WHY THERMAL HYDROLYSIS WITH ANAEROBIC DIGESTION IS RISING TO THE TOP IN NORTH AMERICA

Williams, T. [1], Whitlock, D.[1], Green, D.[1], DCunha, L.[1], Berg, M.[1], Burrowes, P.[1]

[1] CH2M HILL

Corresponding Author: Todd Williams tel: 1-804-789-0979 email: todd.williams@ch2m.com

Abstract

Managing biosolids has become increasingly challenging and costly to wastewater utilities in North America. With the introduction of the thermal hydrolysis process (THP) as a pre-treatment to mesophilic anaerobic digestion (MAD), a new and sometimes cost effective technology alternative has been added to the toolset for biosolids management planning. In recent years, CH2M HILL has conducted biosolids facility plans for clients dispersed throughout North America. These planning efforts included evaluating a wide range of different wastewater residual processing options. Three case studies are presented to illustrate how THP followed by MAD is rising to the top of technology options selected for long-term biosolids management in North America.

Keywords

Thermal Hydrolysis, Anaerobic Digestion, Biosolids Facility Planning, Renewable Energy, Greenhouse Gases, Benefit-Cost, Alternatives Analysis

Introduction

With ever increasing attention to cost, biosolids quality, and resource recovery in biosolids management, the market has responded with the introduction of the thermal hydrolysis process (THP) as a pre-treatment to mesophilic anaerobic digestion (MAD), a new and sometimes cost effective technology alternative. While Kruger-Veolia and other vendors are developing thermal hydrolysis technologies, the establishment of the thermal hydrolysis process is primarily due to the innovativeness and diligence of Cambi, Inc. Indeed, while the thermal hydrolysis process is somewhat new, there are more than 40 installations globally, with most of those installations being Cambi. Now that the thermal hydrolysis process has its first installation in North America at DC WATER with several other projects in the planning and design phase, wastewater utilities are commonly choosing to compare THP with MAD as an alternative to include in biosolids planning analyses.

CH2M HILL has conducted biosolids facility plans for clients dispersed throughout North America, which include evaluating a wide range of wastewater residual processing options. **Table 1** summarizes some of these facility plans and the ultimate solids processing recommendation resulting from the alternatives evaluation. As illustrated in **Table 1**, THP with MAD is an option that is rising to the top of many planning efforts.

Table 1: Summary of Recent Biosolids Facility Plans Conducted by CH2M HILL

Plant	Location	Year	Recommended Alternative
Southeast Water Pollution Control Plant	San Francisco, CA	2014	Thermal hydrolysis and mesophilic anaerobic digestion
Regional Water Quality Control Plant	Palo Alto, CA	2014	Thermal hydrolysis and mesophilic anaerobic digestion
Village Creek Water Reclamation Facility	Fort Worth, TX	2013	Implement mesophilic anaerobic digestion plus thermal drying now with consideration to either 1) add WAS-only Thermal hydrolysis, 2) increase mesophilic anaerobic digestion capacity, or 3) temperature phased anaerobic digestion conversion, once the digesters reach their capacity in about 10 years.
North Texas Municipal Water District, Wilson Creek	Wylie, TX	2013	Thermal hydrolysis and mesophilic anaerobic digestion
North Texas Municipal Water District, South Mesquite	Wylie, TX	2013	Thermal hydrolysis and mesophilic anaerobic digestion
F. Wayne Hill Water Reclamation Center	Gwinnett County, GA	2011	Expansion of the Conventional High Rate Mesophilic Anaerobic Digestion
NEW Water	Green Bay, WI	2011	Conventional High Rate Mesophilic Anaerobic Digestion + Partial Thermal Drying* + Fluidized Bed Incineration
City of Calgary (Bonneybrook, Fish Creek and Pine Creek Wastewater Treatment Plants)	Calgary, AB	2011	Conventional High Rate Mesophilic Anaerobic Digestion and partial co-composting with municipal organic waste and land application**

*Partial drying step was added during basis of design development after facility planning

**Thermal hydrolysis of waste activated solids is being implemented at Bonneybrook as part of the plant expansion

The manuscript will summarize results of several of these planning efforts including:

- methodology used in the biosolids facility plans

- a summary of results of selected recent projects
- a discussion of the attributes of thermal hydrolysis and anaerobic digestion and why it is performing so well in the alternatives analyses

Evaluation Methodology

To evaluate technology alternatives, a stepwise approach was used. The purpose of this methodology was to use a process that involves a collaborative, transparent, and consensus-building approach; provides clear, defensible, well-documented results; and considers the economic, social, environmental and technical aspects of the project.

As shown in **Figure 1**, the analysis is initiated by establishing the goals for the project, then developing the technology alternatives and evaluation criteria. At this initial step it is also important to identify the major stakeholders, charter a decision team, and develop a simple or comprehensive decision model, as needed, to enable the team to make decisions throughout the planning phase. Formulating alternatives includes brainstorming sessions attended by key stakeholders and technical experts. Screening criteria are defined to identify and eliminate alternatives with fatal flaws from further evaluation. If, at the end of the alternatives evaluation, there is a need for further evaluation to confirm that the right decision is being made, sensitivity analysis may be conducted to illustrate the change in economic and benefit-cost outputs as a function of changing a variable; for example, the cost of power. Based on the evaluation results, a preferred alternative is selected, followed by development of an implementation plan.

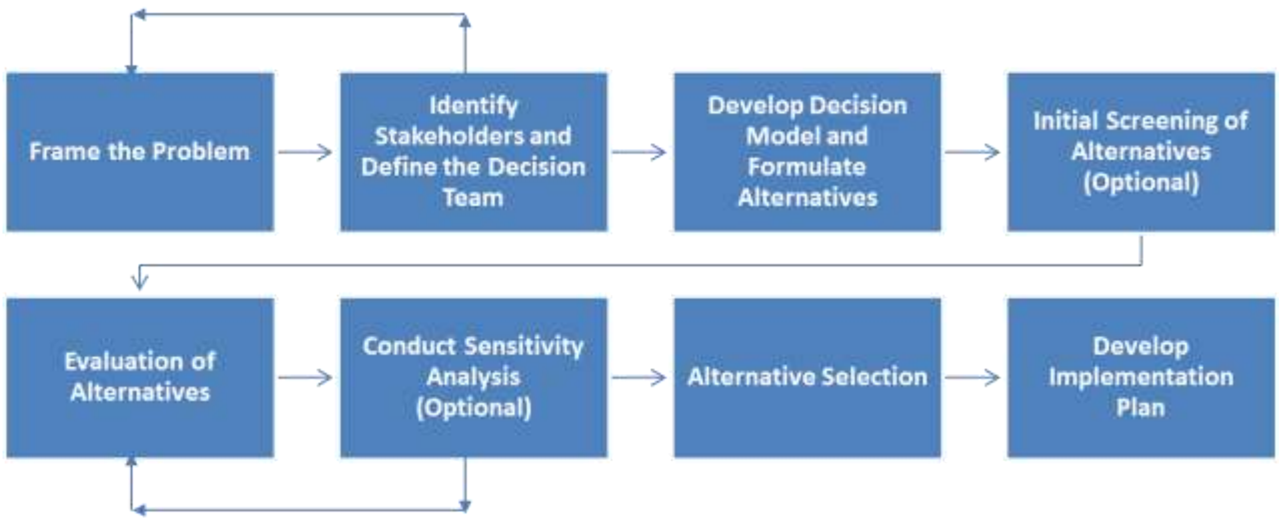

Figure 1: Stepwise Technology Alternatives Evaluation Approach

Evaluation of Alternatives

Financial Analysis. A financial analysis was conducted using the life cycle cost analysis approach. For each alternative, a preliminary estimate was developed for capital cost and operations and maintenance (O&M) cost. The accuracy of cost estimates was order-ofmagnitude, based on the definitions of the American Association of Cost Engineers. The NPV was calculated for the specified planning period, using a stated discount rate and an inflation rate.

Non-financial Analysis. The multi-criteria analysis (MCA) approach was used to conduct a structured evaluation of the non-financial risks and benefits of the alternatives. The approach included the following three key steps:

Determine Evaluation Criteria and Performance Measures: Evaluation criteria were developed based on project objectives. To make the process effective, the number of criteria were limited, typically to 12 to 15. (If the number of criteria identified were greater than 15, then like criteria were combined as subsets into more global criteria.) Performance measures for the evaluation criteria and criteria range scale, typically 0 to 100 or simply 0 to 10, were developed. Preferred options scored higher on the scale. In certain cases, environmental criteria were not assigned scores; instead, relative ratios from environmental analysis results (if available) were used.

Establish Criteria Weights: These are intended to reflect the relative importance of each criterion. "Forced ranking" was used where each criterion was compared with another to rank the importance of the criterion relative to one another.

Calculate Benefit Scores: The alternative total (or cumulative) benefit score was calculated as the sum of criteria scores multiplied by criteria weights.

Environmental Analysis: In addition to financial and non-financial analyses, an environmental analysis for comparing technology alternatives was performed, as applicable. This included one or more of the following:

- Net energy: Included an estimate of the net energy resulting from net power consumption/ generation, and net fuel consumption/offset (including plant processes and hauling).
- Net anthropogenic greenhouse gases (GHGs**):** included an estimate of the net anthropogenic GHG emissions/offset based on emissions and offsets (or credits) from power consumption/generation, and fuel consumption/offset (including plant processes and hauling).
- Truck traffic: Included an estimate of hauling miles per year and number of truck trips per year.

Benefit-cost Analysis. The MCA methodology incorporates a benefit-cost analysis, which includes financial costs and benefits, as well as non-financial impacts and benefits. For each alternative, a benefit-cost ratio of the total benefit score to its NPV was calculated.

The following section presents the technology alternatives evaluation from three biosolids facilities planning projects. The stepwise approach described above was used on all three projects; however, for the purposes of this manuscript, only the Evaluation of Alternatives and Alternative Selection steps are presented.

The following sections include a summary of the results of three of these facility plans, which resulted in the recommendation of thermal hydrolysis and mesophilic anaerobic digestion:

- North Texas Municipal Water District:
  - Wilson Creek Regional WWTP
  - South Mesquite WWTP
- Palo Alto, CA, Regional Water Quality Control Plant
- San Francisco Public Utility Commission, Southeast Plant

North Texas Municipal Water District

Introduction

North Texas Municipal Water District (NTMWD or District) operates 4 wastewater treatment plants (WWTPs) in its Regional Wastewater System, and an additional 11 treatment plants are included in the District Sewer System. NTMWD currently produces approximately 78 dry tons per day (DT/d) of wastewater residuals, with a projected amount of 140 DT/d in 2040. Currently, most District facilities dewater the solids, add lime at some plants, and ultimately dispose the residuals in a landfill. NTMWD currently sends 41 truckloads per day of wastewater residuals to the landfill, with an average annual tipping fee of $1.8 million per year. With continued landfill disposal, 2040 projections estimate NTMWD would send 51 truckloads per day and spend $11.3 million per year.

Biosolids handling alternatives evaluations were performed that progressively refined and narrowed the optimal biosolids handling approach for NTMWD. The analyses considered options that incorporated all of the District's facilities, including regionalization and consolidation of biosolids operations. The recommendations focused on NTMWD's two largest facilities; improvements at these two facilities are expected to yield the greatest benefit-cost of the options considered.

Plant Process Type and Capacity. The treatment processes employed at both the Wilson Creek regional wastewater treatment plant (RWWTP) and the South Mesquite RWWTP are essentially the same. The South Mesquite RWWTP has a capacity of approximately 33 million gallons per day (mgd), and Wilson Creek RWWTP has a current capacity of approximately 48 mgd. Raw wastewater entering each facility is screened, followed by primary clarification, activated sludge aeration, secondary clarification, filtration, disinfection, and dechlorination.

Summary of Current Solids Handling System. Primary solids are thickened in the primary clarifiers. Waste activated sludge (WAS) is thickened using gravity belt thickeners, after which the thickened primary sludge (PS) and WAS are combined and dewatered using belt filter presses. Lime is added for odor control and as a desiccant; solids are disposed of at local landfills.

System Planning Parameters. The master plan estimated the current and future quantity of residuals that would be produced at the Wilson Creek and South Mesquite RWWTPs, accounting for the recommended transfer of solids from other, smaller nearby facilities. The solids projections are presented in **Table 2**.

Table 2: Projected Maximum Month Wastewater Residuals at Wilson Creek and South Mesquite RWWTPs[a]

WWTP	Maximum Month Projections (DT/d)			
	Current	2020	2030	2040
South Mesquite	23	32	40	46
Wilson Creek	62	73	86	97

[a] Includes recommended solids transferred from nearby smaller facilities.

Project Drivers. Because of the current and future costs of wastewater residuals management, the changing fuels market, and advancements in wastewater residuals treatment processes, NTMWD initiated a Biosolids Master Plan to evaluate the various methods available for handling, treating, disposing, and beneficially reusing biosolids generated at NTMWD WWTPs, with particular focus on deriving energy from wastewater residuals via anaerobic digestion (AD) in order to offset operating costs and mitigate the risk of price variability of conventional power and transportation fuel.

Results and Discussion of Evaluation

The initial alternatives evaluation considered the following technology alternatives:

1. Unclassified Solids:
   a. Landfill Disposal – The current disposal method in use by the District
   b. Landfill Biogas-fueled SlurryCarb™ Thermal Hydrolysis Process (THP) to Landfill Disposal
2. Class B Biosolids:
   a. AD with Biogas-fueled Combined Heat and Power (CHP)
3. Class A Biosolids:
   a. Landfill Biogas-fueled SlurryCarb™ THP to Class A
   b. Composting
   c. Landfill Biogas-fueled Thermal Drying
   d. Lime Stabilization
   e. Thermal Hydrolysis followed by AD and Biogas-fueled CHP
   f. Temperature-phased Anaerobic Digestion (TPAD) with Biogas-fueled CHP

Financial Analysis: **Table 3 and Table 4** summarize the financial evaluations for the Wilson Creek and South Mesquite RWWTPs, respectively. Note that for both facilities, the three AD alternatives are within 20 percent net present value (NPV) of the lowest cost solution.

Table 3: Wilson Creek RWWTP Financial Summary

Alternative	Construction Cost, $ million	Annual 2030 O&M Cost, $ million	Total NPV, $ million	NPV Cost Rank	NPV Cost Ratio Relative to Least-cost Option
TPAD	67.2	1.2	70.1	1	1.0
Thermal Hydrolysis	85.7	0.7	77.4	2	1.1
AD	65.7	2.2	79.5	3	1.1
Landfill	17.0	4.9	96.6	4	1.4
Compost	71.6	3.4	103.4	5	1.5
Thermal Dry	111.1	1.1	104.5	6	1.5
Lime Stab	26.4	6.3	107.9	7	1.5
SlurryCarb™ to Class A	101.1	5.1	147.3	8	2.1
SlurryCarb™ to landfill	101.1	5.5	141.6	9	2.0

Table 4. South Mesquite RWWTP Financial Summary

Alternative	Construction Cost, $ million	Annual 2030 O&M Cost, $ million	Total NPV, $ million	NPV Cost Rank	NPV Cost Ratio Relative to Least-cost Option
TPAD	24.5	0.8	36.0	1	1.0
AD with CHP	22.3	1.2	39.0	2	1.1
Thermal Hydrolysis	38.3	0.5	41.5	3	1.2
Compost	31.4	1.3	49.4	4	1.4
Landfill	10.8	3.2	63.2	5	1.8
Lime Stabilization	15.5	3.8	76.3	6	2.1

Non-financial Analysis. **Figure 2** summarizes the non-financial comparison of the alternatives for the Wilson Creek RWWTP. Similar results were achieved for South Mesquite RWWTP, except that SlurryCarb™ and thermal drying were not considered because of a lack of available landfill gas.

As illustrated in **Figure 2**, thermal drying results in the greatest non-financial benefit to the District for both plants. The relative contribution of each criterion can be seen in the various colored blocks making up each cumulative score. For example, reduced odor potential and truck traffic are the largest contributors to thermal drying's high score. Following thermal drying, thermal hydrolysis and composting received very similar ratings, and landfill disposal received the lowest benefit score.

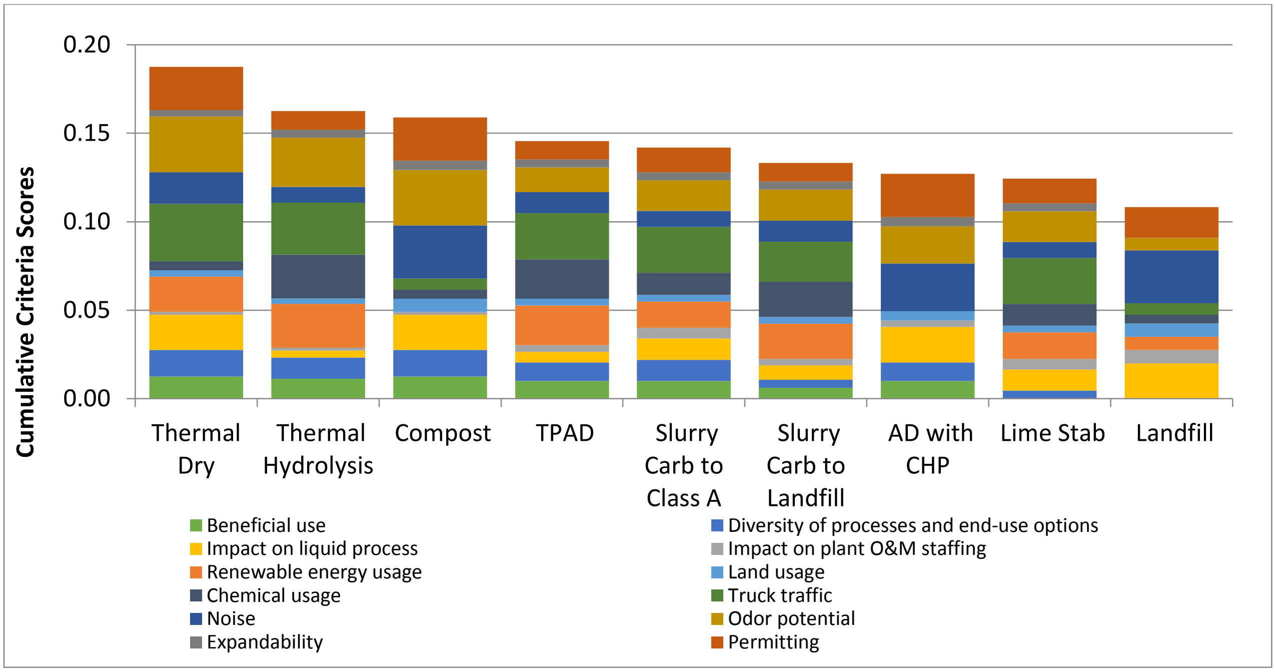

Figure 2: Wilson Creek RWWTP Benefit Score Results.

Benefit-cost Analysis. Combining the benefit scores with the estimated NPV results, **Figure 3** provides the resulting benefit-cost scores for Wilson Creek RWWTP, and a similar analysis was conducted for South Mesquite RWWTP. Thermal hydrolysis and TPAD received the highest and very similar scores, followed by thermal drying and AD with CHP, respectively. From South Mesquite benefit-cost analysis, TPAD and thermal hydrolysis received the highest and very similar scores, followed by AD with CHP and composting, respectively.

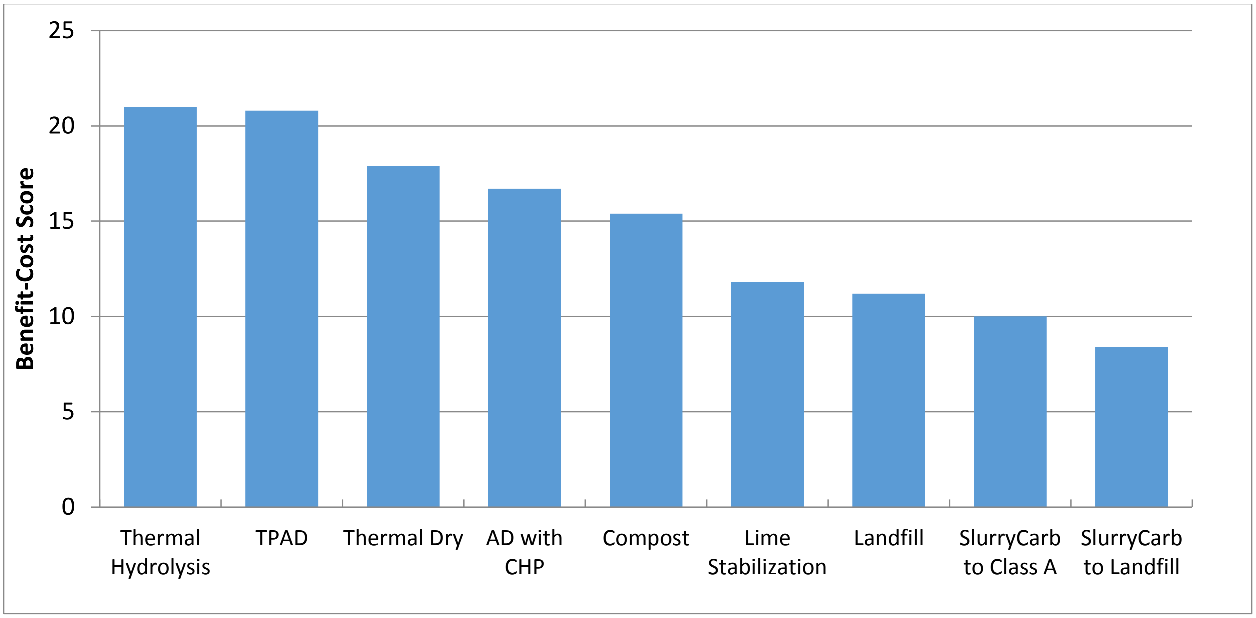

Figure 3: Benefit-cost Scores, Wilson Creek RWWTP.

Reasoning for Recommendation

For both the Wilson Creek and South Mesquite RWWTPs, it was recommended that the AD alternatives Mesophilic AD, Thermal Hydrolysis, and TPAD be considered for further analysis. Each of these alternatives includes converting the energy-rich biogas from the process to CHP for use at the facilities.

A refined comparison of the three AD alternatives focused on the differences between the options, and did not consider components that were common to all three alternatives. The results of the comparison eliminated TPAD from further consideration. Although the TPAD product meets Class A biosolids requirements, it was eliminated for two main reasons: biosolids product marketability, and system operability. The product marketability of the TPAD product is limited because of its physical characteristics and odors. The operation of TPAD is more complex than conventional AD and more prone to process upsets than thermal hydrolysis. Given the physical characteristics of the TPAD biosolids product, the additional complexities associated with operating a TPAD system are not warranted.

Conventional AD and Thermal Hydrolysis with Mesophilic AD were within a 4 percent difference for the NPV over the planning period. There are significant differences in the potential energy production and operational complexities of these two options. It was recommended that the District further consider these two options during a subsequent preliminary engineering evaluation, and that the District examine facilities that have implemented these systems to gain a better understanding of these systems' operation. The following were the primary drivers that led to Thermal Hydrolysis with Mesophilic AD as the recommended alternative:

- Cost
- Low product odor potential

- Reduction in truck traffic
- Renewable energy usage

A process flow diagram of the recommended alternative is shown in .

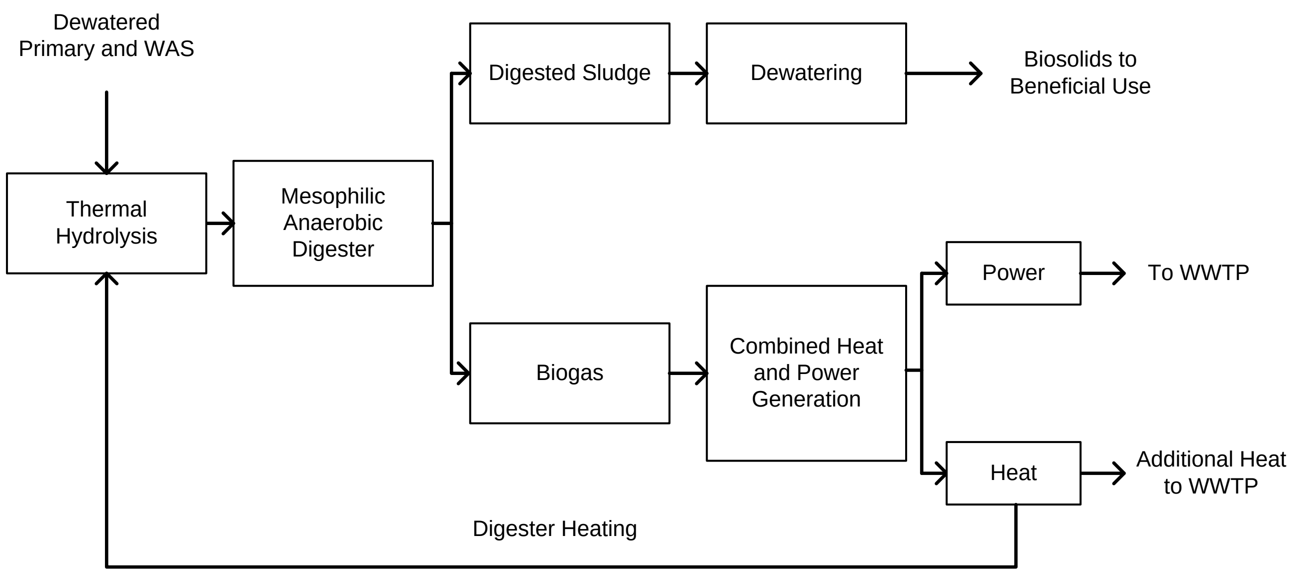

Figure 4: Thermal Hydrolysis Alternative at Wilson Creek RWWTP.

Regional Water Quality Control Plant, City of Palo Alto

Introduction

The City of Palo developed a Long Range Facilities Plan (LRFP) for the Regional Water Quality Control Plant (RWQCP) (Carollo, 2012) that provided for the near-, mid-, and long-term capital improvement of the RWQCP over a 50-year planning horizon (2012 to 2062). One of the key needs identified was for the existing incineration process to be retired because of its deteriorating condition, limited remaining useful life, regulatory pressures, and available alternatives for future solids processing. Palo Alto's City Council required decommissioning of the multiple-hearth furnaces (MHFs) by the year 2019. The City prepared the Biosolids Facility Plan (BFP) to select a cost-effective biosolids management strategy to protect public health and the environment and to position the City to respond to rapidly-evolving biosolids regulatory, technological, and end-use opportunities. The focus of the BFP was to develop and evaluate sustainable biosolids-only processing and reuse alternatives. In parallel, the City evaluated the integration of recovered organics (i.e., food scraps and yard trimmings) with biosolids processing, as documented in the Palo Alto Organics Facilities Plan (April 2014).

Plant Process Type and Capacity. The existing treatment processes at the RWQCP consist of headworks, primary clarification, two-stage fixed film/suspended growth secondary treatment, tertiary filtration, disinfection, and recycled water treatment, as well as dewatering and solids incineration, with an average dry weather flow capacity of 39 million gallons per day (mgd) and peak hour wet weather capacity of 80 mgd.

Summary of Current Solids Handling System. The RWQCP solids treatment and handling facilities consist of screenings and grit handling, sludge and scum handling, dewatering, incineration, and ash handling. Primary sludge (PS) and waste activated sludge (WAS) are co-thickened in gravity thickeners. Thickened sludge is pumped to the blend tank and then dewatered by belt filter presses. The belt filter presses, along with polymer and sodium hypochlorite addition, provide dewatering and odor control of the thickened sludge before incineration in the MHFs. Typical sludge cake off of the belt filter press is 28 percent dry solids. Collected scum (from the primary sedimentation tanks and grease deliveries) is pumped into the scum concentrator and then blended with dewatered sludge as it is conveyed to the MHFs. The RWQCP air permit limits the total capacity of the MHFs to 32 dry tons per day (DT/d) [monthly maximum] and 55 DT/d [daily maximum]. Currently, the MHFs process approximately 20 DT/d.

System Planning Parameters. Based on a planning period of 30 years, the 2045 maximum month projections for PS, WAS, and fats/oils/grease (FOG) were used for alternative facility sizing and associated capital costs estimation. The 2015 annual average solids projections were used to evaluate annual operations and maintenance costs. The projected quantities are summarized in **Table 5.** Also, approximately 275 standard cubic feet per minute (scfm) (or 396,000 cubic feet per day [cf/d], based on 2005-2011 sampling results) of landfill gas from the adjacent landfill was projected as an available energy source for use in the biosolids processing solutions. Food scraps and yard trimmings were not included in the original analysis; however, the onsite alternatives could be designed to co-process food scraps with the PS and WAS.

Table 5: Palo Alto RWQCP Solids Projections

Parameter	**2015 Average Annual (dry pounds per day)**	**2045 Maximum Month (dry pounds per day)**
PS and WAS Dry Mass	44,460	64,516[a]
FOG/Scum Dry Mass	2,200	2,200

[a] Assumed maximum month/annual average peaking factor = 1.16

Project Drivers. Key drivers for the BFP need and schedule were:

- Retire the RWQCP MHFs by 2019. This need is driven by seismic and reliability issues because of the age of the incinerators and the two-fold community mandate to reduce greenhouse gas (GHG) emissions within the City and to beneficially use City-generated organics.
- Complete the RWQCP long-range planning process to result in a comprehensive, sustainable, and cost-effective strategy for long-term management of biosolids at the RWQCP.
- Evaluate RWQCP biosolids-only solutions on a parallel time-frame and integrated with the City's evaluation of management options for all City-generated organics.

Results and Discussion of Evaluation

Eight viable alternatives, categorized into "Dewater and Haul Solutions" and "Onsite Processing Solutions," were evaluated:

1. Dewater and Haul (Raw Sludge) Solutions:
   a. Synagro Central Valley Compost Facility
   b. East Bay Municipal Utility District (EBMUD) Anaerobic Digestion
   c. Kirby Canyon Landfill
2. Onsite Processing Solutions (with truck haul to final land application, or landfill alternative daily cover (ADC))
   a. Mesophilic Anaerobic Digestion (MAD) with Biogas-fueled Combined Heat and Power (CHP)
   b. Temperature-phased Anaerobic Digestion (TPAD) with Biogas-fueled CHP
   c. Thermal Hydrolysis, MAD with Biogas-fueled CHP
   d. Dewatering and Landfill Gas-fueled Thermal Drying
   e. Dewatering and Thermal Drying/ Gasification

Financial Analysis. **Table 6** presents the estimated capital, O&M, and total NPV for the alternatives. For comparison, the alternatives are ranked based on NPV. Economically, two of the three dewater and haul solutions emerged as most feasible when compared to the onsite processing solutions, with hauling to the Synagro Central Valley Compost Facility achieving the lowest (best) NPV, followed by hauling to EBMUD. It was recognized that beneficial use of biosolids was a key project goal. Raw sludge must be stabilized to some degree to be used as landfill ADC; therefore, Alternative 1c, which assumes the landfilling of unclassified sludge (not ADC), was determined to be the least desirable among the dewater and haul alternatives, and was only considered as an emergency backup solution. Among the onsite processing solutions, MAD achieved the lowest NPV (although MAD would only produce a Class B product), followed by THP and TPAD, respectively, indicating anaerobic digestion (AD) as the most economically viable biosolids processing solution. Both thermal drying and gasification alternatives were the lowest-ranking solutions.

Table 6: RWQCP Alternatives Evaluation Financial Summary

Alternative		Biosolids Classification	End Use	Capital ($MM)	2015 Annual O&M ($MM/y)	2015 NPV ($MM)	NPV Rank
1a	Dewater and Haul to Synagro Central Valley Compost Facility	Class A	Compost	14	1.6	53	1
1b	Dewater and Haul to EBMUD Anaerobic Digestion	Class B	Land application	14	2.0	62	2

Table 6: RWQCP Alternatives Evaluation Financial Summary

Alternative		Biosolids Classification	End Use	Capital ($MM)	2015 Annual O&M ($MM/y)	2015 NPV ($MM)	NPV Rank
1c	Dewater and Haul to Kirby Canyon Landfill	Unclassified	Landfill	14	2.3	69	4
2a	MAD with Biogas-fueled CHP	Class B	Land application	53	0.5	64	3
2b	TPAD with Biogas-fueled CHP	Class A	Land application	70	0.5	83	6
2c	THP and MAD with Biogas-fueled CHP	Class A	Land application	69	0.4	79	5
2d	Dewatering and Landfill Gas-fueled Thermal Drying	Class A	Land application	57	1.6	95	7
2e	Dewatering and Thermal Drying/Gasification	Ash	Landfill	53	2.2	106	8

$MM = million dollars.
$MM/y = million dollars per year.

Environmental Analysis. **Table 7** summarizes the estimated net energy and anthropogenic GHG emissions. Relative to the existing system, Alternatives 1b, 2a, 2b, and 2c were the solutions that resulted in net energy production. The AD solutions (Alternatives 2a, 2b, and 2c) result in significant net energy production because these include a CHP system to beneficially use energy from biogas. Alternative 1b also showed net energy production based on the energy recovered by the CHP system at EBMUD from the solids that will be imported from the RWQCP. Alternative 2d was the most energy-intensive solution because of the natural gas required for thermal drying.

Comparing anthropogenic GHG emissions, relative to the existing system, Alternatives 2a, 2b, and 2c were the solutions that resulted in a significant net reduction or offset in GHG emissions, proportional to the net energy produced by each as described previously. All three AD technology alternatives provide annual GHG offsets greater than the annual GHG emissions from the existing system. With respect to adding GHG emissions to the environment, Alternative 1c was the least desirable because of the partial release of methane to the atmosphere.

Table 7: RWQCP Environmental Analysis Summary

	Alternative	Net Energy (MWh/year)	Anthropogenic GHG Emissions (MT CO_2e/year)	Hauling Miles (truck miles/year)	Truck Trips (vehicles/year)
	RWQCP Existing Solids Handling System	-15,007	3,057		
1a	Dewater and Haul to Synagro Central Valley Compost Facility	-2576	714	311,300	1,354
1b	Dewater and Haul to EBMUD Anaerobic Digestion	5482	-1660	101,500	1,354
1c	Dewater and Haul to Kirby Canyon Landfill	-1255	3104	92,000	1,354
2a	MAD with Biogas-fueled CHP	13481	-3642	135,900	755
2b	TPAD with Biogas-fueled CHP	12515	-3335	129,500	719
2c	THP and MAD with Biogas-fueled CHP	14219	-3846	91,280	507
2d	Dewatering and Landfill Gas-fueled Thermal Drying	-4706	1061	55,590	397
2e	Dewatering and Thermal Drying/Gasification	-341	101	4,170	61

Note: Negative net energy represents net energy consumed, and positive net energy represents net energy produced. Negative GHG emissions represent a reduction in emissions, and positive GHG emissions represent an increase in emissions.

MT CO_{2e}/year = metric tons equivalent carbon dioxide per year.

MWh/year = megawatt-hours per year.

Non-financial Analysis. **Figure 5** presents the non-financial evaluation results. Alternative 2c (THP + MAD) resulted in the greatest non-financial benefit. Following the THP alternative, the TPAD, thermal drying, and MAD benefit scores were closely matched. Alternative 1c, the landfill disposal option, resulted in the lowest benefit score among all the alternatives. In multi-criteria analysis, criteria scores are typically positive. However, in this evaluation, both positive and negative criteria scores can be observed. This was because the scores for GHG emissions, renewable energy production, and vehicle traffic were not assigned but calculated as relative ratios from the environmental analysis results, summarized in **Table 7** previously. Since values for net energy and GHG emissions were both positive and negative, the calculated scores although positive and negative, were retained for accuracy. Therefore, in this case, negative criteria scores reflect negative benefits.

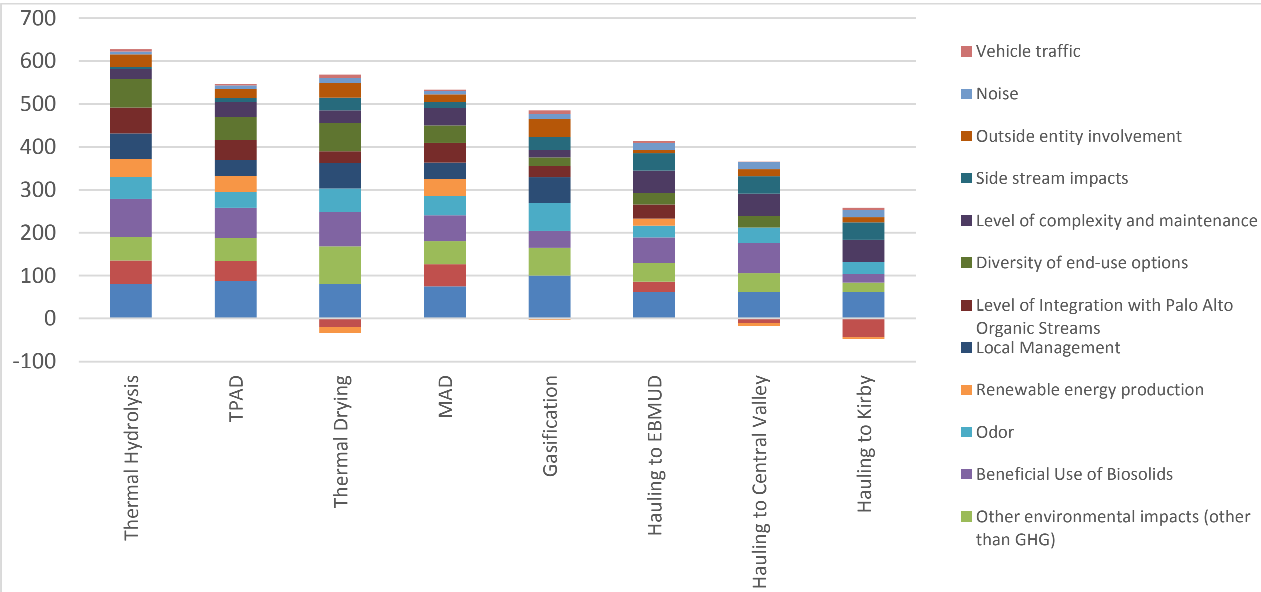

Figure 5: RWQCP Cumulative Benefit Scores.

Benefit-Cost Analysis. Each alternative's benefit-cost ratio was calculated by dividing total benefit score by the total NPV. The results of this analysis are presented in **Figure 6.** MAD received the highest benefit-cost ratio, followed closely by the thermal hydrolysis (THP+MAD) alternative.

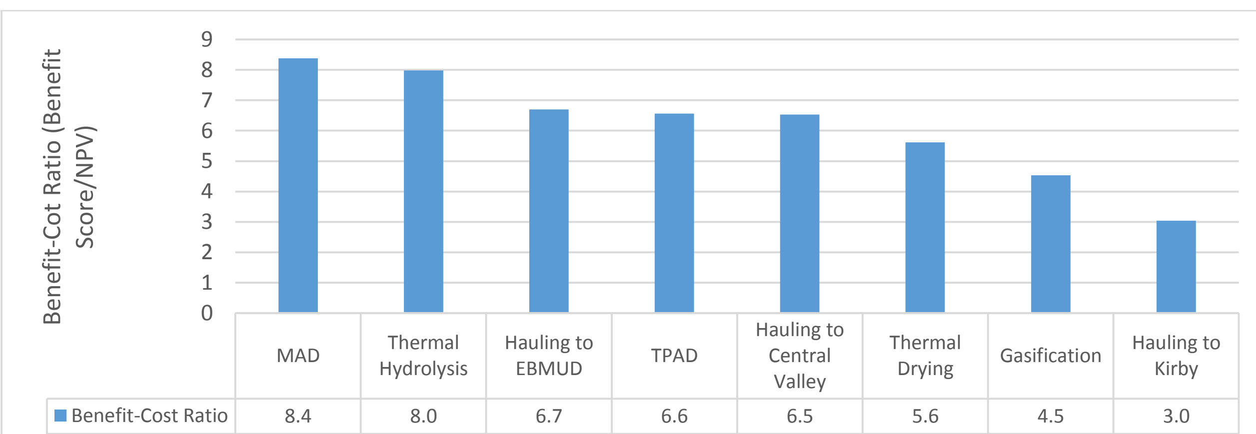

Figure 6: RWQCP Benefit-Cost Ratio Comparison.

Reasoning for Recommendation

Hauling to Synagro Central Valley Compost Facility and to the EBMUD AD system alternatives involve the hauling of unclassified sludge, leaving the sludge processing and final biosolids product disposition to outside parties, outside the control of the RWQCP. These dewater haul solutions were evaluated as viable near-term solutions for the RWQCP, but they are likely not viable solutions for the entire 30-year planning period. Although the dewater and haul alternatives have relatively low NPV values, the net energy, GHG offsets, and non-financial scores were not as favorable as the AD alternatives. Hence, the dewater and haul solutions (Synagro Central Valley Compost Facility and EBMUD AD) were recommended as the first step in the overall program, addressing concerns with the existing incinerators and site space/availability.

Among AD technologies, the THP+MAD alternative, followed by the MAD alternative, appear to be best-suited to the RWQCP. Both AD options offer the opportunity to co-digest food scraps, which is of interest to Palo Alto as part of its overall organics management program. The THP alternative resulted in the best net energy, GHG emission offsets, and overall benefit score for all the alternatives. THP+MAD resulted in the second highest benefit-cost ratio, with MAD having a slightly higher benefit-cost ratio than THP+MAD. Because the NPV of MAD is lower than THP, the benefit-cost ratio is slightly higher; however, THP provides several distinct advantages over MAD:

- MAD results in quality Class B biosolids. Thermal hydrolysis (THP+MAD) results in a higher-quality Class A biosolids product that provides for more end-use outlets and more resiliency to regulatory changes.
- THP hydrolyzes food and sludge, resulting in better overall system performance: better digestion, more biogas production, and fewer biosolids for hauling.
- THP anaerobic digesters can be loaded at a much higher rate, resulting in significantly less anaerobic digester volume.
- THP biosolids can be dewatered to a higher extent (higher percent solids), resulting in significantly less hauling (fewer truck trips per year).

Based on this analysis, for a biosolids-only alternative that can produce a Class A product, the THP+MAD solution was recommended. The shift from incineration to THP+MAD could be implemented in two phases, as follows:

- Component 1 would implement the dewatering and loadout facility in the near term
- Component 2 would implement THP+MAD facilities that would utilize the dewatering and loadout facility.

This approach would enable the RWQCP to implement an interim strategy (construct the dewater/haul facility) that allows decommissioning of the incinerators on schedule. Once the incinerators are demolished and removed, the THP+MAD project could proceed on the open site at the RWQCP.

Figure 7 shows the process flow diagram, including mass/energy balance (for 2015 annual average condition) and key preliminary design criteria for the unit processes. This process does not include food scraps because they are a potential future process feedstock.

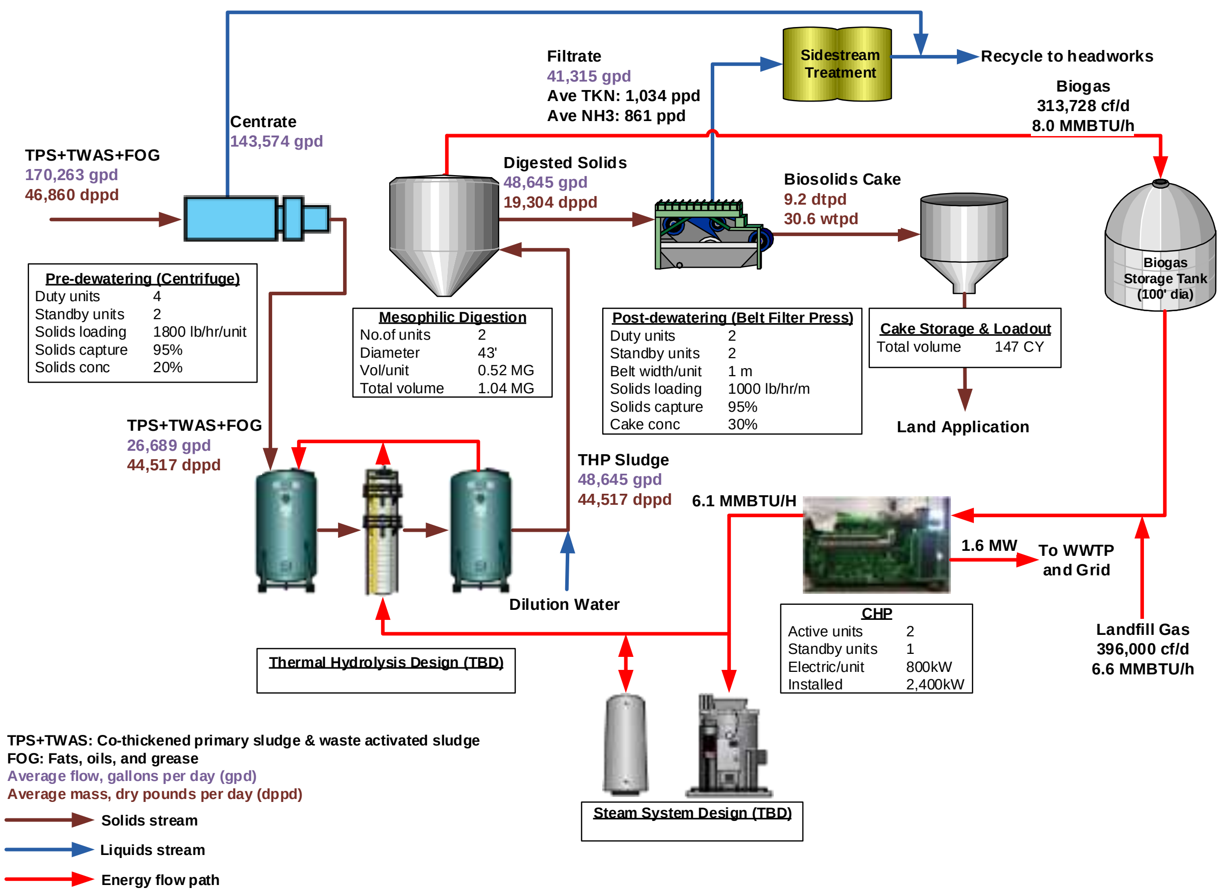

Figure 7: Process Flow Diagram for THP and MAD with Biogas-fueled CHP.

(cf/d = cubic feet per day; CY = cubic yards; dppd = dry pounds per day; dtpd = dry tons per day; gpd = gallons per day; kW = kilowatts; lb/hr/m = pounds per hour per meter; m = meter; MG = million gallons; MMBtu/h = million British thermal units per hour; ppd = pounds per day; MW = megawatts; TKN = total Kjeldahl nitrogen, TPS = thickened primary sludge; TWAS = thickened waste activated sludge; wtpd = wet tons per day; WWTP = wastewater treatment plant.)

Southeast Water Pollution Control Plant, San Francisco Public Utilities Commission

Introduction

The San Francisco Public Utilities Commission (SFPUC) owns and operates a combined sewer system to collect, store, transport, and treat both sanitary sewage and stormwater runoff for the City and County of San Francisco (City), as well as small volumes of sanitary sewage from other agencies. Their treatment facilities include the Southeast Water Pollution Control Plant (SEP), Oceanside Water Pollution Control Plant, and North Point Wet Weather Facility. The SFPUC's 2030 Sewer System Master Plan (SSMP) (2009) led to the development and commissioning of their Sewer System Improvement Program (SSIP) (2010) with recommended capital improvements to address several system-wide challenges. The SEP Biosolids Digester Facilities Project (BDFP) is the largest project in the SSIP. The SFPUC conducted an alternatives analysis (ongoing) to identify a recommended biosolids processing technology, other solids processes (e.g., thickening, dewatering, odor control, biogas use), and a preferred site layout.

Plant Process Type and Capacity. The SEP was designed to treat San Francisco's bayside dry-weather flows, with daily average design and peak-hour design flows of 85.4 and 142 mgd, respectively. Current dry-weather flow averages approximately 69.6 mgd (2008 to 2011 historical average). The SEP treatment process consists of screening and grit removal, primary clarification, high-purity oxygen secondary treatment, disinfection, and sludge stabilization and dewatering. Solids handling treatment processes consist of gravity belt thickening for WAS, mesophilic anaerobic digestion (MAD), and centrifuges for dewatering. The biosolids are either used for land application, composting, or landfill alternative daily cover (ADC). Biogas is used in internal combustion engines for combined heat and power production.

System Planning Parameters. SEP influent flow and population projections developed by the SFPUC Wastewater Enterprise and their Program Management Consultant were used as the basis for the BDFP planning. The solids projections summarized in **Table 8** include influent loads for the design year 2045. These projections were used for the alternatives analysis; however, the SFPUC and BDFP Consulting Team is working to improve data quality and refine these projections before detailed design commences.

Table 8: SEP 2045 Solids Projections (lb/day)

	Annual Average	Maximum 30-day	Maximum 15-day	Maximum 7-day	Maximum Day
Combined solids	257,600	324,600	383,800	450,800	577,000

Project Drivers. The SFPUC launched the SSIP to meet the Wastewater Enterprise's levels of service goals, achieve regulatory compliance, and promote sustainable operations of the City's sewer system. Key drivers included:

- Aging infrastructure and poor condition of existing facilities
- Seismic deficiencies and lack of structural integrity
- Limited operating flexibility and lack of redundancy
- Ongoing need to protect the environment and public health, meet regulatory challenges, and conserve resources

Results and Discussion of Evaluation

The four viable biosolids processing alternatives developed for the BDFP were:

- Alternative 1: Conventional high rate mesophilic anaerobic digestion followed by thermal drying (MAD+TD)

- Alternative 2: Conventional high rate mesophilic anaerobic digestion followed by aerated static pile composting (MAD+COMP) and CHP
- Alternative 3: Temperature-phased anaerobic digestion (TPAD) and CHP
- Alternative 4: Thermal hydrolysis process followed by mesophilic anaerobic digestion (THP+MAD) and CHP
- Alternative 4C: THP+MAD with GBTs and Gas Turbines

Alternative 4C was one of the sub-alternatives evaluated during the sensitivity analysis step of the evaluation with variations on Alternative 4 for thickening technology and biogas utilization. Alternative 4C assumed GBTs for solids thickening in lieu of dissolved air floatation thickeners (DAFTs) and as an alternative to using reciprocating engines and steam boilers to use the biogas and generate the steam required to drive the THP process, gas turbines were evaluated. The primary driver for evaluating the turbine option is the ability of the turbine to generate steam directly from the exhaust heat recovery through a heat recovery steam generator (HRSG), which is a type of steam boiler. The ability to generate adequate steam from the waste heat of the turbine allows all the biogas produced to be used in the generation of power, a significant difference from the engine option.

Financial Analysis. Comparative Class 4 capital cost estimates were developed for the viable treatment alternatives. The facilities were sized to accommodate the projected flows and loads for design year 2045. Base construction costs were developed for the BDFP facilities in 2014 dollars and escalated to the midpoint of construction (2020). **Figure 8** (y-axis truncated) presents the cost ratios for the alternatives relative to the alternative with the highest base construction cost estimate. Lower ratios are more economical. As shown, Alternative 1, MAD+TD, resulted in the lowest base construction cost with escalation, and relatively similar costs across the other alternatives.

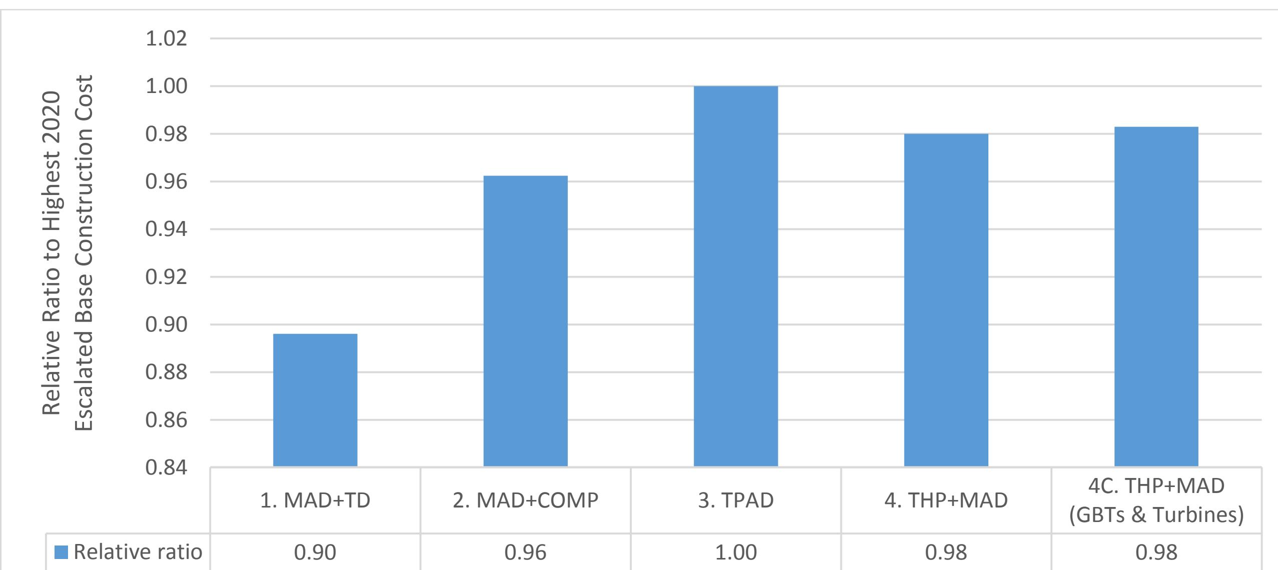

Figure 8: SEP BDFP comparative base construction cost ratios.

Comparative annual O&M costs were estimated based on processing the annual average solids loadings and gas production at the midpoint of the project life (2033). For the purposes of the alternatives evaluation, two viable end uses were selected for each alternative, with the biosolids product split evenly between the two options. Based on the team's biosolids end-use market assessment to date, probable (conservative) scenarios for each end-use option and unit costs for the products were used. The cost ratios for the alternatives relative to the alternative with the highest annual O&M cost estimate is presented in **Figure 9**. Lower ratios are more economical. Based on this, Alternatives 3 and 4 rank higher than Alternatives 1 and 2.

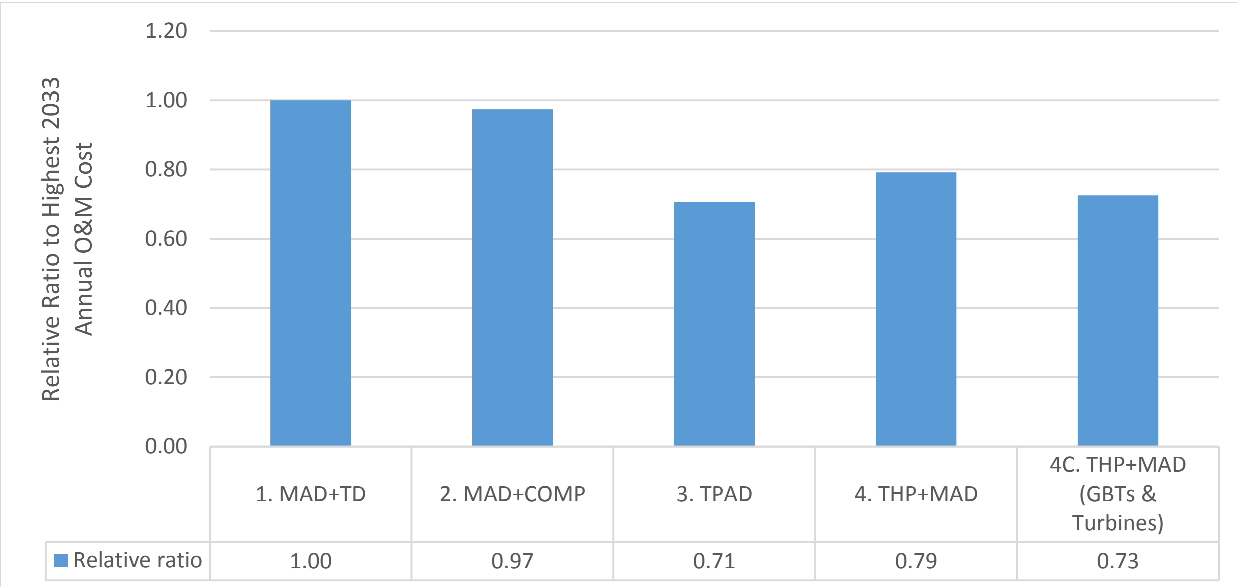

Figure 9: **SEP BDFP comparative annual O&M cost ratios.**

Comparative NPV for each alternative as relative ratio to the highest 2014 NPV is presented in **Figure 10** (y-axis truncated).

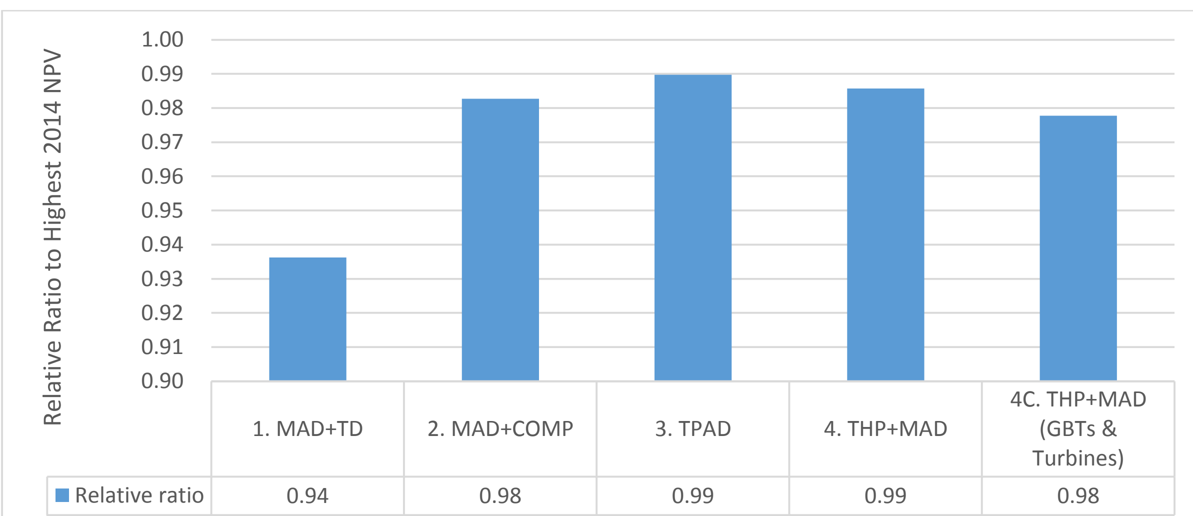

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Figure 10: **SEP BDFP comparative net present value ratios**

Non-financial Analysis. The non-financial evaluation results were calculated from the scores for each criterion with their respective weights. The benefit scores are presented in **Figure 11**, Alternative 3, TPAD, and Alternative 4C, THP+MAD (GBTs & Turbines) resulted in similar scores. Two key criteria that factored into the higher non-financial scores for these alternatives were net renewable power generation and GHG emissions offset.

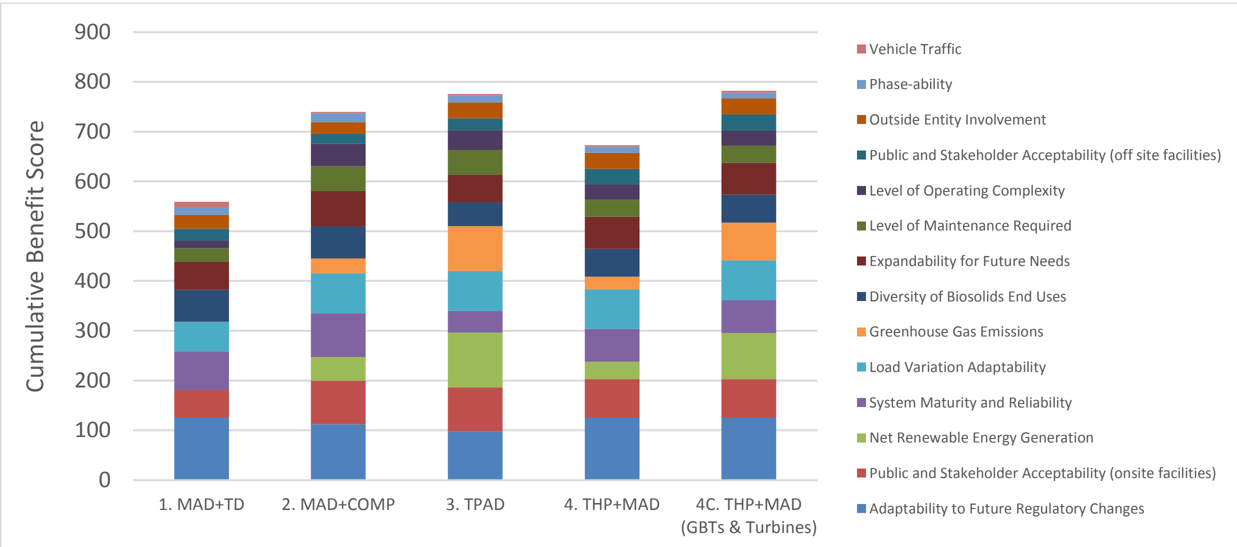

Figure 10: SEP BDFP non-financial scores comparison.

Benefit-Cost Analysis. Typically, in benefit-cost analysis, a benefit-cost ratio is calculated by dividing total benefit score by the total NPV. However, as discussed previously, the NPV results did not provide much differentiation between the BDFP alternatives. The net annual O&M cost or operating expenses (OPEX) estimated for each alternative was, therefore, used instead of NPV. The results of this analysis are presented in **Figure 11**. Alternative 3, TPAD, and Alternative 4C, THP+MAD (GBTs & Turbines) resulted in the highest benefit-cost ratios.

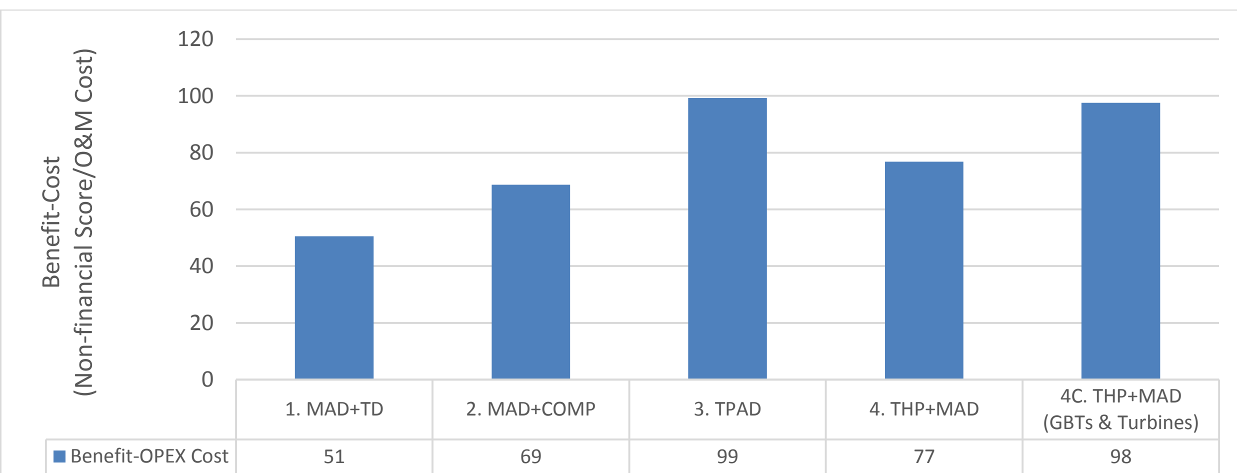

Figure 11: SEP BDFP benefit-cost ratio comparison.

Reasoning for Recommendation

To further evaluate the four alternatives, key differentiators were identified: net power, net GHG offsets, end product quality, annual O&M costs, onsite odor risk, vehicle traffic, and safety. Of these differentiators, the highest-priority differentiators were used to compare viable alternatives. Qualitative scoring were developed for each criterion as presented in **Table 9**. Alternatives 3, 4, and 4C, TPAD, THP+MAD, THP+MAD (GBTs & Turbines) ranked the highest for all priority differentiators. Comparative capital costs for the alternatives were essentially equal, and O&M for Alternatives 1 and 2 were significantly higher than for Alternatives 3, 4 and 4C. Alternatives 1 and 2, MAD+TD and MAD+COMP, were not competitive with Alternatives 3 and 4, TPAD and THP+MAD, therefore, Alternatives 3 and 4, TPAD and THP+MAD, were retained for further consideration.

Table 9: SEP BDFP Alternatives Priority Differentiators

Criterion	1. MAD+TD	2. MAD+COMP	3. TPAD	4. THP+MAD	4C. THP+MAD (GBTs & Turbines)
Net anthropogenic GHG	-	-	+	+	+
Net power	-	-	+	+	+
Annual O&M costs (labor+consumables)	-	-	+	+	+
Safety	-	+	+	+	+

Capital and O&M costs for Alternatives 3 and 4, TPAD and THP+MAD, were comparable; therefore, selection of a preferred alternative was based on differentiating non-financial factors. As shown in **Table 10**, alternative 4, THP+MAD, was selected as the preferred alternative because it ranked higher in most criteria, especially:

- Process robustness and industry trends
- Operability/maintainability
- End product quality
- Regulatory change
- Regrowth issues

Table 10: SEP BDFP Priority Differentiators for TPAD and THP+MAD Alternatives

Criterion	3.TPAD	4. THP+MAD
Process robustness and industry trends	-	+
Operability/maintainability		+
End product quality		+
Biogas use	+	+
Regulatory change	-	+
Regrowth	-	+
Construction schedule	-	
Sole source		-

The new BDFP at the San Francisco SEP includes THP with MAD to achieve a Class A biosolids product. **Figure 12** presents key unit processes and preliminary design assumptions corresponding to 2045 flows and loads, including unit process design criteria, number of units (duty and standby), equipment size and performance. The process flows correspond to average annual year 2045 conditions. Note that the unit process technologies shown were assumed for alternatives evaluation purposes only and are not indicative of selected technologies at this time.

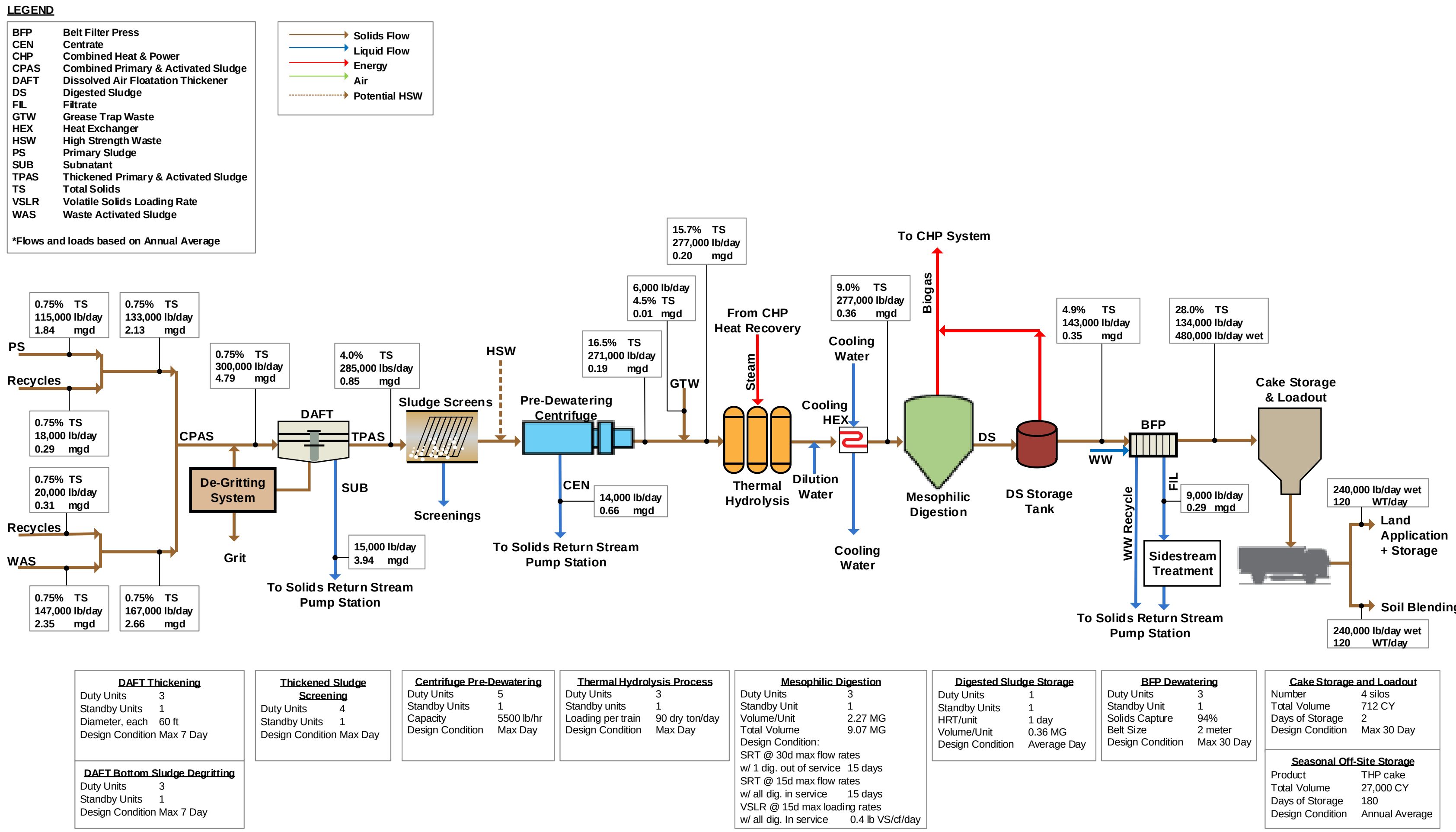

Figure 12: SEP BDFP process flow diagram.

Key Attributes of Thermal Hydrolysis Solutions

The results of these facilities plans indicate that the THP system with anaerobic digestion includes enough positive attributes to push it to the top of many of the biosolids facility planning evaluations; however, not all of them.

The following is list of positive, variable (that is, the attributes are sometimes positive or negative compared other alternatives), and negative attributes that make thermal hydrolysis with anaerobic digestion less attractive for wastewater utilities.

Positive attributes with the THP systems:

- Class A biosolids product
- Exceptional quality, low odor product
- Product resistant to pathogen or pathogen indicator resuscitation or sudden increase
- Product dewaters well with low polymer dosing rate
- Minimized anaerobic digestion volume
- Reduction in final product volume and attractive product consistency and quality

Variable attributes with THP systems:

- Net energy production
- Improvement in VSr
- Improvement in biogas production
- Improvement in biogas yield
- Net improvement in GHG emission offsets
- Lowest capital cost alternative
- Lowest NPV alternative
- Higher feed concentration leads to increased ammonia which can cause metabolic inhibition
- Site footprint

Negative attributes with THP systems:

- Additional pre-THP processes: screening, degritting, dewatering,
- Wear parts: THP feed and transfer pumps, knife gate, nozzles
- Steam exerts additional heat demand reducing the quantity of power produced from biogas for systems with CHP
- THP sludge cooling
- Disinfected/filtered water requirements for processes downstream of THP
- Potential for ammonia inhibition in the anaerobic digestion process
- Potential for refractory nitrogen impact on liquid stream process
- Potential for ammonia loading impact on liquid stream process
- Sidestream treatment (and associated site footprint), if required

What has been observed through these biosolids facility planning efforts is that while THP has not always been the lowest cost nor necessarily the system that produces the most energy, it was the sum of the THP plus AD attributes that has made this processing technology alternative competitive, and compelled some wastewater utilities to choose this technology solution.

Summary

Wastewater utilities are placing an ever-increasing level of importance on sustainable, resource recovery driven solutions for biosolids management. More and more often, solutions utilizing the thermal hydrolysis process (THP) with anaerobic digestion are rising to the top of these biosolids management planning efforts. THP with anaerobic digestion offers many advantages for biosolids management including providing utilities with a Class A, EQ biosolids product that is attractive to farmers and soil blenders, while at the same time reducing product volume and eliminating the need for additional digester infrastructure as populations and influent loading rates grow. The three case studies presented demonstrate that while THP with anaerobic digestion is not a panacea, the overall benefits of this new technology are compelling utility managers to embrace it for long term biosolids management and implementation.

Acknowledgements

The authors of this paper would like acknowledge the efforts of the many individuals, utilities, vendors, and teaming partners who contributed to this work.

Palo Alto. Jamie Allen, Phil Bobel, and Matt Krupp/Palo Alto City were integral in the development of the Palo Alto Biosolids Facility Plan.

North Texas MWD. Bruce Cole/NTMWD galvanized the effort and provided guidance in the planning; Jeff Ray, Jeff Mayfield, Randy Barton, and Bob Reeves/NTMWD were actively involved in shaping the facility plan and provided guidance during planning. Tiffany Currie/NTMWD and Jenna Covington/CH2M HILL provided strong project management throughout.

San Francisco Public Utilities Commission. There are too many people involved in this project to attempt to name individuals; however, SFPUC were actively involved in shaping the facility planning and guiding the effort; Brown and Caldwell, as the lead teaming partner, contributed to and guided the facility planning; Black and Veatch led the biogas utilization analyses for the planning alternatives; and many other teaming partners contributed to this effort. The authors would like to individually recognize the project managers, Carolyn Chiu/SFPUC and Tracy Stigers/Brown and Caldwell, for their wisdom and guidance, and the project engineers, Rosanna Tse/SFPUC and Dave Green/CH2M HILL, for their diligence, attention to detail, and leadership through planning.

Cambi, Inc. Thanks to Paul Christy and Keith Panter/Cambi for their responsiveness and willingness to collaborate through these planning efforts.

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