generate steam for that hydrolysis rather than heat the digesters directly.

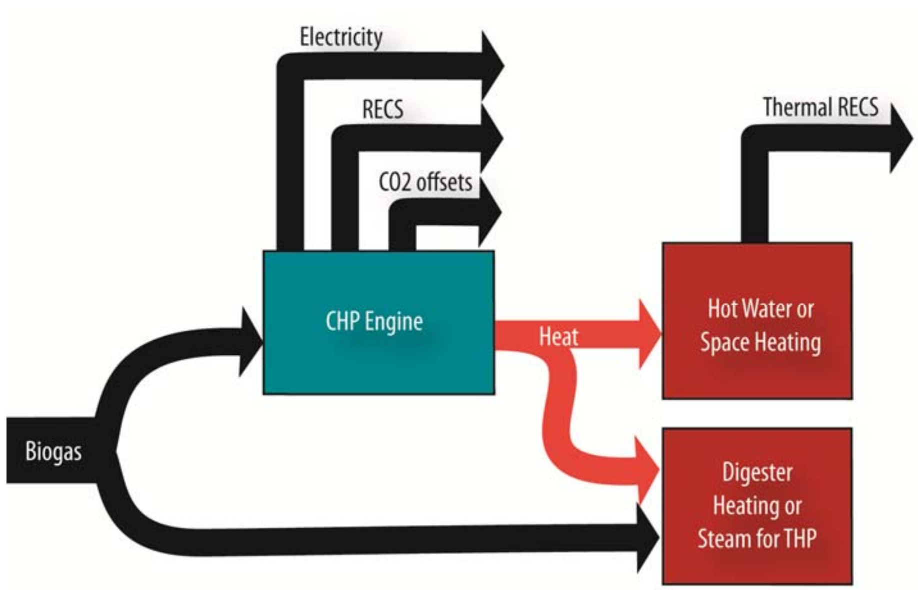


Figure 6-1 General CHP Process Schematic

6.1.1 Electricity Generation

The principal benefit of CHP is the ability to generate electrical power from biogas. This electricity can be used in several ways to maximize the economic value of the system. **Table 6-1** summarizes the possible outlets for the electricity, which are discussed further below.

Table 6-1 Options for Monetizing Electricity Produced

Option	Electricity Value	Ability to Sell RECs	Notes
Net Metering	Retail	No	Must produce <1 MW to qualify. Requires Interconnection agreement.
Parallel Generation	Retail	Yes	Requires Interconnection Agreement. Standby charges apply.
Sale to Utility	Negotiated	Yes	Requires Interconnection Agreement and standard or negotiated Power Purchase Agreement. Negotiated rate may be greater than retail rate if long-term agreement signed. Monthly seller charge applies.

6.1.1.1 Net Metering

Under net metering, any power produced by the CHP system is simply subtracted from the electricity used by the plant. This is accomplished by means of a single electric meter that can read power going in both directions. As a result, the value of the electricity is equal to the price normally paid on the electric bill, because it offsets a portion of demand. In North Carolina, facilities are only eligible for net metering if they have a generation capacity of 1 MW or less. It is likely that the NRWWTP will produce enough biogas to support more than 1 MW of generation (provided all the biogas is used for electricity).

Facilities that take advantage of net metering are not eligible to sell Renewable Energy Credits (RECs).

6.1.1.2 Parallel Generation

Parallel generation implies that the CHP engine would be connected much like a standby generator, providing power directly to equipment within the NRWWTP. This type of connection requires that sufficient electrical distribution infrastructure be present on the plant site to transmit the power from the engine to the locations where it will be used. Since standby generators are common at WWTPs, this infrastructure may already be in place.

This approach offers many of the benefits of net metering without the capacity limitation. The CHP system offsets a portion of the plant's electrical demand, thereby reducing the bill. As such, the electricity is valued at the same rate normally paid. In addition, this approach may require a larger capital investment if additional electrical distribution infrastructure is required.

A CHP system connected in parallel with the electric utility would be subject to PEC's standby service rider (SS-40), which imposes monthly charges for the supplementary capacity that the utility would have to provide if the CHP system were offline. Standby charges are estimated to be approximately $150/mo for the CHP system at NRWWTP.

6.1.1.3 Sale to the Electric Utility

All electricity produced by the CHP system can be sold to the electric utility according to a Power Purchase Agreement (PPA). Progress Energy has a standard PPA in place for small generation facilities up to 5 MW (rate schedule CSP-27), which pays variable market rates or fixed rates for up to 15-years for the energy. A separate credit is paid for both the total energy produced and the energy produced during on-peak periods. Together, these credits may exceed the average cost of power currently paid by CORPUD. However, a monthly seller charge of approximately $280/mo is also required. On-site gas storage could be used to increase power production during on-peak periods to maximize revenue.

6.1.2 Renewable Energy Credits

Electricity produced by renewable sources also generates Renewable Energy Credits (RECs). RECs are certificates issued by a third party who verifies that power is being produced by renewable means. These credits can be purchased by electric utilities or other organizations, who then "retire" the certificate and claim the environmental benefits associated with the renewable energy. All electricity produced by a CHP system using biogas would qualify to produce RECs.

The NC Green Power program and electric utilities are two potential buyers for the RECs. NC GreenPower is a nonprofit organization that uses fees from program participants to fund subsidies for renewable power generation. Facilities that generate power can apply to be a part of the program and collect a subsidy if approved. NC GreenPower periodically issues requests for proposals for additional producers to join the program, but these are limited by the revenue available through user fees. At present, the program is not seeking any additional producers of the scale or type that a CHP system would represent. Furthermore, these agreements typically only last for 5 years, which lessens the impact of the subsidy on the financing of a project at this size.

Progress Energy Carolinas (PEC) and other NC electric utilities also purchase RECs in order to meet the Renewable Energy Portfolio Standard set by North Carolina. PEC has a standing request for proposals, through which an agreement to sell both electricity and associated RECs could be made. The value of RECs fluctuates depending on many factors, particularly when selling to utilities. For planning purposes, a value of $5/MWh was assumed (Panzarella, 2012).

6.1.3 Thermal Energy Production

In addition to power production, CHP systems capture 'waste' heat from the power producing equipment. Using a series of heat recovery loops and heat exchangers, this energy can be transferred and used as the digester-heating source.

Thermal energy recovered by the CHP engines can be used as the source of heat for anaerobic digestion. If the amount of heat recovered is insufficient to meet the maximum digester heating demand, supplemental energy can be provided by diverting digester gas from electricity production. This is achieved either by reducing the electrical production efficiency and recovering more thermal energy or by firing some of the biogas in the existing boilers dedicated to the sludge heating system.

Because the thermal hydrolysis process requires higher temperatures than conventional anaerobic digestion, only the high temperature heat, which accounts for roughly half of the total thermal energy recovered by the CHP engines, can be used with this strategy. The low-temperature heat would be wasted or perhaps used for utility needs such as water or space heating.

Additional energy for digester or THP heating can also be obtained by supplementing the digester gas with another fuel source such as natural gas. The supplemental fuel can be fired in the engine generators or in a boiler dedicated to the sludge heating system.

Any heat that is used outside the digestion process (e.g. for hot water or space heating) may qualify for thermal RECs, because it displaces fossil fuels. It is unlikely that heat used by the digestion process (or thermal hydrolysis) would qualify for thermal RECs (Panzarella, 2012; Ostema, 2012).

6.1.4 Carbon Emission Offsets

Any electricity produced from biogas will displace electricity generated through other means, including the combustion of fossil fuels. As such, operating a CHP engine would offset carbon emissions associated with that electricity. Various third-party organizations provide mechanisms for quantifying such reductions in greenhouse gas emissions (usually expressed in tons of CO_2 equivalents, or CO_2e). These organizations define rules and eligibility for obtaining credits, provide verification and certification that the process is effective in reducing greenhouse gas emissions, and facilitate monetizing these credits by establishing markets for them.

Unfortunately, markets for potential carbon credits resulting from a CHP installation at the NRWWTP are very limited. The Climate Action Reserve operates a nationwide program of certification and verification, but biogas derived from digestion of municipal biosolids does not qualify for credits (Climate Action Reserve, 2011). Another major provider of carbon credits in the U.S. was the Chicago Climate Exchange, but it ceased operations at the end of 2010. Two regional programs – the Regional Greenhouse Gas Initiative and the Western Regional Climate Action Initiative—provide markets for carbon credits, but North Carolina is not a member of either of these.

A voluntary market still exists for carbon credits. Buyers in this market are organizations or companies that wish to voluntarily offset their carbon footprint through the purchase of offsets. The value of carbon credits in this market is much lower than in a cap-and-trade market like the Chicago Climate Exchange. While it may be possible to monetize carbon credits on the voluntary market, the costs of hiring a broker or doing in-house research to find a buyer are likely to be prohibitive (Austin, 2012). Moreover, most buyers of RECs in North Carolina will expect the REC to include any environmental benefit from carbon emissions offsets.

While future regulations may expand opportunities to claim and sell carbon credits, at present it appears that there will be no way to monetize the greenhouse gas emissions reduction associated with CHP.

6.2 Combined Heat and Power (CHP) Technologies

Various options are available for CHP systems, including fuel cells, microturbines, and reciprocating engine generators. A brief description of these options is provided below.

6.2.1 Internal Combustion Engines

Spark-ignition internal combustion engines (ICE) are among the most common technologies used to produce energy from biogas. Much like an automobile engine, these engines combust the gas to convert it into mechanical work, which is then used to power a generator. Heat energy can be recovered from the exhaust gases and engine cooling water (Lupo et al., 2009).

Exhaust emissions are a significant challenge for ICE at WWTPs, because facilities with enough flow to warrant the use of CHP tend to be near heavily populated areas with more stringent air quality regulations (EPA, 2010). Older biogas-fired ICE, classified as "rich burn," were relatively inefficient compared to modern engines. In the last decade, "lean burn" engines with much lower emissions and much higher efficiencies have been developed (EPA, 2010). Even so, ICE tend to produce greater nitrous oxide (NOx) emissions than alternative technologies. These can be mitigated with exhaust treatment (e.g. catalytic converter) technology, but such treatment can be costly (Lupo et al, 2009).

ICE CHP systems have been used at WWTPs for many decades; the first such system in the United States was installed in Charlotte, NC in 1928 (EPA, 2010). Major manufacturers of these engines include Caterpillar, GE Jenbacher, and Cummins. ICE are relatively high-maintenance pieces of equipment, so it is important to consider the system availability (the fraction of the time that the engine is functioning) in evaluating potential energy savings. Most manufacturers offer all-inclusive maintenance contracts to prevent this burden from falling to plant staff.

Table 6-2 summarizes the advantages and disadvantages of ICE in comparison with other CHP technologies.

Table 6-2 Advantages and Disadvantages of Internal Combustion Engines[1]

Advantages	Disadvantages
▪ Widely used, proven technology ▪ Highest efficiency (if all heat can be used) ▪ Less stringent fuel pretreatment requirements	▪ Higher NOx emissions ▪ High maintenance

Source: U.S. EPA, 2010, p. 2-5

6.2.2 Combustion Gas Turbines

The combustion gas turbine is an alternate and well-established technology for extracting energy from biogas. Much like an aircraft engine, the gas turbine compresses atmospheric air using several stages of blades rotating at high speed. The compressed air is then mixed with biogas and combusted. The expanding exhaust gases are forced through a second set of blades that extract mechanical work to power the compressor stage and an electrical generator (EPA, 2010).

Heat energy can be extracted from the turbine exhaust. Due to higher temperatures than ICE, the heat recovered from the exhaust gases can be used for water heating or to generate high- or low-pressure steam (NCSC, 2009). Gas turbines generate fewer emissions than ICE, but still generally require exhaust treatment to comply with air quality regulations. **Table 6-3** summarizes advantages and disadvantages of this system.

Table 6-3 Advantages and Disadvantages of Gas Turbines

Advantages	Disadvantages
▪ Widely used, proven technology ▪ High efficiency ▪ Less frequent maintenance than ICE	▪ Fuel must be pressurized, which is costly ▪ Specialized maintenance ▪ Limited number sizes

Source: U.S. EPA, 2010, p. 2-9

6.2.3 Microturbines

Microturbines are similar, but smaller versions of the combustion gas turbine. They offer many of the same advantages but in a much smaller package. Because of the precision, high-speed nature of these turbines, very clean fuel is required (EPA, 2010). Microturbines produce low levels of emissions, particularly when operated at or near full load (EPA, 2010). Due to the availability of smaller size turbines, it is easier to match the size of the equipment to the available gas, and thereby minimize emissions.

Table 6-4 Advantages and Disadvantages of Microturbines

Advantages	Disadvantages
▪ Availability in appropriate size range ▪ Low emissions ▪ Quiet operation	▪ Low efficiency ▪ Fuel must be pressurized, which is costly ▪ Requires significant pre-treatment of fuel

Source: U.S. EPA, 2010, p. 2-12

6.2.4 Fuel Cells

Fuel cells are an exceptionally clean and quiet means of generating electricity from biogas. Because fuel is not combusted inside the cell, emissions are essentially zero (NCSC, 2009). However, considerably less heat can be recovered, meaning that biogas would likely need to be diverted from power production to make up the shortfall (EPA, 2010). Compared to the other technologies, fuel cells are considerably more expensive, complex, and less established for use with biogas.

Table 6-5 Advantages and Disadvantages of Fuel Cells

Advantages	Disadvantages
▪ Lowest emissions ▪ High efficiency ▪ Quiet operation	▪ Require significant fuel pre-treatment ▪ Specialized maintenance ▪ Limited competition and experience at WWTPs

Source: U.S. EPA, 2010, p. 2-15

6.2.5 Steam Turbines

It is possible to use the biogas in a conventional steam boiler, then use the steam generated to drive a turbine, which in turn powers an electrical generator. Compared to the CHP technologies discussed above, however, this approach results in a considerably lower efficiency.

6.2.6 Summary

Table 6-6 summarizes the performance of each of the above technologies along several key parameters. As shown, the internal combustion engine offers high efficiency with the lowest capital cost range of the technologies considered. The technology with the next lowest cost (microturbine) is considerably less efficient. Gas turbines were deemed infeasible for the NRWWTP due to high capital cost and limited availability in the size ranged needed. Finally, fuel cells were ruled out due to very high capital cost and the less-established nature of the technology.

CDM Smith

Table 6-6 Summary of CHP Technologies

Technology	Total System Efficiency (%)	NOx Emissions (lb/MMBTU)	Installed Cost ($/kWh)	O&M Cost ($/kWh)	System Availability (%)
Internal Combustion Engine	71% – 91%	0.02 – 0.90	$500 – 1,600	$0.010 – 0.025	90% – 96%
Microturbine	56% – 67%	0.12 – 0.19	$800 – 1,700	$0.012 – 0.025	85% – 90%
Gas Turbine	61% – 90%	0.10 – 0.30	$1,200 – 2,000	$0.008 – 0.015	95% – 97%
Fuel Cell	70% – 85%	<0.01	$4,400 – 4,700	$0.004 – 0.019	90% – 95%

Source: U.S. EPA, 2010, p. 2-1 through 2-13

The process details and economic viability of using CHP with internal combustion engines are discussed in more detail in the following sections. Models supplied by Jenbacher were assumed for the purposes of this analysis. Multiple manufacturers including Caterpillar, Waukesha and GE Jenbacher are well established providers of this technology and have routinely been subject to competitive bidding environments against one another, so the Jenbacher system is expected to be comparable in both features and cost with others available. **Figure 6-2** shows an example process diagram for a CHP process using an internal combustion engine.

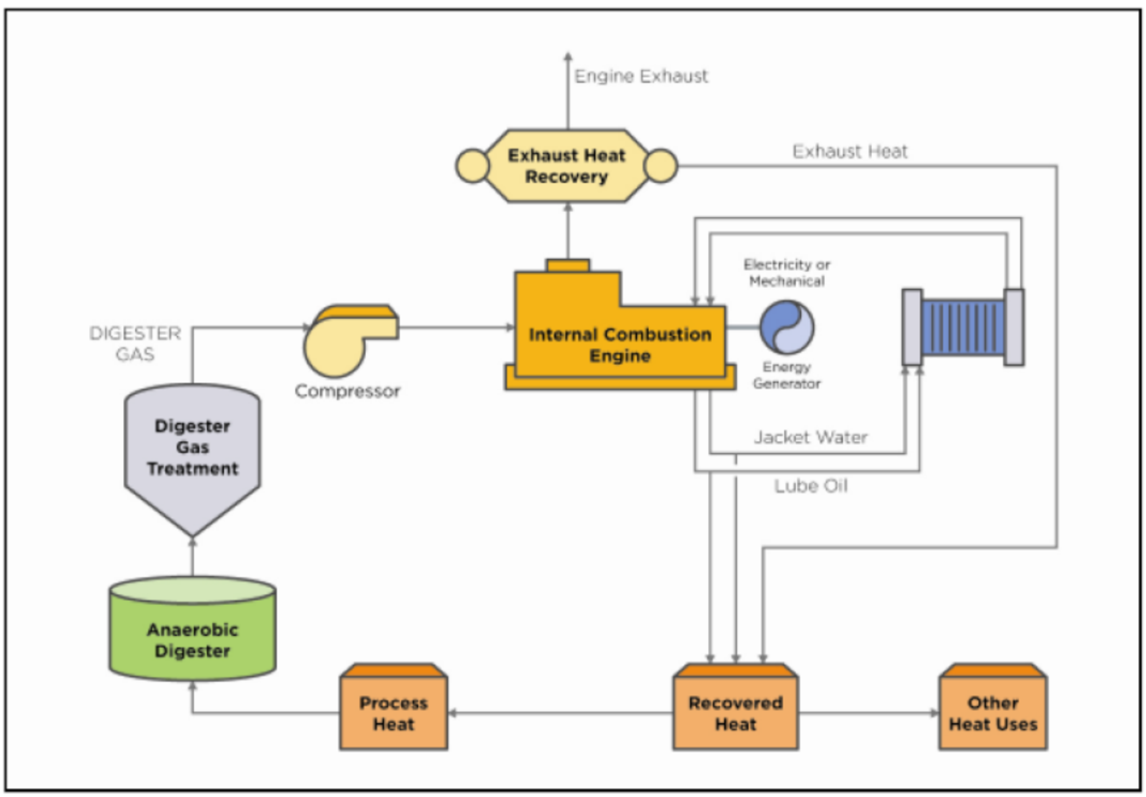


Figure 6-2 Example Process Flow Diagram of an Internal Combustion Engine CHP System (source: U.S. EPA, 2010)

6.3 Maintenance Requirements

The equipment associated with a cogeneration system requires a significant effort in routine preventative maintenance. As is the case for any internal combustion engine, smaller components such as lubricant oil systems and spark plugs require frequent replacement. This potential disadvantage of CHP systems must be weighed against the cost benefits of generating both electricity and thermal power. Manufacturers of CHP engines typically offer preventive maintenance contracts up to 60,000 operating hours (10 years) and inclusive of oil changes as well as minor and major overhauls.

Worker safety must be carefully addressed at CHP installations. Staff accessing CHP equipment can be exposed to local hazards such as high-temperature process piping and increased noise exposure. Combined heat and power systems often also include a dense core network of process piping that can restrict direct, overall access. All of the above can be mitigated through proper worker safety precautions.

6.4 Biogas Pretreatment Requirements

Prior to being ignited in the engines, the biogas must be typically treated in order to remove hydrogen sulfide (H_2S) and siloxane compounds. These compounds are removed after the digesters and prior to arriving at the co-generation system.

6.4.1 Hydrogen Sulfide

An iron sponge system is a typical removal method of H_2S from the biogas. This type of system consists of large diameter steel vessels packed with removal media. Biogas enters the top of the vessel, flows through the removal media and exits the bottom of the vessel via an outlet pipe. Iron sponge vessels with new media typically achieve H_2S concentrations less than 10 ppm at the outlet. Over time, as the media is spent, the outlet concentration gradually increases until the media must be replaced.

6.4.2 Silicon-Organic Compounds

A second category of contaminants found in biogas produced from anaerobic digestion of municipal sludge are siloxanes. These gas-phase silicon compounds produce solid silica when combusted, which is of particular concern when using gas for internal combustion engines due to the abrasive nature of silica within the engine block. Due to the potential damage to internal engine components, engine manufacturers have set fuel gas standards at less than 5 mg/m^3 (as Si). Testing of the biogas at NRWWTP would be required to determine whether siloxane removal equipment would be needed to achieve this standard.

If required, a siloxane removal system is included ahead of the cogeneration engine (and downstream of the H_2S removal system). Siloxane treatment is available as a packaged system provided by the suppliers of the engine generators, and it includes a gas drying system followed by a siloxane filtration package. This system typically includes two heat exchangers, the first of which uses hot gas from compression to reheat the cold gas from the second heat exchanger, which uses chilled glycol to cool the gas to 40 degrees F.

After the gas is chilled, it is directed through a water knockout before entering the opposite side of the first heat exchanger where it is reheated to 80 degrees F. After the gas drying stage, the gas is properly conditioned for siloxane filtration, which would consist of multiple stainless steel vessels containing carbon media and a final particulate filter.

The Siloxane is absorbed onto carbon media in addition to water vapor, reduced sulfur compounds, volatile organize compounds, and halogenated compounds, all of which decrease its useful life. The carbon media is a consumable media with an estimated lifecycle of one-year before requiring replacement. Each vessel can be refilled individually, while the other(s) remain on-line so there would be no downtime during planned maintenance. Carbon media can be removed using a typical vacuum-truck and disposed of in a non-hazardous area.

Siloxane treatment is available from GE Jenbacher as a packaged system with the engine generators that include a gas drying system followed by a siloxane filtration package. **Figure 6-3** shows an example of a gas treatment system.

Figure 6-3 Gas Treatment System

6.5 Design Features

6.5.1 Containerized Engine

GE Jenbacher's scope of supply for containerized engine units includes pre-installation (factory assembly) of all components and equipment located inside a container. These components include: the gas train; hot water expansion tanks; high temperature and low temperature jacket water pumps; lube oil pumps; generator control panel; generator control switchgear; and all interconnecting piping, conduit, wiring, etc.

The contractor's installation efforts are limited to providing a concrete slab (or other suitable foundation) for the container, installing a limited number of items shipped loose (a jacket water heat exchanger, an exhaust heat recovery unit, and the heat radiators), providing piping and electrical connections between the items shipped loose and the container, and connecting the digester gas connection and plant hot water systems.

Integration into the central engine control panel for engine/generator management is an optional item which can be provided by GE Jenbacher, thus allowing a single tie-in point with the rest of the plant SCADA system and simplifying the instrumentation and control process. Containerized units can be located outdoors. Typical containerized solutions mount the exhaust system and the waste heat radiators on the roof of the containers.

6.5.2 Heat Recovery System

One of the key components increasing the thermodynamic efficiency of co-generation is the heat recovery system. The heat recovery system of GE Jenbacher engines has two different water circuits. The H/T (high temperature) circuit contains the heat from jacket water, the oil, and the exhaust gases. The L/T (low temperature) circuit receives heat from the second intercooler stage. A similar arrangement can be obtained for the Caterpillar engines.

The jacket water portion of the H/T circuit recovers heat from the lube oil, first stage of the intercooler, and the engine block. Heat from the lube oil is recovered via a mounted plate heat exchanger integrated in the warm water circuit. A plate heat exchanger mounted on the container, called the decoupling heat exchanger, recovers the produced engine heat off the H/T circuit. The intercooler recovers heat from the fuel/air mixture through gilled pipes.

Hot water, returning from the plant, is pulled from the hot water return system and pumped to the decoupling heat exchanger and to a water-to-gas heat exchanger to capture heat from the exhaust gases and then returned to the plant hot water system. GE Jenbacher provides both the decoupling heat exchanger and the exhaust heat recovery heat exchanger. The decoupling heat exchanger is a plate and frame heat exchanger and the exhaust heat recovery heat exchanger is a single-duct tube-type heat exchanger. A steel exhaust silencer with required flanges and seals is provided for the exhaust gas not diverted to the exhaust heat exchanger. GE Jenbacher also provides a steel exhaust gas silencer and required flanges, seals, and fixings. An exhaust gas bypass valve with strictly open/close service is provided to regulate the amount of heat sent to the heat exchanger versus the exhaust gas wasted in the exhaust silencer. In addition, one secondary loop pump is required per engine.

6.5.3 Waste Heat System

Radiators will be used to reject excess heat into the atmosphere. Excess heat will need to be handled when more heat is recovered from the engines than the plant processes need. Engines are equipped with a dedicated dual core radiator system, with one core dedicated to continuous heat wasting from the L/T circuit. The other core is connected with the H/T system and will waste heat that is not recovered in the plant hot water system.

6.5.4 Lube Oil System

The lube oil system consists of a fresh oil tank, combined electric-driven fresh oil and waste oil pump, level switches, shut-off devices, and all the necessary pipe work between the engine module and the oil tanks. The system is set up for fresh and waste oil connections. To assist in lube oil changes, a fresh oil storage tank and waste oil tank need to be located near the engine facilities. Fresh oil storage and waste oil storage, and corresponding pumps, piping, and valves are not provided by the manufacturer of the CHP engine.

6.6 Procurement Options

Commonly, centralized solids processing facilities are procured through the traditional design-bid-build project delivery method. Some in the industry are concerned about the efficiency of the design-bid-build method in terms of project cost, schedule, and productivity. There is growing interest among local and state agencies to experiment with alternative project delivery methods. Energy services companies offer such an alternative procurement option for energy-related projects. This section presents a qualitative assessment of two different procurement options, design-bid-build and Energy Service Companies.

6.6.1 Design-Bid-Build

Design-bid-build (DBB) is the most commonly employed procurement option for public agencies. With this method, design and construction are contracted separately to engineering and construction firms.

Combined heat and power (CHP) system procurement is multidisciplinary in nature, requiring the services of mechanical, electrical, and structural engineers and contractors, equipment suppliers, environmental consultants and financiers. The traditional design-bid-build approach may require a high level of project management of the owner. Alternatively, this procurement method allows the owner more flexibility and control over the project. Though the risk of economic losses is assumed solely by the owner, the design-bid-build method also maximizes the potential for economic returns to the owner. Such risks, as well as advantages, associated with the design-bid-build procurement option are described below.

Designs are generally 100% complete prior to awarding the project's construction to the low-bid contractor. Since the contractor is brought into the project after designs are complete, there is little opportunity for collaborative efforts between the engineer and contractor. Superior alternatives that are more cost effective or feasible in terms of construction may go unevaluated during the design phase. Once construction is underway, issues may arise that were unaddressed in the designs, which can lead to change orders, delay of schedule and increased cost.

6.6.2 Energy Services Companies

An alternative procurement option is utilizing a third-party energy services company (ESCO) that is assumes responsibility for financing, building, and operating the CHP system. An alternative procurement option is to collaborate with an energy service company (ESCO), which generally acts as a project developer. ESCOs are hired to recommend and implement energy-saving facility improvements. Owners compensate the ESCO with funds proportional to the cost savings from the increase in energy efficiency. There are a range of possible partnership options between an ESCO and the facility owner. The ESCO may assume responsibility for financing, constructing, and/or operating a CHP facility. In some instances, the biosolids producer even relinquishes ownership of the CHP system to an ESCO, with the option to transfer ownership after a predetermined timeframe. The biosolids producer, in turn, agrees to purchase energy from the ESCO, for a period of time, under a predefined rate structure (further described below). In most cases the ESCO guarantees that energy savings meet or exceed annual payments to cover the total project cost, generally paid off in 7-10 years. In the event that the predicted savings are not achieved, the ESCO will pay the difference. Generally the ESCO procurement process begins with the owner issuing a request for qualifications or a request for proposals for qualified ESCOs. After an ESCO is selected, the owner and the ESCO collaborate to develop a scope of work. Once the scope and the associated benefits are approved, the owner and the ESCO select measurement and verification methods for those benefits.

ESCOs may offer services beyond energy efficiency offers, such as engineering, design, construction or manufacturing. Energy efficiency must be their primary service offering, however, and they must assume some performance risk during the economic life of the project according to the EPA's regulatory definition.

There are several payment options that are typically available:

- *Market based:* Owner agrees to pay the ESCO for the energy it consumes at a unit cost based on real time energy market pricing. Energy prices fluctuate greatly between peak and valley demand periods. Therefore, this option presents the highest risk and the greatest opportunity for cost savings.
- *Block and Index*: Owner agrees to pay a fixed energy unit price for a predetermined amount of energy consumption. Energy consumed in excess of this "base energy load" would be subjected to real time energy market prices. Owners that pursue this option assume some risk according to market conditions, but only on the variable portion of the energy demand. The opportunity for cost savings does not exist if market prices for energy dip below the fixed energy unit price.
- *Firm fixed price*: Owner agrees to a fixed energy unit price for any and all energy consumed. This option eliminates any cost risk related to exposure to market pricing. In turn, it also eliminates the opportunity for cost savings as a result of energy demand management.

Table 6-7 Comparison of Procurement Options

Attribute	Design-Bid-Build	ESCO
Source of Financing	Capital outlay	Current budget
Bond/Tax/Rate Increase	Yes	No
Savings Guarantee	No	Yes, for financing term
Performance Guarantee	No	Yes, for financing term
Possibility for Change Orders	Yes	No
Design Guarantee	No	Yes, for financing term
Contractors	Low bid	Most qualified
Risk	Owner	ESCO

6.7 Performance and Cost Analysis

A 20-year lifecycle cost analysis was conducted to evaluate the economic feasibility of CHP under both Alternative 2 and Alternative 3. The revenue from the cogeneration system was estimated over the 2016-2035 period under scenarios representing net metering (where applicable), parallel generation, and sale of the electricity to the utility. **Table 6-8** summarizes the assumptions that were used in the analysis of each scenario.

Table 6-8 Summary of Electricity Revenue Assumptions

Sale Type	Electricity Value $/kWh	REC Value $/kWh	Monthly Charges $	Natural Gas Cost $/MMBTU
Net Metering	$0.075	n/a	$0	$8
Parallel Generation	$0.075	$0.005	$143	$8
Sale to Utility	$0.091	$0.005	$278	$8

This conceptual analysis was based on GE Jenbacher engines, using models recommended by the manufacturer. The engines supplied by GE Jenbacher, Caterpillar and others are characterized by different electrical and thermal efficiencies, but are expected to be similar to one another at this level of analysis. For Alternative 2, two 1,029kW engines are recommended, while for Alternative 3, a single 1,750kW engine is recommended. These engines are sized based on an 80% capacity criterion: that is, enough biogas must be available to run the engines at least at 80% capacity. For Alternative 2, the first engine is installed immediately, and the second is phased in when the above criterion is satisfied.

The estimated capital costs of the CHP system, in present-value 2012 dollars, is estimated to be $7.9 million for Alternative 2 and $7.8 million for Alternative 3. This cost includes the engines, biogas pre-treatment systems, a concrete slab, hot water and digester gas piping, and electrical work required to make the interconnection with the utility grid. The cost to provide natural gas service to NRWWTP, which may be needed to supplement the digester boilers if all biogas is used for electricity production, is not included.

Net revenue is calculated as follows:

Net Revenue = Revenue from Electricity + Revenue from RECs – Supplemental Natural Gas Cost – Maintenance Cost

Table 6-9 summarizes the results of the lifecycle cost analysis. Based on projected biogas production, it appears that a CHP system is economically favorable for Alternative 3, with payback periods of 12 to 13 years. For Alternative 2, the payback period appears to be slightly longer than 20 years. However, it is important to note that several factors such as energy cost, REC value, and the cost of supplemental natural gas may deviate significantly from projections, increasing or decreasing the projected payback period.

The table also shows that implementing CHP would result in a significant reduction in GHG emissions over the lifetime of the unit, ranging from nearly 100,000 to 173,000 metric tons CO_2e, depending on the alternative. These reductions are a result of displacing electricity production from less-sustainable sources.

Table 6-9 Lifecycle Cost of CHP Engine Generators

Alternative		Biogas Available	Engine Size	Sale Type	Capital Cost[1]	Net Revenue[2]	Total NPV Revenue	GHG Offset[3]	Payback Period
2	Anaerobic Digestion	13-19 MMBTU/hr	1 @ 1,029 kW	Net Metering	$ 6.4M	$ 5.3M	-$1.1 M	98,700	>20
			2 @ 1,029 kW	Parallel Generation	$ 7.9M	$ 6.3M	-$1.6 M	140,000	>20
			2 @ 1,029 kW	Sale to Utility	$ 7.9M	$ 6.6M	-$1.3 M	140,000	>20
3	Thermal Hydrolysis	16-24 MMBTU/hr	1 @ 1,750 kW	Parallel Generation	$ 7.8M	$ 11.8M	$4.0 M	173,000	12 yrs
			1 @ 1,750 kW	Sale to Utility	$ 7.8M	$ 11.1M	$3.3 M	173,000	13 yrs

1 Present value capital cost. Engines are installed in two phases, beginning in 2016. All costs are reported in 2012 dollars.

2 20-year net present value, beginning in 2016. Includes revenue (or avoided cost) from the sale of electricity and Renewable Energy Credits, less O&M costs. RECs from power are assumed to be sold at $5/MWh. Natural gas cost = $8.00/MMBTU. Cost does not consider tax credits or the sale of thermal RECs. Electricity prices for Net Metering and Parallel Generation are inflated according to the schedule prepared for the Falls Lake Hydropower Study, available in Appendix B. Projected electricity prices included consideration of the impact of the Duke – Progress Energy merger.

3 Metric tons of CO_2 equivalent emissions avoided from electricity generation over the lifecycle of the engine

Revenue from electricity would be greater if CORPUD chooses to implement co-digestion of fats, oils, and greases or food waste, due to the higher rate of biogas production. Note that this cost analysis does not include the impact of any tax credits or other incentives that may be available if CORPUD procures the system through an ESCO. Such incentives would shorten the payback period even further.

In addition to economic benefits, the CHP system offers a significant reduction in greenhouse gas emissions associated with electricity production, as shown in Table 6-10. Depending on the number and size of the engines, between 98,000 and 173,000 metric tons of CO_2 equivalent emissions would be prevented over 20-years. This is equivalent to preventing the combustion of between 11 and 19 million gallons of gasoline over the life of the facility (U.S. EPA, 2012).

6.8 CHP Generator System Recommendation

Based on this analysis, it is recommended that CORPUD make plans to implement CHP generation alongside the selected biosolids management alternative. CORPUD may wish to issue an RFP for third-party financing of the system to determine whether this option would be more economical than purchase and operation of the equipment in-house. In either case, the economic feasibility of the system should be confirmed during the design phase when economic, regulatory, and financial conditions impacting the project are known with more certainty.

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Section 7

Recommended Capital Improvement Plan

This section describes the recommended facilities in detail and presents a suggested capital improvement plan for their implementation.

7.1 Recommended Facilities

Alternative 3 (thermal hydrolysis plus solar drying) is the recommended management strategy for CORPUD, due to its low life cycle cost, high non-cost score, alignment with the City's sustainability goals, and the degree of operational flexibility it affords. Option A, in which the existing dewatering and truck loading facilties remain in service, is recommended over option B. As noted in Section 5, continued use of the existing building provides a capital cost savings of $1.4 million to $5.7 million over construction of a new building, depending upon whether the existing equipment is replaced in 2028. Keeping existing facilities in service preserves available space on the plant site and maximizes the value of the capital investments that have already been made.

Anaerobic digestion coupled with THP will provide a high degree of volatile solids destruction, reducing both the digester volume and the quantity of solids that must be dewatered and transported to end use. The high temperatures involved in THP will facilitate the production of Class A biosolids, expanding the possible outlets for this material. The addition of solar dryers to the process will provide an alternate pathway to Class A biosolids that supports the City's sustainability goals. Implementation of these facilities will offset approximately 14,000 metric tons of CO_2 equivalents per year (comparable to the emissions of 2,900 passenger cars), and result in significant long-term savings in operations costs. The addition of a combined heat and power engine will offset another 8,600 metric tons CO_2e (1,800 cars) per year.

The individual facilities comprising this alternative are discussed below. Refer to **Figure 5-5** for a process schematic and mass balance of this option. The proposed layout of the facilities is shown on **Figure 5-6.**

7.1.1 Pre-Screening Facility

The pre-screening facility will consist of two mechanical screens designed to remove grit from the primary and secondary sludge, which will be blended in a tank upstream of this process. The screens will be installed on an elevated steel platform, allowing the grit to fall into a dumpster below. The platform would be housed inside a pre-engineered metal building to facilitate odor control. A typical layout of the interior of this facility is shown in **Figure 7-1.**

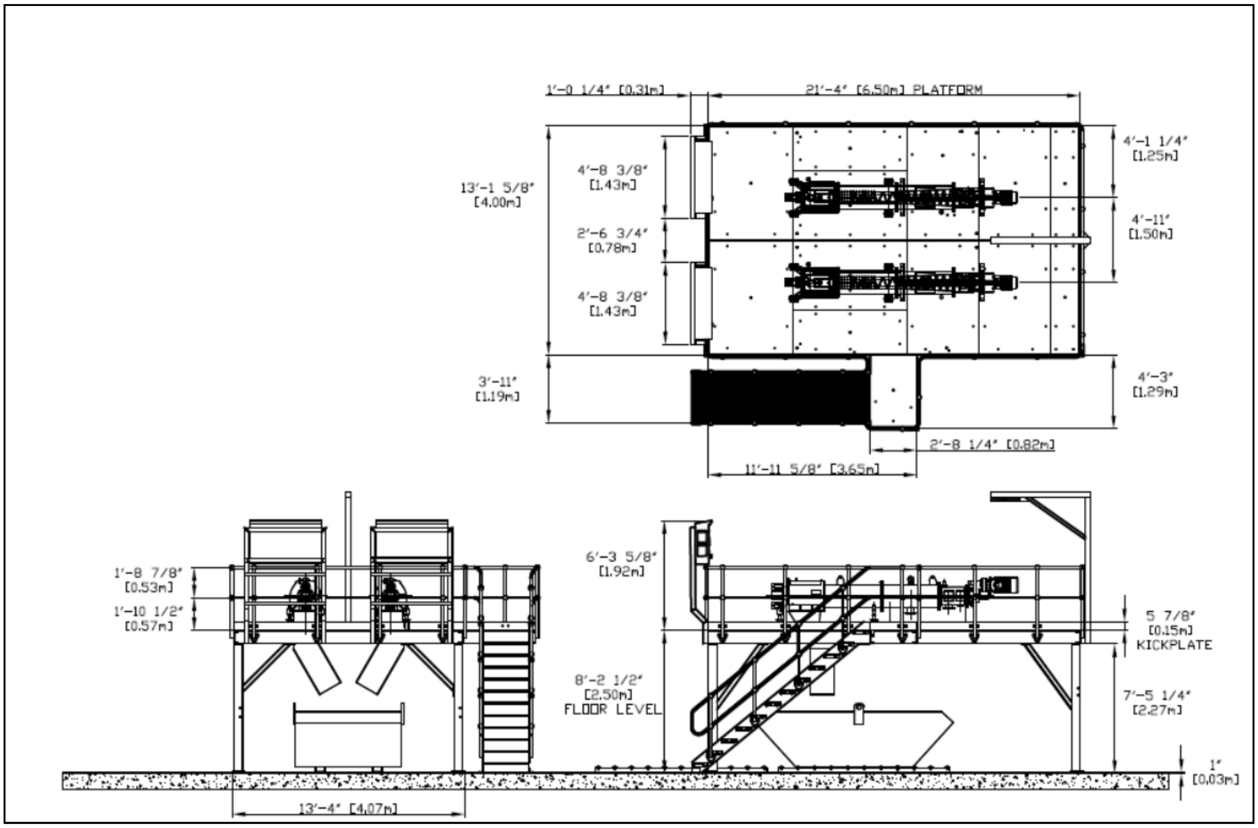

Figure 7-1 Typical Pre-screening Facility Layout (enclosure and odor control system not shown; image courtesy Hydro International).

7.1.2 Pre-Dewatering Facility

The pre-dewatering facility will process screened sludge, dewatering it to approximately 17% in preparation for the thermal hydrolysis process downstream. A total of four pre-dewatering centrifuges will ultimately be required, of the same size and type as the existing centrifuge.

Pre-dewatering will be located in a two-level building, 1,500-square foot building, with the centrifuges installed at the top level. The lower level will contain piping, feed pumps, and a polymer batching system. Dewatered material will exit the centrifuges via screw conveyors similar to those in the existing dewatering facility and be dropped into two live-bottom cake bins located outdoors and immediately adjacent to the building. The bins will convey the material to feed pumps for the thermal hydrolysis process, which will be housed inside the building.

7.1.3 Thermal Hydrolysis Process

The thermal hydrolysis equipment will be installed outdoors on an approximately 50-ft x 75-ft slab. This pre-engineered package contains the following equipment:

- <u>Pulper</u>: receives dewatered cake from the cake bin. Flash steam from the reactors and the flash tank pre-heats the sludge in the pulper.
- <u>Reactors (3):</u> Steam is added to increase both temperature and pressure for each batch reactor cycle for a predetermined period, after which the steam is transferred to pre-heat the solids in

the pulper. The reactor's solids are then transferred to the flash tank by using the remaining pressure.

- Flash tank: A short-term buffer tank. The gas/steam released from the pulper is highly odorous and saturated with water. The foul gases are compressed to the necessary pressure using closed circuit ejectors and injected into the sludge pipe entering each digester.

- Digester Feed Pumps: The hydrolyzed solids are continuously withdrawn from the flash tank by the digester feed pumps and delivered to the digesters at a temperature of about 194 degrees F. The hydrolyzed solids are blended with circulated digested solids at an operator-adjustable ratio prior to entering the digester cooling heat exchangers to reduce the temperature to mesophilic range of typically 100 degrees F.

Between the flash tank and the digesters the sludge may have to be diluted from 13%-15% dry solids to 8%-12% dry solids to decrease the temperature and viscosity of the sludge, and avoid high concentrations of ammonia in the digester. The dilution water feed rate is set by the operators based upon sampling of the sludge.

A proposed layout of this equipment is shown in **Figure 7-2.**

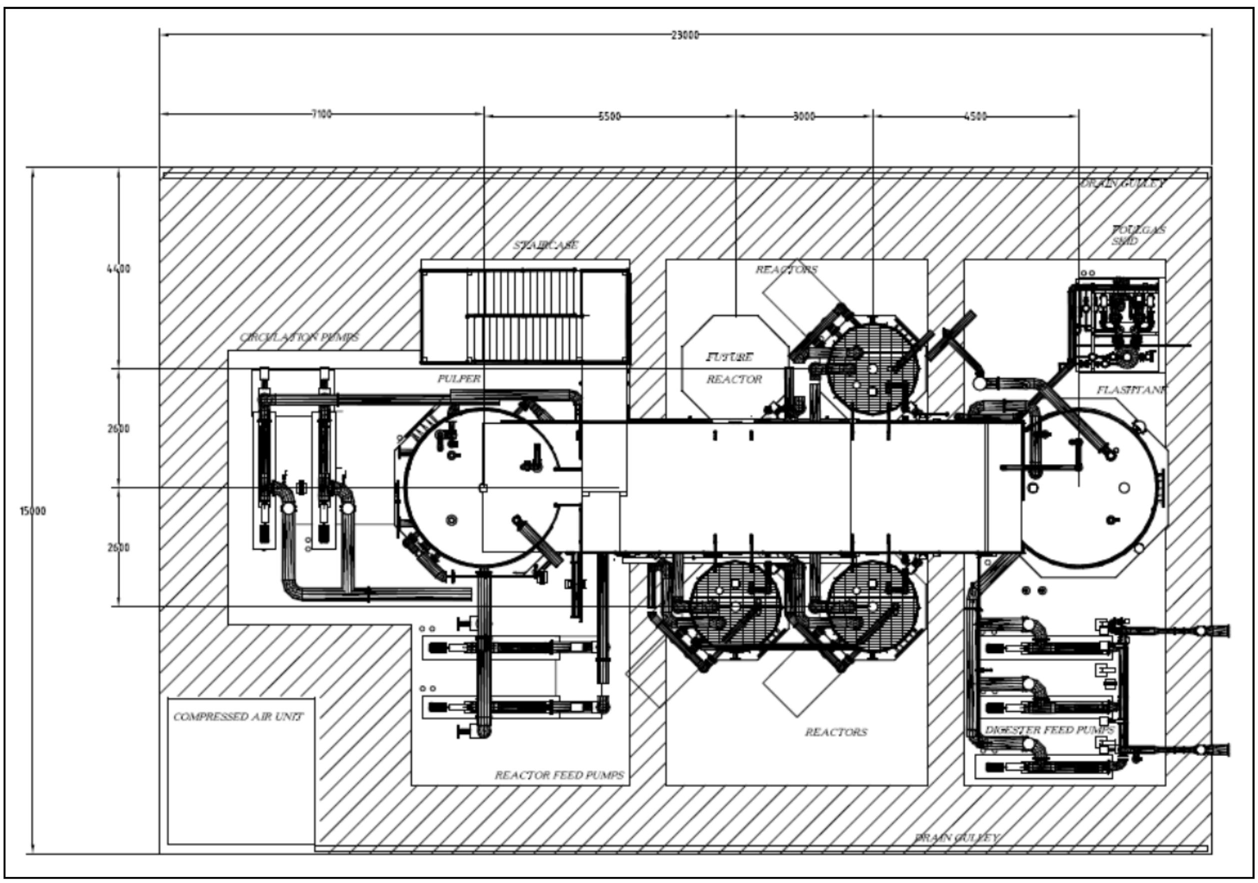

Figure 7-2 Proposed Layout of Thermal Hydrolysis Equipment (image courtesy Cambi)

7.1.4 Anaerobic Digesters

Two 1.6-MG anaerobic digesters will be constructed adjacent to the THP equipment. Each will consist of a 64-ft diameter prestressed concrete tank with a sidewater depth matching the diameter (64-ft). The tanks will be constructed partially underground to allow for a sloped floor. Each digester will include three draft tube mixers mounted to the concrete cover, and a flare for digester gas.

Immediately adjacent to the digesters, a 6,500 square foot building will house recirculation and cooling water pumps, sludge withdrawal pumps, electrical gear, and other ancillary equipment. The heat exchangers will be of the concentric tube type to provide cooling instead of heating and will be located outdoors.

A photo of a typical anaerobic digester design is shown in **Figure 7-3.**

Figure 7-3 Typical Anaerobic Digester Design

7.1.5 Post-Dewatering Facility

Final dewatering will take place in the existing dewatering facility. Three, new, 2m belt filter presses will replace the existing equipment, while the existing centrifuge will remain in service. Other miscellaneous building improvements to improve ventilation and mitigate corrosion will be made as well.

7.1.6 Solar Dryers

Eight 42-ft x 435-ft solar drying chambers (greenhouses) are proposed. This quantity of dryers will have sufficient capacity to replace the Class A treatment currently provided by the alkaline stabilization facilities. Each greenhouse will contain fans, louvers, and environmental controls to optimize conditions for drying, as well as a robotic windrow turner. A typical solar drying facility layout is shown in **Figure 7-4.**

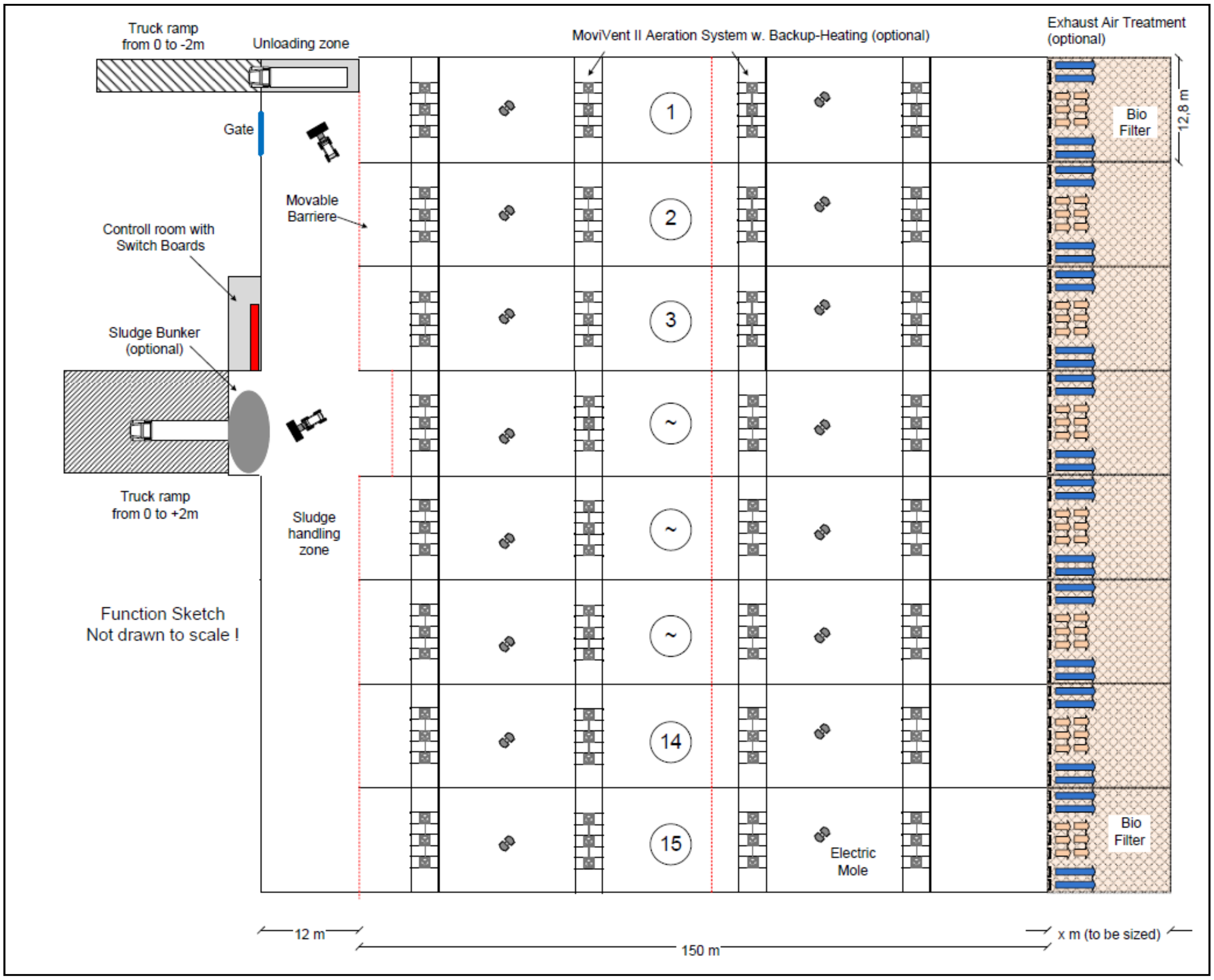

Figure 7-4 Example Solar Drying Facility Layout (image courtesy Kruger)

7.1.7 Dewatered Cake Storage

The ability to store dewatered biosolids for an extended period is critical to the success of any land application-based end use of the material. The NRWWTP currently has approximately 60,000 square feet of concrete storage area for biosolids, but only half of it is covered. A typical 300 wet-ton batch through the alkaline stabilization process occupies roughly the entire existing covered area. For implementation options in which construction of the solar dryers is delayed into the second phase, it is recommended that the remainder of the existing cake storage pad be covered, since all dewatered biosolids would need to be used via land application. The estimated cost of this improvement is approximately $0.8 million.

7.1.8 Combined Heat and Power Engine Generator

As discussed in Section 6, a CHP engine generator appears to be a cost-effective addition to this alternative, furthering the City's sustainability goals while generating revenue for CORPUD. This equipment may be purchased directly or procured through a third party ESCO. Depending upon economic and financial conditions closer to the time of construction, the City may wish to re-examine which option would be most-cost effective.

7.1.9 Nutrient Recovery

As discussed in Section 3, a nutrient recovery system is an optional addition to anaerobic digestion that could offer several benefits, including recovery of valuable resources (e.g. phosphorous), alignment with the City's sustainability goals, and mitigation of the impact of concentrated side-streams on the liquid treatment process. Preliminary opinion costs suggest that a nutrient recovery system may cost $7.7 million to implement (including equipment and structure). However, further study of the performance of the liquid treatment system would be required to determine the size and cost of these facilities with more accuracy. This is a system that could be added at any time. Nitrogen in the recycled stream also required to be managed. While a side-stream treatment system can be considered, it is assumed that the main plant can handle this stream through equalization and managed feeding.

7.2 Capital Cost

Table 7-1 provides a summary of the capital costs associated with each of the facilities included in Alternative 3, as well as the cost of a CHP engine generator and additional dewatered cake storage, which is recommended to facilitate the transition to the new processes (see discussion below)..

CDM Smith

Table 7-1 Summary of Capital Costs for Recommended Alternative, CHP engine, and Cake Storage

Facility	Equipment Cost	Labor & Materials Cost	Total Cost[1]
Pre-Screening Platform	$0.6 M	$1.1 M	$1.7 M
Pre-Dewatering Building	$3.8 M	$3.1 M	$6.9 M
Thermal Hydrolysis Process	$7.3 M	$1.6 M	$8.9 M
Anaerobic Digesters	$3.5 M	$7.2 M	$10.7 M
Replace Existing Belt Filter Presses	$1.6 M	$1.4 M	$3.0 M
Replace Conveyance Equipment (2028)	$0.8 M	$0.3 M	$1.1 M
Replace Truck Loading Station (2028)	$0.9 M	$0.3 M	$1.2 M
Solar Dryers	$7.5 M	$5.2 M	$12.7 M
Subtotal Alternative 3 Process Facilities	**$26.0 M**	**$20.2 M**	**$46.2 M**
Cake Storage Improvements	-	$0.8 M	$0.8 M
Combined Heat and Power Engine[2]	$3.2 M	$1.5 M	$4.7 M
Subtotal Direct Construction Cost	**$29.2 M**	**$22.5 M**	**$51.7 M**
Subtotal Direct Construction Cost + Contractor OH&P			**$66.3 M**
Total Capital Cost (w/Contingency, Admin, Engineering)[3]			**$90.9 M**

[1] All capital costs are reported in December 2012 dollars (ENR CCI = 9412.25), with the exception of Conveyance and Truck Loading replacement, which are assumed installed in 2028, at the end of the current facility design life. These costs are escalated assuming annual inflation of 4.5% for capital costs and a 4.7% nominal discount rate.

[2] Capital cost may be reduced or eliminated if third-party financing is used.

[3] Includes markups for taxes, permits, bonds, insurance, contractor's general conditions, overhead and profit, engineering services during design and construction, administrative costs, and contingency. A detailed description of these markups is provided in Section 4.

7.3 Phasing and Implementation Schedule

Phased implementation of these facilties is recommended as a means of rendering the large capital cost more compatible with the City's budget. Per discussion with CORPUD at Workshop No. 4, implementation was broken into phases with the goal of limiting capital outlays to approximately $40 million every five years. Three implementation options are presented below for consideration. For planning purposes, Phase I was assumed to occur in 2016, and Phase 2, five years later in 2021.

All options include a third phase of repair and replacement is included for planning purposes in 2028, when the existing truck loading station and biosolids conveyance equipment may be nearing the end of their design life. While it is possible that much of this equipment will still be in serviceable condition at that time, the cost for complete replacement of these facilities is included below for planning purposes.

7.3.1 Implementation Option 1: THP and Anaerobic Digestion

This implementation option brings the anaerobic digestion and THP processes online as soon as possible, with the majority of the proposed facilities constructed in Phase 1. Only the solar dryers and belt filter press replacement are delayed until Phase 2.

Because this option will require treatment of all dewatered biosolids through the alkaline stabilization process until the solar dryers are constructed, additional covered cake storage is recommended. This implementation option includes a cost for covering the remainder of the existing storage area to provide additional flexibility in the event that wet weather interferes with land application.

This option has the advantage of enabling NRWWTP to convert the entire treatment process over to anaerobic digestion in a single phase, providing savings in operating costs because parallel treatment trains (e.g., aerobic digestion) do not need to remain online. This option also allows the City to begin producing energy from biogas as soon as possible.

7.3.2 Implementation Option 2: Solar Dryers

A second option is to construct all eight of the solar drying modules in Phase 1, along with the proposed pre-screening and pre-dewatering facilities. Construction of the dewatered cake bins would be deferred until Phase II, allowing the lower level of the pre-dewatering building to be configured for truck loading. These facilities would be used in conjunction with the existing treatment processes until Phase II. To ensure continued reliable operation, replacement of the existing belt filter presses would also occur during Phase 1.

The new dewatering facilities and solar dryers would be able to dry a portion of the biosolids from the current process, and allow CORPUD to immediately improve the sustainability biosolids management while adding an alternate means of producing Class A biosolids. When all phases are complete, the eight solar dryers will have sufficient capacity to replace the existing Alkaline Stabilization process, provided that biosolids continue to be sent to composting at the contracted rate. Before anaerobic digestion comes online, the solar dryers can be used to reduce the solids loading to alkaline stabilization, but they will not have the capacity to replace it entirely.

The second phase will consist of the thermal hydrolysis process, both anaerobic digesters, and the CHP engine generator. In addition, the pre-dewatering building will be reconfigured to feed the THP process by adding dewatered cake bins and pumps. This phase will include construction of a pipeline to convey digested sludge back to the existing biosolids day tanks, allowing the existing final dewatering facilities to remain in service.

7.3.3 Implementation Option 3: Anaerobic Digestion and Solar Drying

In this option, the solar dryers and anaerobic digesters are constructed in Phase 1, separately from the THP process. However, without the large solids reduction achieved by hydrolysis, they could only be used to treat a portion of the NRWWTP biosolids (even in 2016). As such, some of the existing treatment systems would need to remain online.

Phase II would include construction of the THP process, pre-screening and pre-dewatering facilities, and final dewatering improvements.

This option allows the City to rapidly improve the sustainable features to its biosolids management strategy by implementing digestion, combined heat and power, and solar drying in the first phase, at the cost of some added operational complexity associated with keeping existing systems in service.

Table 7-2 summarizes the capital improvement costs associated with each of the above options. Costs are reported in net present value terms, reflecting a 4.5% annual capital cost inflation rate and a 4.7% discount rate.

Table 7-2 Summary of Capital Improvement Options

Phase	Year	Description	Cost
Option 1: THP and Anaerobic Digestion			
Phase I	2016	Pre-screening, pre-dewatering, thermal hydrolysis, anaerobic digesters, CHP engine, additional cake storage	$59.3 M
Phase II	2021	Eight solar drying modules, BFP replacement and final dewatering building improvements	$26.2 M
Phase III	2028	Replace existing conveyance equipment and truck loading station	$4.3 M
Option 2: Solar Drying and Pre-Dewatering			
Phase I	2016	Pre-screening, pre-dewatering, eight solar drying modules, BFP replacement	$38.2 M
Phase II	2021	Thermal hydrolysis, two anaerobic digesters, CHP engine	$45.9 M
Phase III	2028	Replace existing conveyance equipment and truck loading station	$4.3 M
Option 3: Anaerobic Digestion and Solar Drying			
Phase I	2016	Anaerobic digesters, eight solar drying modules, CHP engine	$49.4 M
Phase II	2021	Pre-screening, pre-dewatering, thermal hydrolysis, BFP replacement and final dewatering building improvements	$34.8 M
Phase III	2028	Replace existing conveyance equipment and truck loading station	$4.3 M

7.3.4 Recommendation

The City has expressed a clear interest in moving towards anaerobic digestion for the treatment of biosolids. As discussed above, this technology will offer numerous benefits that support CORPUD's goals for the biosolids program. As such, option 1 is the recommended implementation approach, as it allows anaerobic digestion, thermal hydrolysis, and combined heat and power to be implemented immediately. These improvements will significantly improve the sustainability of the biosolids management program at NRWWTP.

As discussed in Section 6, CORPUD may wish to issue a request for proposals to determine whether third-party financing might be more economical than purchase of the CHP engine. Financial arrangements with a third party ESCO may prevent CORPUD from having to make a large capital expenditure for this equipment.

Appendix A

O&M Cost Development

Appendix A

O&M Cost Development

This appendix contains the calculations used to develop operations and maintenance costs for each biosolids treatment and disposal process. Detailed calculations are provided on the following pages and are organized by unit process. Table A-1 summarizes each process' unit costs in the form of dollar per dry ton of residuals entering the process.

Information for proposed equipment was obtained from vendor proposals and substantiated by CDM Smith's experience with similar facilities. Detailed information for existing equipment, such as horsepower and operating schedule, originated from the 2008 Master Plan and was verified by plant staff.

City staff provided up-to-date electricity prices and fully-allocated labor costs of $0.076 per kWh and $34.09 per hour, respectively. The price of natural gas used for these calculations was $8.00 per MMBTU. This price is a conservative estimate derived from NYMEX Natural Gas Price projections released on December 19, 2011.

Table A-1

Process Unit Cost (Per Dry Ton Entering Unit Process)	Alternative 1	Alternative 2	Alternative 3
Gravity Belt Thickening	$74	$40	-
Aerobic Stabilization	$118	-	-
Anaerobic Stabilization	-	$6	$3
Dewatering (Belt Filter Press)	$37	-	$41
Dewatering (Centrifuge)	$90	$67	-
Pre-Dewatering (Centrifuge)	-	-	$25
Solar Drying	-	$25	$18
Thermal Hydrolysis Process	-	-	$9
Alkaline Stabilization	$187	$184	$177
Off-Site Composting (<16 DTPD)	$177	$162	$124
Off-Site Composting (>16 DTPD)	$206	$188	$144
Liquid Land Application	$350	$468	$225
Dewatered Material Land Application	$144	$132	$101
Solar/Thermal Drying	-	$85	-
Thermal Drying	-	$143	$106

Gravity Belt Thickening Solids Operating Costs			
	Alt. 1	Alt. 2	
Gravity Belt Thickener (GBT) Solids Loading Rate (SLR) Capacity	575	900	lb(dry)/hour-meter
GBT Hydraulic Loading Rate (HLR)Capacity	125	250	gpm/meter
GBT Operating Width	2	3	meters
GBT Feed Solids Concentration	0.90%	0.90%	dry solids
GBT Capacity (SLR Controlled)	1,150	2,700	lb(dry)/hour
GBT Capacity (HLR Controlled)	1,126	3,378	lb(dry)/hour
Controlling GBT Capacity	1,126	2,700	lb(dry)/hour
Number of GBTs Operating	2	2	
Total Operating GBT Capacity	2,252	5,400	lb(dry)/hour
Operating Labor Unit Cost			
FTE Equivalent Loading - Dewatering	1.50	1.50	per hour
Operating Labor Unit Cost (Fully Allocated)	$34.09	$34.09	per hour
Operating Labor Cost (Fully Allocated)	$51.14	$51.14	per hour
Total Operating GBT Capacity	1.13	2.70	tons (dry)/hour
Operating Labor Unit Cost (Mass Basis)	$45.42	$18.94	per ton (dry)
Operating Energy Unit Cost			
GBT Drive Motor Size	5.0	4.0	HP/GBT
GBT Sludge Feed Pump Motor Size	25.0	25.0	HP/GBT
GBT Polymer Feed Pump Motor Size	3.0	3.0	HP/GBT
TWAS Pump Conveyor Motor Size	15.0	15.0	HP/GBT
Spray Water Pumping (50 gpm/GBT @ 250-ft TDH)	5.0	7.5	HP/GBT
Total Installed Horsepower	53.0	54.5	HP/GBT
Total Power Demand	79.08	81.31	KWH/hour
Total Operating GBT Capacity	1.13	2.70	tons (dry)/hour
Electrical Power Demand	70.23	30.12	KWH/ton (dry)
Electrical Power Unit Cost	$0.076	$0.076	per KWH
Electrical Power Unit Cost (Mass Basis)	$5.34	$2.29	per dry ton
Operating Conditioning Chemical Cost			
Conditioning Chemical Polymer Dose	10	10	lb(active)/dry ton
Conditioning Chemical Polymer Unit Cost	$1.59	$1.59	per lb(active)
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$15.90	$15.90	per dry ton
Operating Maintenance Cost Allowance			
Operating Maintenance Cost Allowance	$4.00	$4.00	per hour/GBT
Total Operating Maintenance Cost	$8.00	$8.00	per hour
Total Operating GBT Capacity	1.13	2.70	tons (dry)/hour
Maintenance Unit Cost (Mass Basis)	$7.11	$2.96	per dry ton
Operating Cost Summary			
Operating Labor Unit Cost (Mass Basis)	$45.42	$18.94	per dry ton
Electrical Power Unit Cost (Mass Basis)	$5.34	$2.29	per dry ton
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$15.90	$15.90	per dry ton
Maintenance Unit Cost (Mass Basis)	$7.11	$2.96	per dry ton
Total Operating Cost (Mass Basis)	$73.76	$40.09	per dry ton

Aerobic Digestion Solids Operating Costs		
	Alt. 1	
Usable Aerobic Digester Total Volume	2.10	million gallons
Aerobic Digester Feed Solids Concentration	5.0%	TS
Aerobic Digester Feed Solids Mass Loading	875,700	lbs TS/cycle
Aerobic Digester Cycle Time (Fill-Aerate-Drain)	45	days
Aerobic Digester Feed Solids VS/TS Fraction	59.50%	
Aerobic Digester Feed Volatile Solids	521,042	lbs VS/cycle
Aerobic Digester Volatile Solids Removal (VSR)	40.0%	
Aerobic Digester Volatile Solids Destroyed	208,417	lbs VS/cycle
Aerobic Digester Total (Effluent) Solids Stabilized	667,283	lbs TS/cycle
Aeration Energy Requirement (UCADs)		
Average Aeration Rate (during cycle)	2,500	SCFM
Weight of Air, lbs/SCFT	0.0752	lbs/SCFT
Air Mass Flow Rate, lbs/second	3.1	lbs/second
Engineering Gas Constant	53.3	(ft-lb)/(lb-R°)
Atmospheric Pressure	14.7	psig
Inlet Air Temperature	60	°F
Absolute Inlet Temperature	521	°R
Relative Inlet Pressure	0.0	psig
Absolute Inlet Pressure	14.70	psia
Relative Outlet Pressure	10.0	psig
Absolute Outlet Pressure	24.7	psia
"k" Factor for Air	1.395	
"n" Factor for Air	0.283	
Compressor Efficiency	75%	
Aeration Energy Power	117.8	HP
Aeration Energy Power	87.9	KW
Aeration Energy Consumption	94,943	KWH
Pumped Mixing Energy Requirement		
Aerobic Digester Mixing - Pump Flow	10,800	GPM per pump
Aerobic Digester Mixing - Pump TDH	27.3	feet
Aerobic Digester Mixing - Pump Efficiency	80%	
Aerobic Digester Mixing - Pumping Energy	93.1	HP per pump
Aerobic Digester Mixing - Total Pumping Energy	69.5	KW per pump
Days Operating One Pump (during cycle)	0	days
Days Operating Two Pumps (during cycle)	45	days
Pumped Mixing Energy Consumption	150,086	KWH/cycle
Aeration Energy Requirement (CADs)		
Average Aeration Rate (during cycle)	4,000	SCFM
Weight of Air, lbs/SCFT	0.0752	lbs/SCFT
Air Mass Flow Rate, lbs/second	5.0	lbs/second
Engineering Gas Constant	53.3	(ft-lb)/(lb-R°)
Atmospheric Pressure	14.7	psig
Inlet Air Temperature	60	°F
Absolute Inlet Temperature	521	°R

Aerobic Digestion Solids Operating Costs Cont'd. Aeration Energy Requirement (CADs)		
Relative Inlet Pressure	0.0	psig
Absolute Inlet Pressure	14.70	psia
Relative Outlet Pressure	10.0	psig
Absolute Outlet Pressure	24.7	psia
"k" Factor for Air	1.395	
"n" Factor for Air	0.283	
Compressor Efficiency	75%	
Aeration Energy Power	188.5	HP
Aeration Energy Power	140.7	KW
Aeration Energy Consumption	151,909	KWH/cycle
Odor Control Energy Requirement		
Average Odor Control Rate (during cycle)	8,000	SCFM
Weight of Air	0.0752	lbs/SCFT
Air Mass Flow Rate	10.03	lbs/second
Engineering Gas Constant	53.3	(ft-lb)/(lb-R°)
Atmospheric Pressure	14.7	psia
Inlet Air Temperature	60	°F
Absolute Inlet Temperature	520.67	°R
Relative Inlet Pressure	0.0	psig
Absolute Inlet Pressure	14.7	psia
Relative Outlet Pressure	1.0	psig
Absolute Outlet Pressure	15.7	psla
"k" Factor for Air	1.395	
"n" Factor for Air	0.283	
Compressor Efficiency	75%	
Odor Control Energy Power	44.8	HP
Odor Control Energy Power	33.4	KW
Odor Control Energy Consumption	36103	KWH/cycle
Chemical Use		
Caustic Consumption Rate	3	loads/yr
Caustic unit cost	$5,700	$/load
Annual caustic cost	$17,100	$/yr
EcoScent consumption Rate	825	gal/yr
EcoScent unit cost	$74	$/gal
Annual EcoScent cost	$61,050	$/yr
Average residuals processed (2009-2012)	1383	DT/yr
No. of cycles/year	4.1	
Odor Control Chemical cost per Cycle	$18,853	$/cycle

Aerobic Digestion Solids Operating Costs Cont'd. Total Operating Cost		
Pumped Mixing Energy Consumption	150,086	KWH/cycle
Aeration Energy Consumption	246,853	KWH/cycle
Odor Control Energy Consumption	36,103	KWH/cycle
Total Energy Consumption	433,042	KWH/cycle
Odor Control Chemical Cost	18,853	$/cycle
Energy Expended per Unit VS Destroyed	2.08	KWH/ lb VS
Energy Expended per Unit VS Destroyed	4156	KWH/ton VS
Electrical Energy Cost	0.076	$/KWH
Aerobic Digestion Energy Cost, $/ton VS Destroyed	$316	
Odor Control Chemical Cost, $/ton VS Destroyed	$181	
Total Aerobic Digestion Operating Cost, $/ton VS Destroyed	$496.74	
Aerobic Digestion Energy Cost, $/ton TS Applied (Digester Influent)	$75.17	
Odor Control Chemical Cost, $/ton TS Applied (Digester Influent)	$43.06	
Total Aerobic Digestion Operating Cost, $/ton TS applied (Dig. Influe	$118.22	
Aerobic Digestion Energy Cost $/ton TS Stabilized (Digester Effluent)	$98.64	
Odor Control Chemical Cost $/ton TS stabilized (Digester Effluent)	$56.51	
Total Aerobic Digestion Operating Cost, $/ton TS stabilized (Dig. Effl	$155.15	

Anaerobic Digestion Cost Solids Operating Costs			
	Alt. 2	Alt. 3	
Anaerobic Digester Feed Solids Mass Loading	136,013	131,813	lb TS/day
Anaerobic Digester Feed Solids Concentration	4.30%	11.00%	
Anaerobic Digester Feed Solids VS/TS Fraction	75.90%	75.80%	
Anaerobic Digester Feed Volatile Solids	103,234	99,914	lb VS/day
Anaerobic Digester Average Volatile Solids Removal (VSR)	50%	65%	
Anaerobic Digester Average Volatile Solids Destroyed	51,617	64,944	lbs VS/day
Anaerobic Digester Effluent Solids Mass Loading	84,396	66,869	lbs TS/day
Number of Digesters	3	2	
Digester Volume (each)	2.7	1.6	MG
Digester Pumped Mixing Energy Requirement			
Anaerobic Digester Mixing - Pumping Input Horsepower	300.0	120.0	HP
Anaerobic Digester Mixing - Total Pumping Energy	223.8	89.5	KW, each
Pumped Mixing Energy Consumption	5,371	2,148	KWH/day
Digester Thermal Energy Requirement			
Incoming Sludge Temperature	68.0	120.0	F
Digester Sludge Temperature	98.0	98.0	F
Specific Heat of Sludge	1.0	1.0	BTU/lb- F
Sludge Heat Requirement	94.9	0.0	MMBTU/day
Digester Heat Loss	65.3	0.0	MMBTU/day
Total Heat Required to Digesters	160	0	MMBTU/day
Boiler Thermal Efficiency	80%	80%	
Total Energy Required for Boilers	200	0	MMBTU/day
Biogas Production Rate	15.0	15.0	SCF/lb VSR
Biogas Heating Value	585.0	585.0	BTU/SCF gas
Energy Available from Biogas	453	570	MMBTU/day
Supplemental (NG) Energy Required	0	0	MMBTU/day
Natural Gas Cost	$8.00	$8.00	$/MMBTU
Supplemental Heating Cost	$0.00	$0.00	$/day
Miscellaneous Pumping Energy Requirement			
Digester Recirculation Pump - Nameplate Motor Horsepower	20.0	20.0	HP
Primary Loop Hot Water Pump - Nameplate Motor Horsepower	10.0	-	HP
Secondary Loop Hot Water Pump - Nameplate Motor Horsepower	5.0	-	HP
Total Installed Nameplate Horesepower	35.0	20.0	HP
Power Utilization Factor (% of Nameplate Used)	70.0%	70.0%	
Power Utilization	24.5	14	HP
Miscellaneous Pumping Energy Consumption	439	251	KWH/day
Total Energy Consumption			
Pumped Mixing Energy Consumption	5,371	2,148	KWH/day
Miscellaneous Pumping Energy Consumption, KWH/day	439	251	KWH/day
Total Energy Consumption	5,810	2,399	KWH/day
Electrical Energy Cost	0.076	0.076	$/KWH
Total Electrical Energy Cost	$442	$182	$/day
Total Thermal Energy Cost	$0.00	$0.00	$/day
Energy Expended per Unit VS Destroyed	0.11	0.04	KWH/lb VS
Energy Expended per Unit VS Destroyed	225	74	KWH/ton VS
Aerobic Digestion Unit Cost	$17.11	$5.62	$/ton VS Destroyed
Aerobic Digestion Unit Cost	$6.49	$2.77	$/ton TS Applied (Digester Influent)
Aerobic Digestion Unit Cost	$10.46	$5.45	$/ton TS Stabilized (Digester Effluent)

Belt Filter Press Dewatering Solids Operating Costs	Alt. 1	Alt. 3	
Belt Filter Press (BFP) Solids Loading Rate (SLR) Capacity	1321	750	lb(dry)/hour-meter
BFP Hydraulic Loading Rate (HLR) Capacity	100	100	gpm/meter
BFP Operating Width	2	3	meters
BFP Feed Solids Concentration	2.64%	5.60%	dry solids
BFP Capacity (SLR Controlled)	2,642	2,250	lb(dry)/hour
BFP Capacity (HLR Controlled)	2,642	8,407	lb(dry)/hour
Controlling BFP Capacity	2,642	2,250	lb(dry)/hour
Number of BFP Operating	3	3	
Total Operating BFP Capacity	7,926	6,750	lb(dry)/hour
Operating Labor Unit Cost			
FTE Equivalent Loading - Dewatering	1.5	1.5	FTE
Operating Labor Unit Cost (Fully Allocated)	$34.09	$34.09	per hour
Operating Labor Cost (Fully Allocated)	$51.14	$51.14	per hour
Total Operating BFP Capacity	3.96	3.38	tons (dry)/hour
Operating Labor Unit Cost (Mass Basis)	$12.90	$15.15	per ton (dry)
Operating Energy Unit Cost			
BFP Drive Motor Size	5.0	6.0	HP/press
BFP Sludge Feed Pump Motor Size	10.0	10.0	HP/press
BFP Polymer Feed Pump Motor Size	3.0	3.0	HP/press
Dewatered Cake Conveyor Motor Size	10.0	10.0	HP/press
Spray Water Pumping (100 gpm/BFP @ 250-ft TDH)	7.5	15.0	HP/press
Total Installed Horsepower	35.50	44.00	HP/press
Total Power Demand	79.45	98.47	KWH/hour
Total Operating BFP Capacity	3.96	3.38	tons (dry)/hour
Electrical Power Demand	20.05	29.18	KWH/ton (dry)
Electrical Power Unit Cost	$0.076	$0.076	per KWH
Electrical Power Unit Cost (Mass Basis)	$1.52	$2.22	per dry ton
Operating Conditioning Chemical Cost			
Conditioning Chemical Polymer Dose	12.5	12.5	lb(active)/dry ton
Conditioning Chemical Polymer Unit Cost	$1.59	$1.59	per lb(active)
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$19.88	$19.88	per dry ton
Operating Maintenance Cost Allowance			
Operating Maintenance Cost Allowance	$4.00	$4.00	per hour/BFP
Total Operating Maintenance Cost	$12.00	$12.00	per hour
Total Operating BFP Capacity	3.96	3.38	dry tons per hour
Maintenance Unit Cost (Mass Basis)	$3.03	$3.56	per dry ton
Operating Cost Summary			
Operating Labor Unit Cost (Mass Basis)	$12.90	$15.15	per dry ton
Electrical Power Unit Cost (Mass Basis)	$1.52	$2.22	per dry ton
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$19.88	$19.88	per dry ton
Maintenance Unit Cost (Mass Basis)	$3.03	$3.56	per dry ton
Total Operating Cost (Mass Basis)	$37.33	$40.80	per dry ton

Dewatering Centrifuge Solids Operating Costs	Alt. 1	Alt. 2 (Dewatering)	Alt. 3 (Pre-Dewatering)	
Centrifuge Solids Loading Rate (SLR) Capacity	2642	3150	4000	lb(dry)/hour
Centrifuge Hydraulic Loading Rate (HLR) Capacity	200	250	270	gpm
Centrifuge Feed Solids Concentration	2.64%	2.50%	3.00%	
Centrifuge Capacity (SLR Controlled)	2,642	3,150	4,000	lb(dry)/hour
Centrifuge Capacity (HLR Controlled)	2,642	3,128	4,053	lb(dry)/hour
Controlling Centrifuge Capacity	2,642	3,128	4,000	lb(dry)/hour
Number of Centrifuges Operating	1	2	3	lb(dry)/hour
Total Operating Centrifuge Capacity	2,642	6,255	12,000	lb(dry)/hour
Operating Labor Unit Cost				
FTE Equivalent Loading - Dewatering	1.5	1.5	1.5	FTE
Operating Labor Unit Cost (Fully Allocated)	$34.09	$34.09	$34.09	per hour
Operating Labor Cost (Fully Allocated)	$51.14	$51.14	$51.14	per hour
Total Operating Centrifuge Capacity	1.32	3.13	6.00	tons (dry)/hour
Operating Labor Unit Cost (Mass Basis)	$38.71	$16.35	$8.52	per ton (dry)
Operating Energy Unit Cost				
Centrifuge Main/Secondary Drive Motor	150	200	200	HP/centrifuge
Centrifuge Sludge Feed Pump Motor	10	10	10	HP/centrifuge
Centrifuge Polymer Feed Pump Motor Size	3	3	3	HP/centrifuge
Dewatered Cake Conveyor Motor Size	10	10	10	HP/centrifuge
Total Installed Horsepower	173.00	223.00	223.00	HP/centrifuge
Total Power Demand	129.06	332.72	499.07	KWH/hour
Total Operating Centrifuge Capacity	1.32	3.13	6.00	tons (dry)/hour
Electrical Power Demand	97.69	106.38	83.18	KWH/ton (dry)
Electrical Power Unit Cost	$0.076	$0.076	$0.076	per KWH
Electrical Power Unit Cost (Mass Basis)	$7.42	$8.09	$6.32	per dry ton
Operating Conditioning Chemical Cost				
Conditioning Chemical Polymer Dose	25	25	5	lb(active)/dry ton
Conditioning Chemical Polymer Unit Cost	$1.59	$1.59	$1.59	per lb(active)
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$39.75	$39.75	$7.95	per dry ton
Operating Maintenance Cost Allowance				
Operating Maintenance Cost Allowance	$5.00	$5.00	$5.00	per hour/BFP
Total Operating Maintenance Cost	$5.00	$10.00	$15.00	per hour
Total Operating Centrifuge Capacity	1.32	3.13	6.00	dry tons per hour
Maintenance Unit Cost (Mass Basis)	$3.78	$3.20	$2.50	per dry ton
Operating Cost Summary				
Operating Labor Unit Cost (Mass Basis)	$38.71	$16.35	$8.52	per dry ton
Electrical Power Unit Cost (Mass Basis)	$7.42	$8.09	$6.32	per dry ton
Conditioning Chemical Polymer Unit Cost (Mass Basis)	$39.75	$39.75	$7.95	per dry ton
Maintenance Unit Cost (Mass Basis)	$3.78	$3.20	$2.50	per dry ton
Total Operating Cost (Mass Basis)	$89.67	$67.38	$25.29	per dry ton

Solar Drying Operating Costs				
General				
	Alt. 2	**Alt. 3**	**Alt. 2B**	
10402.5				
Solar Dryer Solids Loading Rate	14,637	11,571	14,637	dry tons per year
Solar Dryer Feed Solids Concentration	23%	30%	23%	dry solids
Solar Dryer Capacity per Module	550	890	760	dry tons per year per module
Number of Solar Drying Modules	16	8	12	
Total Evaporation Rate	44,122	23,141	21,818	wet tons per year
Solar Dryer Dried Sludge Solids Concentration	75%	75%	35%	dry solids
Operating Labor Unit Cost				
FTE Equivalent Loading	1.25	1.00	1.00	per hour
Operating Labor Unit Cost (Fully Allocated, per working hour)	$34.09	$34.09	$34.09	per hour
Operating Labor Cost (Fully Allocated, per working hour)	$42.61	$34.09	$34.09	per hour
Annual Labor Cost (Fully Allocated)	88,634	70,907	70,907	$/yr
Operating Labor Unit Cost (Mass Basis)	$6.06	$6.13	$4.84	per ton (dry)
Operating Energy Unit Cost				
Total Power Demand	110	60	110	KWH per dry ton
Electrical Power Unit Cost	$0.076	$0.076	$0.076	per KWH
Electrical Power Unit Cost (Mass Basis)	$8.36	$4.57	$8.36	per dry ton
Operating Maintenance Cost Allowance				
Operating Maintenance Cost Allowance	$1.14	$1.14	$1.14	per hour/solar module
Total Operating Maintenance Cost	$18.44	$9.13	$13.58	per hour
Total Operating Solar Dryer Capacity	1.7	1.3	1.7	tons (dry)/hour
Maintenance Unit Cost (Mass Basis)	$11.03	$6.91	$8.13	per dry ton
Operating Cost Summary				
Operating Labor Unit Cost (Mass Basis)	$6.06	$6.13	$4.84	per dry ton
Electrical Power Unit Cost (Mass Basis)	$8.36	$4.57	$8.36	per dry ton
Maintenance Unit Cost (Mass Basis)	$11.03	$6.91	$8.13	per dry ton
Total Operating Cost (Mass Basis)	$25.45	$17.61	$21.33	per dry ton

Alkaline Stabilization				
Solids Operating Costs				
	Alt 1	**Alt 2**	**Alt 3**	
Throughput Capacity	7,750	7,750	7,750	dry pounds per hour
Dewatered Solids Concentration	21.00%	23.00%	30.00%	
Raleigh Plus Mass Ratio	6.76	6.35	5.33	tons (product) per dry ton solids
Chemical Cost				
	Alt 1	**Alt 2**	**Alt 3**	
LKD Admixture Cost	$64.00	$64.00	$64.00	per ton admixture
Admixture Blending Ratio	2.00	2.00	2.00	ton admixture per dry ton solids
Conditioning Chemical Cost	$128.00	$128.00	$128.00	per dry ton
Labor Unit Cost				
	Alt 1	**Alt 2**	**Alt 3**	
FTE Equivalent Loading	1.0	1.0	1.0	FTE per hour
Operating Labor Unit Cost (Fully Allocated)	$34.09	$34.09	$34.09	per hour
Labor Cost	$8.80	$8.80	$8.80	per dry ton
Maintenance Cost Allowance				
Mainenance Cost	$4.00	$4.00	$4.00	per dry ton
Equipment Rental Revenue				
	Alt 1	**Alt 2**	**Alt 3**	
Sale of Raleigh Plus Revenue	$4.70	$4.70	$4.70	per ton (as product)
Sale of Raleigh Plus Revenue	$31.78	$29.83	$25.07	per dry ton
Hauling Cost				
	Alt 1	**Alt 2**	**Alt 3**	
Raleigh Plus Hauling Cost (<35-miles)	$9.00	$9.00	$9.00	per product ton
Raleigh Plus Hauling Cost (36-55-miles)	$11.50	$11.50	$11.50	per product ton
Raleigh Plus Hauling Cost (56-70-miles)	$14.50	$14.50	$14.50	per product ton
Raleigh Plus Hauling Cost (71-91-miles)	$16.50	$16.50	$16.50	per product ton
Raleigh Plus Hauling Cost (<35-miles)	$60.86	$57.13	$48.00	per dry ton
Raleigh Plus Hauling Cost (36-55-miles)	$77.76	$73.00	$61.33	per dry ton
Raleigh Plus Hauling Cost (56-70-miles)	$98.05	$92.04	$77.33	per dry ton
Raleigh Plus Hauling Cost (71-91-miles)	$111.57	$104.74	$88.00	per dry ton
Operating Cost Summary				
	Alt 1	**Alt 2**	**Alt 3**	
Net O&M Cost (Hauling 36-55 miles)	$186.78	$183.96	$177.06	per dry ton

Compsoting Costs

Composting

	Alt 1	Alt 2	Alt 3	
Dewatered Solids Concentration	21.00%	23.00%	30.00%	dry solids
Tipping and Hauling Cost (<= 4 trailers per day - 16 DTPD)	$37.22	$37.22	$37.22	per wet ton
Tipping and Hauling Cost (=>5 trailers per day - 16 DTPD)	$43.22	$43.22	$43.22	per wet ton
Tipping and Hauling Cost (<= 4 trailers per day - 16 DTPD)	177.00	162.00	124.00	per dry ton
Tipping and Hauling Cost (=>5 trailers per day - 16 DTPD)	206.00	188.00	144.00	per dry ton

Liquid Land Application Costs

Hauling and Disposal

	Alt 1	Alt 2	Alt 3	
Post-Digestion Solids Concentration	3.60%	2.69%	5.60%	total solids
Liquid Land Application Cost	$0.0385	$0.0385	$0.0385	per gallon (0-15 mi)
Liquid Land Application Cost	$0.0475	$0.0475	$0.0475	per gallon (16-30 mi)
	$0.0525	$0.0525	$0.0525	per gallon (31-60 mi)
	$0.0568	$0.0568	$0.0568	per gallon (61-90 mi)
Liquid Land Application Cost	$256.00	$343.00	$165.00	per dry ton (0-15 mi)
Liquid Land Application Cost	$316.00	$423.00	$203.00	per dry ton (16-30 mi)
	$350.00	$468.00	$225.00	per dry ton (31-60 mi)
	$378.00	$506.00	$243.00	per dry ton (61-90 mi)

Dewatered Material Land Application Costs

Disposal

	Alt 1	Alt 2	Alt 3	
Post-Digestion Solids Concentration	21.00%	23.00%	30.00%	total solids
Land Application of Dewatered Material Fee	$16.45	$16.45	$16.45	per cubic yard
	$89.27	$81.51	$62.49	per dry ton (at 65 lb/cu

Hauling Cost

	Alt 1	Alt 2	Alt 3	
Raleigh Plus Hauling Cost (<35-miles)	$9.00	$9.00	$9.00	per wet ton
Raleigh Plus Hauling Cost (36-55-miles)	$11.50	$11.50	$11.50	per wet ton
Raleigh Plus Hauling Cost (56-70-miles)	$14.50	$14.50	$14.50	per wet ton
Raleigh Plus Hauling Cost (71-91-miles)	$16.50	$16.50	$16.50	per wet ton
Raleigh Plus Hauling Cost (<35-miles)	$42.86	$39.13	$30.00	per dry ton
Raleigh Plus Hauling Cost (36-55-miles)	$54.76	$50.00	$38.33	per dry ton
Raleigh Plus Hauling Cost (56-70-miles)	$69.05	$63.04	$48.33	per dry ton
Raleigh Plus Hauling Cost (71-91-miles)	$78.57	$71.74	$55.00	per dry ton

Operating Cost Summary

	Alt 1	Alt 2	Alt 3
Operating Cost Summary	$144.03	$131.51	$100.82

Solids Operating Costs		
Thermal Drying		
	Alt. 2B	
Thermal Dryer Solids Handling Capacity		
Thermal Dryer Evaporative Capacity	2,485	kg(water)/hr
	5,477	lb(water)/hr
Feed Solids Concentration	35.00%	TS
Dried Sludge Pellet Solids Concentration	90%	TS
Thermal Dryer Dewatered Sludge Cake Feed Rate(annual)	11571	dry tons / yr
Thermal Dryer Dewatered Sludge Cake Feed Rate	3,137	lb(dry)/hr
Operating Hours per year	7,377	hr/yr
Evaporation Thermal Energy Unit Cost		
Dryer Thermal Efficiency	0.85	kWh/kg(water)
Dryer Thermal Efficiency	1316	BTU/lb(water)
Dryer Evaporation Heat Requirement	7.21	MMBTU/hr
Digester Gas Heat Available	11	MMBTU/hr
Supplemental (NG) Heat Required	0	MMBTU/hr
Supplemental (NG) Heat Required	0	MMBTU/ton(dry)
Natural Gas Cost	$8.00	$/MMBTU
Evaporation Thermal Energy Unit Cost	$0.00	$/ton(dry)
Dryer Operating Labor Unit Cost		
Unit Labor Cost (Fully Allocated, per working hour)	$34.09	per hour
Preventive Maintenance	320.00	hr/yr
Corrective Maintenance	360.00	hr/yr
Predictive Maintenance (outside contractor)	$18,000	$/yr
Admin and Laboratory	18	hr/wk
Full Time Equivalents Required for Thermal Dryer	1.75	FTE/shift
Operating Labor Unit Cost	$44.35	$/ton(dry)
Dryer Electrical Energy Unit Cost		
Power Usage	1,478,842	KWH/year
Power Usage	108	KWH/ton(dry)
Power Cost	$0.076	$/KWH
Electrical Energy Unit Cost	$8.18	$/ton(dry)
Drying Maintenance Unit Cost		
Estimated Dryer Equipment Capital Cost (equipment only)	$5,650,000	
Annual Equipment Mainentance Cost (%Equipment Costs)	2%	
Dryer Facility Area	20,000	square feet
Dryer Facility Unit Cost	$200.00	per sq. ft.
Estimated Dryer Facility Capital Costs (w/o equipment)	$4,000,000	
Annual Facility Maintenance Cost (%Facility Costs)	1.00%	
Estimated Annual Facility Maintenance Cost	$153,000	$/year
Annual Sludge Production	13,739	tons(dry)/yr
Maintenance Unit Cost	$11.14	$/ton(dry)
Total Termal Dryer Operating and Maintenance Unit Cost (Excluding Distribution & Marketing)		
Thermal Dryer Operating and Maintenance Unit Cost	**$63.67**	**$/ton(dry)**

Thermal Hydrolysis Process (THP) Solids Operating Costs		
	Alt. 3	
THP Solids Loading Rate	24,054	dry tons per year
Operating Labor Unit Cost		
FTE Equivalent Loading	0.53	FTE
Operating Labor Unit Cost (Fully Allocated, per working hour)	$34.09	per hour
Operating Labor Cost (Fully Allocated, per working hour)	$17.95	per hour
Annual Labor Cost (Fully Allocated)	37,329	$/yr
Operating Labor Unit Cost (Mass Basis)	$1.55	per ton (dry)
Operating Energy Unit Cost		
Total Power Demand	11.7	KWH per dry ton
Electrical Power Unit Cost	$0.076	per KWH
Electrical Power Unit Cost (Mass Basis)	$0.89	per dry ton
Steam Required	1,900.0	lb per ton (dry)
Steam Required	2.00	MMBTU/ton (dry)
Boiler Efficiency	80%	
Energy Required for Bolier	165	MMBTU/day
Energy Available from Biogas	570	MMBTU/day
Supplemental (NG) Energy Required	0	MMBTU/day
Natural Gas Cost	$8.00	$/MMBTU
Thermal Energy Cost	$0.00	$/ton(dry)
Chemical Cost Allowance		
Maintenance Unit Cost (Mass Basis)	$3.10	per dry ton
Operating Maintenance Cost Allowance		
Operating Maintenance Cost Allowance	$80,000.00	per year
Maintenance Unit Cost (Mass Basis)	$3.33	per dry ton
Operating Cost Summary		
Operating Labor Unit Cost (Mass Basis)	$1.55	per dry ton
Electrical Power Unit Cost (Mass Basis)	$0.89	per dry ton
Steam Power Cost (Mass Basis)	$0.00	per dry ton
Chemical Unit Cost (Mass Basis)	$3.10	per dry ton
Maintenance Unit Cost (Mass Basis)	$3.33	per dry ton
Total Operating Cost (Mass Basis)	$8.87	per dry ton

Appendix B

Projected Future Electricity Prices

Appendix B

Projected Future Electricity Costs

Progress Energy Avoided Energy Costs

Per 2011 H&S Report - Falls Lake Dam Hydropower Project Pre-Feasibility Study

	Real 2011 $/MWh			Real 2012 $/kWh		
	Base	**High**	**Low**	**Base**	**High**	**Low**
2012	68.76	69.12	68.40	0.071	0.071	0.071
2013	69.52	70.26	68.80	0.072	0.073	0.071
2014	70.04	71.15	68.94	0.072	0.073	0.071
2015	74.53	76.05	73.04	0.077	0.078	0.075
2016	75.22	77.15	73.35	0.078	0.080	0.076
2017	75.96	78.31	73.70	0.078	0.081	0.076
2018	76.75	79.53	74.08	0.079	0.082	0.076
2019	77.58	80.82	74.50	0.080	0.083	0.077
2020	78.47	82.18	74.96	0.081	0.085	0.077
2021	79.67	83.89	75.72	0.082	0.087	0.078
2022	80.63	85.37	76.23	0.083	0.088	0.079
2023	81.64	86.92	76.78	0.084	0.090	0.079
2024	82.69	88.54	77.36	0.085	0.091	0.080
2025	86.12	92.57	80.27	0.089	0.096	0.083
2026	87.04	93.95	80.80	0.090	0.097	0.083
2027	91.24	98.70	84.55	0.094	0.102	0.087
2028	93.93	101.91	86.80	0.097	0.105	0.090
2029	94.48	102.76	87.10	0.098	0.106	0.090
2030	97.46	106.10	89.80	0.101	0.109	0.093
2031	98.85	108.02	90.75	0.102	0.111	0.094
2032	100.22	109.99	91.63	0.103	0.114	0.095
2033	101.43	111.77	92.38	0.105	0.115	0.095
2034	103.18	114.24	93.55	0.106	0.118	0.097
2035	104.82	116.67	94.58	0.108	0.120	0.098

2011 dollars were escalated by 3.2% to convert to 2012 dollars, in accordance with the change in consumer price index in 2011.

Appendix C

Non-Cost Evaluation Criteria Rating Exercise

Non-Cost Evaluation Criteria Ranking Worksheet

Below is a list of non-monetary evaluation criteria that will be used to score alternatives proposed in the Biosolids Management Master Plan Update. Please complete this worksheet to help CDM Smith understand the relative importance of each criterion to the City.

STEP 1: READ THE FOLLOWING LIST OF CRITERIA AND THEIR DEFINITIONS

Regulatory Requirements: This criterion rates the ability to meet both the current and anticipated future federal, state, and local regulations.

Reliability: The ability of a given treatment process to consistently perform in accordance with the intended design with minimal down time. Systems that require extensive equipment or incorporate newer technologies may be considered less reliable than other systems using simpler, proven technologies with a long history of success.

Sustainability: The extent to which a treatment alternative contributes to achieving the City's stated sustainability goals related to energy efficiency and greenhouse gas emissions reduction. It also considers the extent to which an alternative uses all potential resource recovery opportunities.

Constructability: The ability to modify and/or expand the existing treatment facility to accommodate each alternative, and to make best use of existing facilities. It will consider the impacts on existing layout and the ability to integrate new equipment to the existing facility.

Operator Friendliness: Considers exposure to potential safety hazards, the amount and type of operator attention required, the degree of automation, and accessibility of equipment.

Ease of Maintenance: Considers the amount and complexity of routine maintenance requirements, required spare parts inventory, availability of parts, and special tools or skill requirements.

Flexibility/Adaptability: Flexibility/adaptability is defined as the ability of a treatment process to accommodate variations in flow, waste load, maintenance service needs (down time), and permit requirements.

Outlet Diversification: The diversity of available outlets for the final product(s) (e.g. Raleigh Plus or Class B biosolids). Multiple outlets allow the treatment system to adapt to changing market conditions.

Side Stream Impacts: Concentrated return flows from biosolids treatment may upset the liquid treatment and result in high levels of nitrogen and phosphorous in the effluent. This criterion measures the potential impact of the solids treatment system on liquid treatment.

Public Acceptance: Includes the positive or negative impact each alternative has on the surrounding community including residents and businesses near the WWTP and at biosolids land application locations. Public acceptance includes aesthetic and ergonomic factors such as traffic, noise, odor, and visual appeal.

Public Health and Environmental Impacts: The ability to meet the Biosolids EMS goal of protecting the environment and public health. Treatment alternatives which minimize impacts such as potential for groundwater contamination, odors, pathogen/vector attraction, and destruction of plant and wildlife habitat will score highly. Treatment alternatives that achieve Class A pathogen reduction will score more highly than those that achieve Class B.

STEP 2: USING THE TABLE BELOW, ASSIGN POINTS TO EACH CRITERION DEPENDING ON HOW IMPORTANT YOU FEEL IT IS.

- **You have 100 total points to distribute between all criteria**
- **Assigning 9 points to each criterion means they are all equally important**
- **Putting all 100 points in 1 criterion means it is the only one that is important**
- **Your responses will not be identified or reported by name. They will be averaged with scores from other co-workers**

Criterion	Score
Regulatory Requirements	______ /100
Reliability	______ /100
Sustainability	______ /100
Constructability	______ /100
Operator Friendliness	______ /100
Ease of Maintenance	______ /100
Flexibility/Adaptability	______ /100
Outlet Diversification	______ /100
Side Stream Impacts	______ /100
Public Acceptance	______ /100
Public Health and Environmental Impacts	______ /100
TOTAL	**/100**

STEP 3: CHECK THAT THE POINTS YOU ASSIGNED ADD UP TO 100.

STEP 4: SCAN THIS FORM AND EMAIL IT TO KINGSBURYRS@CDMSMITH.COM

THANK YOU FOR YOUR INPUT!

CDM Smith

Appendix D

Solar Dryer Installation List

1401 West Cypress Creek Road
Fort Lauderdale FL 33309-1969

Phone 954.974.6610
Fax 954.974.6182

North American Installations
THERMO-SYSTEM® Active Solar Sludge Dryer

Rogue River, OR

Plant size:	~ 0.3 MGD
Initial dry solids:	5 % d.s.
Final dry solids:	80 - 85 % d.s.
Biosolids disposal	Landfill
Drying chambers:	1 (33' x 92')
Drying area:	402 yd²
Covering:	PE air-bubble foil
Year of construction:	2002

Keowee Key, SC

Plant size:	~ 0.7 MGD
Initial dry solids:	6.5 % d.s.
Final dry solids:	75% d.s.
Biosolids disposal:	Public use (free give away)/Agriculture
Drying chambers:	2 (40' x 125')
Drying area:	1,110 yd²
Covering:	PE air-bubble foil
Year of construction:	2002

Discovery Bay, CA

Plant size:	~ 1.6 MGD
Initial dry solids:	15 % d.s.
Final dry solids:	75 % d.s.
Biosolids disposal	Agriculture/Reclamation of mining site
Drying chambers:	2 (42' x 204')
Drying area:	2,153 yd²
Covering:	Polycarbonate cellular sheets
Year of construction:	2004

www.parkson.com
technology@parkson.com

Rio Vista , CA

Plant size:	~ 2.5 MGD
Initial dry solids:	17 % d.s.
Final dry solids:	75 % d.s.
Biosolids disposal	Agriculture
Drying chambers:	4 (42' x 192')
Drying area:	3,584 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2005

Lincoln, CA

Plant size:	~ 2.5 MGD
Initial dry solids:	20 % d.s.
Final dry solids:	75 % d.s. (Class A)
Biosolids disposal	Agriculture
Drying chambers:	2 (42' x 204')
Drying area:	2,153 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2007

Salida, CA

Plant size:	~ 1.5 MGD
Initial dry solids:	15 % d.s.
Final dry solids:	75 % d.s.
Biosolids disposal	Agriculture
Drying chambers:	2 (42' x 204')
Drying area:	2,153 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2007

Carmel, IN

Plant size:	~ 8 MGD
Initial dry solids:	20 % d.s.
Final dry solids:	75% % d.s.
Biosolids disposal	City land/Agriculture/Public use
Drying chambers:	1 (42' x 204')
Drying area:	1.077 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2007

Utilizing ~ 1MM BTU/H of waste heat

Okeechobee, FL

Plant size:	~ 3 MGD
Initial dry solids:	20 % d.s.
Final dry solids:	75% % d.s.
Biosolids disposal:	City land/Agriculture/Public use
Drying chambers:	3 (42’ x 200’)
Drying area:	2,800 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2007

Noblesville, IN

Plant size:	~ 6 MGD
Initial dry solids:	20 % d.s.
Final dry solids:	75% % d.s.
Biosolids disposal:	City land/Agriculture/Public use
Drying chambers:	2 (42’ x 108’)
Drying area:	1,010 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2010

Wiamea, HI (Water Plant Residuals Drying)

Plant size:	xxxx
Initial dry solids:	2.5% d.s.
Final dry solids:	25% d.s.
Biosolids disposal:	Landfill
Drying chambers:	2 (42’ x 108’)
Drying area:	1,010 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2010

Site construction photo
Startup/Commissioning Dec. 2010

Clinton, MS

Plant size: ~1.1 MGD
Initial dry solids: 18% d.s.
Final dry solids: 75% d.s.

Biosolids disposal: City land/Agriculture/Public use

Drying chambers: 2 (42' x 204')
Drying area: 1,010 yd^2
Covering: Polycarbonate cellular sheets
Year of construction: 2010

Under construction
Startup/Commissioning Dec. 2010

Natchez, MS

Plant size: ~1.1 MGD
Initial dry solids: 18% d.s.
Final dry solids: 75% d.s.

Biosolids disposal: City land/Agriculture/Public use

Drying chambers: 2 (42' x 204')
Drying area: 1,010 yd^2
Covering: Polycarbonate cellular sheets
Year of construction: 2010

Site construction photo
Startup/Commissioning Jan. 2011

Kent County, MD

Plant size: ~1.5 MGD
Initial dry solids: 18 % d.s.
Final dry solids: 85% % d.s.

Biosolids disposal City land/Agriculture/Public use

Drying chambers: 3 (42' x 204')
Drying area: 2,856 yd^2
Covering: Glass
Year of construction: 2011
Utilizing ~ 680,000 BTU/hr of waste heat

Site construction photo
Startup/Commissioning Feb. 2011

Berlin, MD

Plant size:	~0.7 MGD
Initial dry solids:	15% d.s.
Final dry solids:	75% d.s.
Biosolids disposal:	City land/Agriculture/Public use
Drying chambers:	2 (42’ x 204’)
Drying area:	1,010 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2011

Site construction photo
Startup/Commissioning Mar. 2011

Fayetteville, AR

Plant size:	~2.8 MGD
Initial dry solids:	17% d.s.
Final dry solids:	75% d.s.
Biosolids disposal:	City land/Agriculture/Public use
Drying chambers:	6 (42’ x 204’)
Drying area:	5,712 yd^2
Covering:	Polycarbonate cellular sheets
Year of construction:	2011

Appendix E

Greenhouse Gas Emissions Assumptions

Appendix E

Greenhouse Gas Emissions Assumptions

Emission Source	Unit	GHG Equivalents / Unit	Reference
Emissions			
Electricity	kWh	.000608	*Updated State-level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000*. Energy Information Administration, 2002.
Diesel Fuel	Gal	.0119	"Method for Conducting a Greenhouse Gas Emissions Inventory for Colleges and Universities" Tufts University, 2006.
Lime Production (for Alkaline Stabilization)	Ton	.0975	Carmeuse Lime and Stone Corporation (assuming natural gas fired kiln)
Woodchip Production (for composting)	Ton	.00041	Peterson-Pacific grinder model 7400B
Fugitive N_2O	Ton	296	Intergovernmental Panel on Climate Change, 2001. *Third Assessment Report*.
Fugitive CH_4	MCF	0.412	Intergovernmental Panel on Climate Change, 2001. *Third Assessment Report*.
Fugitive N_2O (from soil)	Ton N	0.139	Eichner, M.J., 1990. "Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data" *Journal of Environmental Quality* 19, p. 272-280.
Offsets			
Energy Production from Biogas	MMBTU	-0.0603	"Method for Conducting a Greenhouse Gas Emissions Inventory for Colleges and Universities" Tufts University, 2006.
Carbon Sequestration	Ton VS	-0.183	Jaynes,W.F. et al, 2003. "Biosolids Decomposition after Surface Applications in West Texas" *Journal of Environmental Quality* 32(5).
Nitrogen	Ton N	-2.95	Samuel Roberts Noble Foundation
Phosphorous	Ton P	-4.75	Worrell, E., Phylipsen, D., Einstein, D., Martin, N, 2000. "Energy Use and Energy Intensity of the U.S. Chemical Industry" Ernest Orlando Lawrence Berkeley National Laboratory. University of California, Berkeley.

CDM Smith

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