Final Report
F. Wayne Hill Water Resources Center
Solids Processing Upgrades

Prepared For

Gwinnett

BLACK & VEATCH

Prepared By

B A L I CONSULTING

Danny Greene, Evan Groome, Danielle Larsen, and Curtis McClelland

10 / 17 / 2021

Executive Summary

The F. Wayne Hill Water Reclamation Center (FWHWRC) treats, on average, 35 million gallons per day (MGD) of wastewater and produces 32 dry tons of biosolid cake per day. Conventionally, the cake would be disposed of in landfills. However, as the Atlanta area's landfilling prices continue to rise, Gwinnett County and FWHWRC have started looking into technologies that will produce Class A biosolids. The benefit of producing Class A biosolids is that the strict regulations that must be attained for increased pathogen destruction render the biosolids suitable for land application rather than landfill disposal. For the plant to achieve Class A biosolids, they must implement an additional technology to their current solids handling system. After completing a Kepner-Tregoe (KT) Analysis, Bali Consulting has advocated for the utilization of Thermal Hydrolysis Process (THP) treatment. THP is most beneficial when a plant requires capacity expansion or is facing hauling/storage limitations. This addresses both of Gwinnett County's concerns. THP lowers the SRT, increases solids loading rate into the digesters, and will essentially cut digester volume in half while producing 1.4 times more biogas. The increase in biogas production will be offset by the input requirements of THP, but overall will decrease greenhouse gas emissions and grid energy purchases. The estimated cost to implement THP technology, adjusted to FWHWRC's expected future capacity, is $31.3 million. If FWHWRC decides to emphasize the plant's ability to handle an increased capacity over producing Class A biosolids, there will be a need to construct two additional anaerobic digesters to meet the expected increase of solids loading associated with the area's future growth.

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TEAM ENTRY FORM
WEFTEC 2021 STUDENT DESIGN COMPETITION

SUBMIT ENTRY FORM BY May 28, 2021

Please note *- Names provided below will be printed in competition brochures, on participation certificates, and on plaques for the winning teams, as shown. Please make sure all names are included and written correctly.*

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☒ Wastewater Design Competition ☐ Water Environment Competition

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Abstract
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BALI CONSULTING

Danny Greene, Evan Groome, Danielle Larsen, and Curtis McClelland

The F. Wayne Hill Water Reclamation Center (FWHWRC) treats, on average, approximately 35 million gallons per day (MGD) of wastewater and produces 32 dry tons of biosolid cake per day. Conventionally, the cake would be disposed of in landfills. However, as the Atlanta area's landfilling prices continue to rise, Gwinnett County and FWHWRC have started looking into technologies that will produce Class A biosolids. The benefit of producing Class A biosolids is that the strict regulations that must be attained for increased pathogen destruction render the biosolids suitable for land application. In addition to solving the issue created by increased landfill fees, the biosolids can act as a revenue source for FWHWRC, being sold to farmers or homeowners as fertilizer. For the plant to achieve Class A biosolids, they must implement an additional technology to their current solids handling system. After completing a Kepner-Tregoe (KT) Analysis, Bali Consulting has advocated for the utilization of Thermal Hydrolysis Process (THP) treatment. This treatment method is the most beneficial when a plant requires capacity expansion or is facing hauling/storage limitations because THP lowers the SRT, increases the loading rate, and allows there to be a lower volume per digester. This method addresses both of Gwinnett County's concerns: the production of Class A biosolids and the ability of FWHWRC to handle the increase in loading.

Summary of Project Team Effort Team: Clemson University"/Bali Consulting"

Danny Greene

For the conceptual design, Danny completed the title page, created the table of figures, formatted the headers and footers, produced a detailed CAD drawing of the solids processes at the plant, carried out calculations to establish a mass balance for the current solids processing, and assisted with overall formatting of the report.

For the final report, Danny completed the title page, formatted the headers and footers, created detailed process flow and CAD drawing of the plant, tackled the calculations for the biogas and steam production and demands, and assisted with overall formatting of the report.

Evan Groome

Evan wrote the introduction section, assisted with research on thermophilic anaerobic digestion and TPAD, helped construct and score each design option in the KT analysis table, established the design to be considered section for the TPAD and thermophilic AD solution, constructed the table of contents, wrote the executive summary, and assisted with the appendices.

Evan greatly contributed to the cost analysis section by helping research reference prices, format the cost tables, create the economic analysis graphs, and write some of the section. He also helped me revise the sections of the report that were carried over from the conceptual design report.

Danielle Larsen

Danielle conducted research for all three design options, wrote the design objectives section, established the design to be considered description for thermal hydrolysis (THP), wrote the design details in regard to THP, created a CAD drawing displaying an example configuration of a THP process and its dimensions, helped construct and score each design option in the KT analysis table, assisted Curtis in writing the design details for additional digesters, and wrote the conclusion.

Danielle researched reference costs to use in the economic analysis and created the table for that, calculated the centrifuge needs of the plant with respect to pre and post dewatering demands, researched and completed the energy and ecological footprint section, helped rewrite some sections that were carried over from the conceptual design, helped write the economic analysis section, and calculated the annual cost savings between landfilling and THP land application savings.

Curtis McClelland

Curtis helped carry out calculations to establish a mass balance for the current solids processing, assisted in writing the design option for thermophilic anaerobic bacteria, wrote the design details for adding additional digesters, produced a graph describing the impact of SRT on digester volume, and was in charge of creating and formatting all citations and the bibliography through Zotero.

Curtis helped with research for the economic analysis section of the report and revised the capacity considerations section that was carried over from the conceptual design. He was also in charge of creating and formatting all citations through Zotero.

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Introduction & Background

Located 36 miles north of downtown Atlanta, FWHWRC is an advanced wastewater treatment plant serving Gwinnett County. This plant has been rated to treat a maximum capacity of 60 million gallons per day (MGD). Meeting some of the strictest effluent quality limits, the plant returns roughly 35 MGD of high-quality effluent to Lake Lanier. A satellite captured image of the plant from above can be seen in **Figure 1**.

Figure 1. Aerial photograph of F. Wayne Hill Water Reclamation Center (FWHWRC) with the solids handling treatment train outlined in red.

The main focus from Bali Consulting will focus on the solids handling, which is outlined in red above in **Figure 1**. At FWHWRC, the solids treatment process utilizes sludge collection pumps to transport primary sludge and waste activated sludge (WAS) to a phosphorus release tank. From here, the sludge goes into rotary drum thickeners (RDT's) where the percentage of solids is increased to roughly 3.5% (3,500 mg solids/L). After this, the thickened sludge along with primary scum, secondary scum, and High Strength Waste (HSW) all make their way into the five anaerobic digesters. The normal solids retention time in these digesters is roughly 20 days. Post-digestion, the liquid stream flows into a sludge storage tank. The recovered methane gas goes into their Combined Heat and Power system (CHP) or gets flared off as waste gas. The CHP system utilizes the produced methane to create usable power that can then in turn heat up the five anaerobic digesters, allowing for mesophilic conditions. The thickened sludge from the storage tank combined with chemical sludge from tertiary treatment then goes into the six dewatering centrifuges to increase solids content to 23%. These produced biosolids eventually get properly disposed of in landfills. The entire outline of this process can be seen in **Figure 2** below.

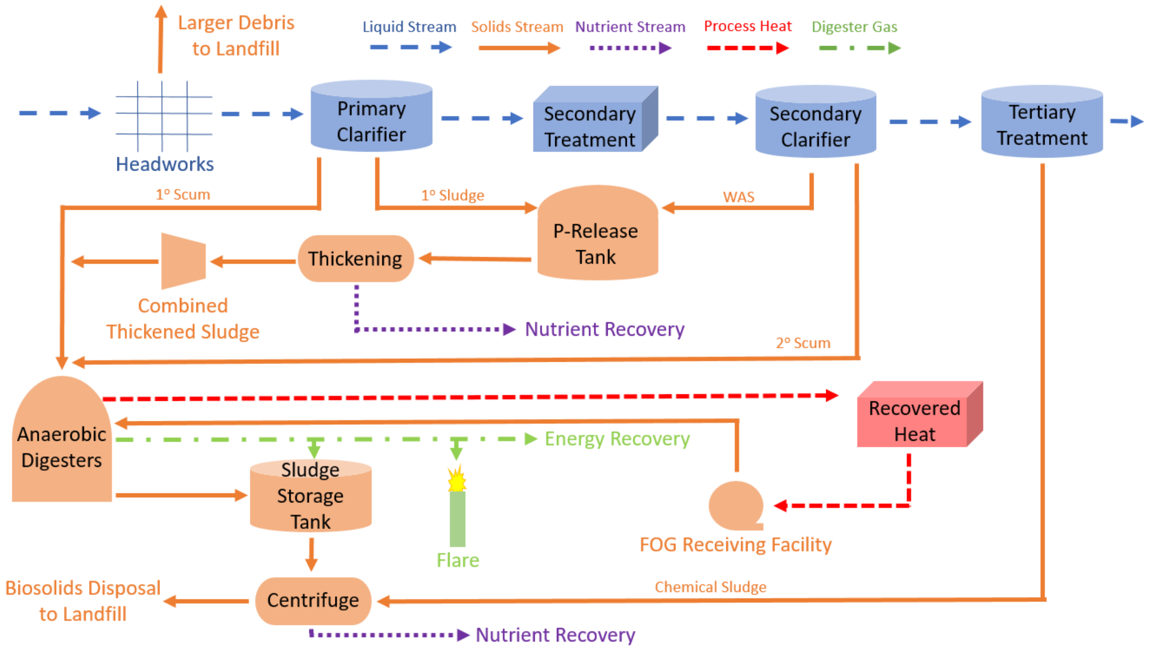

Figure 2. Current solids treatment flow process of FWHWRC.

But, as Gwinnett County's population continues to increase, FWHWRC must start considering their future needs in regards to the handling and disposing of biosolids produced from the treatment process. **Figure 3** and **Table 1** showcase the satellite imagery of the majority of the solids handling processes that will be looked at further. Alongside this, **Figure A2** (located in the appendix of this report) also shows the plan view of all the solids treatment processes.

Figure 3. A zoomed-in aerial photograph of the solids handling treatment process at FWHWRC with numbers correlating the structure to its unit operation, as seen below in **Table 1.**

Table 1. The critical equipment used in the solids treatment train at FWHWRC.

Number	1	2	3	4	5	6	7	8	9
Unit Processes	Anaerobic Digester	Waste Gas Flare	FOG Intake Tanks	Rotary Drum Thickeners, Dewatering Centrifuge, and Thickening Polymer System	Digested Sludge Storage	Pressurized Gas Storage Tanks	Chemical Thickeners	WASSTRIP Tank	Odor Scrubber

In 2000, the plant began operation and disposed of their biosolid cake in nearby landfills post-dewatering. Landfilling biosolids has long been the most reliable, convenient, and cost-effective option for most treatment plants over the years.

However, after the Eagle Point landfill slope failure in 2018, Atlanta's metropolitan area started to see a sharp increase in the cost to dispose of biosolids in landfills [1]. It is anticipated that the high price of landfilling is here to stay, forcing

FWHWRC to start looking for new alternatives to either reduce, repurpose, or choose an alternative disposal route for their biosolids. **Bali Consulting will initially calculate baseline metrics to determine if the current solids treatment process will accommodate future growth. Bali will also consider various methods capable of producing Class A biosolids to avoid increasing landfill disposal costs.** The three main routes of interest when it comes to accommodating the production of Class A biosolids will be:

(i) Thermophilic Anaerobic Digestion with an extended solids retention time
(ii) Temperature-Phased Anaerobic Digestion (TPAD)
(iii) Thermal Hydrolysis Process (THP) treatment.

Design Objectives

The purpose of the proposed project is to enhance the quality of the biosolid cakes produced at FWHWRC by achieving Class A designation by implementing a new solids treatment technology. Attaining Class A biosolids identification ultimately seeks to lower the volume of biosolids produced as well as the cost allotted to landfilling the cakes. Additionally, the project strives to accommodate future growth at the plant by analyzing the current solids processing flows and determining the supplementary volume for the predicted growth, if any is deemed necessary. To eventually accommodate this future growth, Bali first looked at the current solids flow of FWHWRC, as seen in **Figure 2**.

Designs to be Considered

To produce Class A biosolids and reduce the volume of those biosolids at FWHWRC, Bali Consulting has considered three main options: Thermophilic Anaerobic Digestion, Temperature-Phase Anaerobic Digestion (TPAD), and Thermal Hydrolysis Process (THP) treatment.

Thermophilic Anaerobic Digestion

Thermophilic anaerobic digestion operates at a higher temperature than mesophilic anaerobic digestion. In general, thermophilic anaerobic digestion allows for higher loading rates with reduced solid retention times (SRTs), increased volatile solids reduction, higher conversion efficiencies, and improved dewaterability of the digested biosolids [2]. However, there are expensive costs as well as long SRTs of up to 15 days. Bali Consulting does not recommend thermophilic anaerobic digestion because of these reasons.

Temperature-Phased Anaerobic Digestion (TPAD)

TPAD is a pre-treatment method with a relatively low energy input and capital cost used before anaerobic digestion. TPAD is a continuous thermophilic-mesophilic system. TPAD has a volatile solids destruction rate above 38%, classifying it as alternative 6 for Class A biosolids. However, thermophilic anaerobic digestion utilizes microbes in the thermophilic temperature range that are typically more sensitive to changes in temperature and pH. As a result, experienced staff members that are trained or specialized in thermophilic anaerobic digestion must oversee the process to keep the sludge stable, which would contribute to higher overall O&M costs. There are also high capital costs associated with TPAD. For these reasons, Bali Consulting decided not to use TPAD.

Thermal Hydrolysis Process (THP) Treatment

The recommended option for implementation is THP as it is predicted to be the most optimal in producing Class A biosolids and lowering biosolids volume at the plant. The thermal hydrolysis process increases the biodegradability and dewaterability of sludge by treating it at a temperature of roughly 165°C and a pressure of 90 to 130 psi for 20 to 30 minutes. The process will ultimately solubilize chemical oxygen demand (COD), create Class A biosolids by destroying pathogens, and preheat the sludge for digestion [8]. THP implementation is the most beneficial when a plant needs capacity expansion, facing hauling or storage limitations, or is interested in a waste-to-energy project. Since Gwinnett County is interested in both capacity expansion and producing Class A biosolids, THP was determined to be a viable option. The treatment process can increase biogas and electrical energy production significantly and allow digesters to operate at roughly two and a half times higher solids loading rate than conventional digestion[9][10]. THP produced biosolids can be classified as Class A, under alternative 1 in EPA's 503 Regulations, indicating that THP treatment falls under one of the EPA designated time-temperature regimes as listed in **Table A2** (located in the appendix of this report). Since the sludge flow from the plant is less than 7% solids and THP operates at a temperature of 165°C for 20 to 30 minutes, the process falls within the parameters of EPA regime C. Studies have shown that biosolids treated through thermal hydrolysis contain virtually no pathogens in the end product cake, making the biosolids easy to sell, transport, or applied to land.

Although the treatment process seems to address the objectives set forth by Gwinnett County successfully, there are drawbacks to using THP treatment. THP requires additional facilities to be installed at the plant to ensure the success of the process. Since the plant already has digesters, dewatering, and a CHP system, the additional facilities needed only include a 5 millimeter screen, steam boiler, cake silos, coolers, an oxidation catalyst system, and piping in addition to installing the THP technology [8][11]. Therefore, the project is estimated to cost roughly $31.3 million. While operation and maintenance costs for THP is typically not considered to be too taxing, it does require trained professionals due to the system's elevated temperature and pressure[12]. If proper precautions are not taken, the THP process can quickly become a safety hazard. It should also be noted that installation of THP may require noise mitigation to some extent depending on the technology's relation to residential areas or other municipalities in the surrounding area [13].

After considering the benefits and costs associated with each of the three potential design options, a Kepner-Tregoe comparative analysis was conducted to determine the optimal design implementation for the F Wayne Hill Water Reclamation Center, as established in **Table 2**. Eight criteria were exercised to effectively and fairly analyze each design option. The criteria considered for each option are efficiency, O&M costs, space requirement, capital cost, ease of implementation, O&M demands, loading rates, and compliance and permitting needs. A score for every criterion was allotted for each design option on a scale of 1 to 5 deemed poor and excellent, respectively. An overall score was calculated by averaging the scores for each option. The design with the highest score can be assumed to be the ideal choice. It can be noted that the absence of a score for the O&M costs of thermophilic anaerobic digestion was taken into account in the overall score as it was calculated out of 7 criteria rather than eight.

Table 2. Kepner-Tregoe (KT) Comparative Analysis of the Options for Consideration.

	Analysis Criteria								
Designs for Consideration	Efficiency	O&M Costs	Space Required	Capital Cost	Ease of Implementation	O&M Demands	Loading Rates	Compliance & Permitting Demands	**OVERALL SCORE**
Thermophilic Anaerobic Digestion	1	-	5	4	3.5	2	2	1	**2.6**
Temperature-Phased Anaerobic Digestion (TPAD)	3	1	3.5	2.5	3	3	3.5	4	**2.9**
Thermal Hydrolysis Process (THP) Treatment	4	4	3	3	3	2	4.5	4	**3.4**

THP Design Details

From the KT comparative analysis in **Table 2**, it can be concluded that with an overall score of 3.4 out of 5, the THP treatment design option is the ideal design for implementation. As previously stated, to execute a THP system, additional facilities need to be added to the solids handling system at FWHWRC. The necessary facilities include a 5 millimeter screen, steam boiler, cake silos, coolers, an oxidation catalyst system, and piping as well as the THP technology itself. A detailed table including all of the design parameters for the Cambi B6-4 unit that the group is advocating for FWHWRC to purchase and implement can be found in the appendix under **Table A4**.

The waste that enters the THP flow consists of fats, oils, and grease (FOG) and high strength waste (HSW). The FOG & HSW streams will be received and combined, prior to dewatering, with WAS (Waste Activated Sludge) before reaching the THP system. As primary sludge and waste activated sludge are the primary two streams that enter the digester, the impact of adding FOG and HSW streams to the THP system are not fully known. Therefore, detailed monitoring and special attention should be paid to the system during the “startup phase”. However, if problems were to occur, because FOG & HSW streams are independent from the domestic wastewater that the plant treats, their addition and flow rate could easily be adjusted to a level where no adverse effects are observed.

After the sludge is blended with the FOG and HSW, it will travel through a 5-millimeter screen to pre-dewatering. Pre-dewatering will ensure the thermal treatment’s efficiency and effectiveness and achieve a solid content as high as 20% before any digestion [14]. Currently, FWHWRC has 6 centrifuges each with a capacity of 336,000 gallons per day and an operation time of 16 hours per day. Therefore, the combined capacity of all six centrifuges is 2,016,000 gallons per day. The current flow of sludge into the five digesters is 268,000 gallons per day which, after THP implementation, would be the influent flow to the THP trains. Since THP needs pre- and post-dewatering, it was calculated that if the centrifuges were split equally between pre and post dewatering, then each set, three centrifuges for each, would have a total capacity of 1,008,000 gallons per day. This value far exceeds the 268,000 gallons per day of sludge that flows through the process. Therefore, it can be concluded that no additional dewatering units are needed if FWHWRC adopted THP treatment.

From the pre-dewatering, the dewatered sludge will then enter a cake silo, which is optional although highly encouraged, as it will ensure a steady flow through the THP and anaerobic digesters as well as provide operational flexibility [11]. In **Table 3**, two cake silos were listed, accounting for one before THP and one after post-dewatering; the cost was based on a 190 m^3 cake silo volume. The sludge then becomes thermally treated in the THP technology, ensuring the destruction of pathogens, solubilization of COD, and reducing volatile solids. After a meeting with Greg Knight, the principal process engineer at Black & Veatch, Bali Consulting decided to reference the THP treatment train at the Liverpool Wastewater Treatment Plant in Medina County, Ohio. Using Black & Veatch's work at the Liverpool plant as a base reference and the configuration details from the THP vendor, Cambi, a viable configuration was determined. The proposed THP configuration to be implemented at Gwinnett County's wastewater treatment plant is the Cambi B6-4 unit, which costs approximately $6.5 million dollars, without installation. Cambi's B6-4 unit indicates that the THP unit will have a volume of 6 m^3 with 4 treatment trains [36].

To increase volatile solids reduction, THP uses a steam boiler. The steam is used to heat the process as hot water to heat anaerobic digesters in conventional digestion. Since FWHWRC already has a CHP system in place, it can generate steam from the exhaust gas rather than use hot water [11]. The plant currently uses a JMS 616 GS-B.L Jenbacher cogeneration engine for their CHP unit. The heat from the generator is available for use from the jacket cooling water, lubrication oil cooling, first stage intercooler, second stage intercooler, and exhaust gases. As of now, the plant recovers heat to generate hot water from the jacket, oil cooling, and first stage intercooler and generates warm water from the heat generated by the exhaust gas. The engine exhaust gases typically leave at a temperature of 400-500°C which can be used in a steam boiler to produce the steam necessary to power THP [37]. Therefore, in addition to installing a steam boiler, the inlet and outlet exhaust gas connections from the CHP unit will need to be rerouted to the new boiler. An oxidation catalyst will be implemented to clean the exhaust gases before use in the steam boiler to ensure the plant is not emitting toxic pollutants to the atmosphere. To ensure that steam is always available for the THP process, a biogas and natural gas stream is supplied to the boiler to account for lack of exhaust gases.

After thermal hydrolysis treatment, the sludge must be cooled via coolers that use effluent from the plant or a closed-loop process with cooling towers. This must be done before the solids enter the anaerobic digesters to prevent the destruction of the mesophilic microbes in the digesters. The coolers will decrease the temperature of the biosolids from approximately 194°F to around 100°F [15]. Once the biosolids are cooled to a temperature suitable for mesophilic microbes, the biosolids undergo anaerobic digestion. An example solids process flow diagram including THP treatment is displayed in **Figure 4**. Compared to conventional digestion, THP has been determined to increase the percent total solids feed into the digesters by about 50% and decrease the digester volume needed by up to 50%, depending on the current required volume for all current digesters [8]. Therefore, it is possible that with the addition of THP, not only will Class A biosolids be achievable, but it will ensure that the plant will be able to handle the future population growth of Gwinnett County as the technology will lower SRT, increase loading rate, and therefore lower the volume needed per digester. The plant currently has five digesters that can individually hold up to 1 million gallons of sludge for a total volume of 5 million gallons of capacity. All the digesters are typically operated at 100% capacity. By implementing THP, the plant would only need to use 2.5 million gallons of digester volume, allowing for increased sludge flow rates into the digesters as Gwinnett County's population increases [8]. Post-dewatering and storage or transportation off-site then follow. THP has been estimated to reduce hauled biosolids volume, in wet tons per day, by around 26% (saving over $2 million annually) and produce biosolid cakes that are stackable, stable, dry, pathogen-free, and have a minimal odor [16][8]. Therefore, storage on site will be less challenging, and the cakes will be able to be land applied rather than landfilled as they are now considered Class A. A proposed plan view of the plant with the installation of THP can be seen in **Figure A3**.

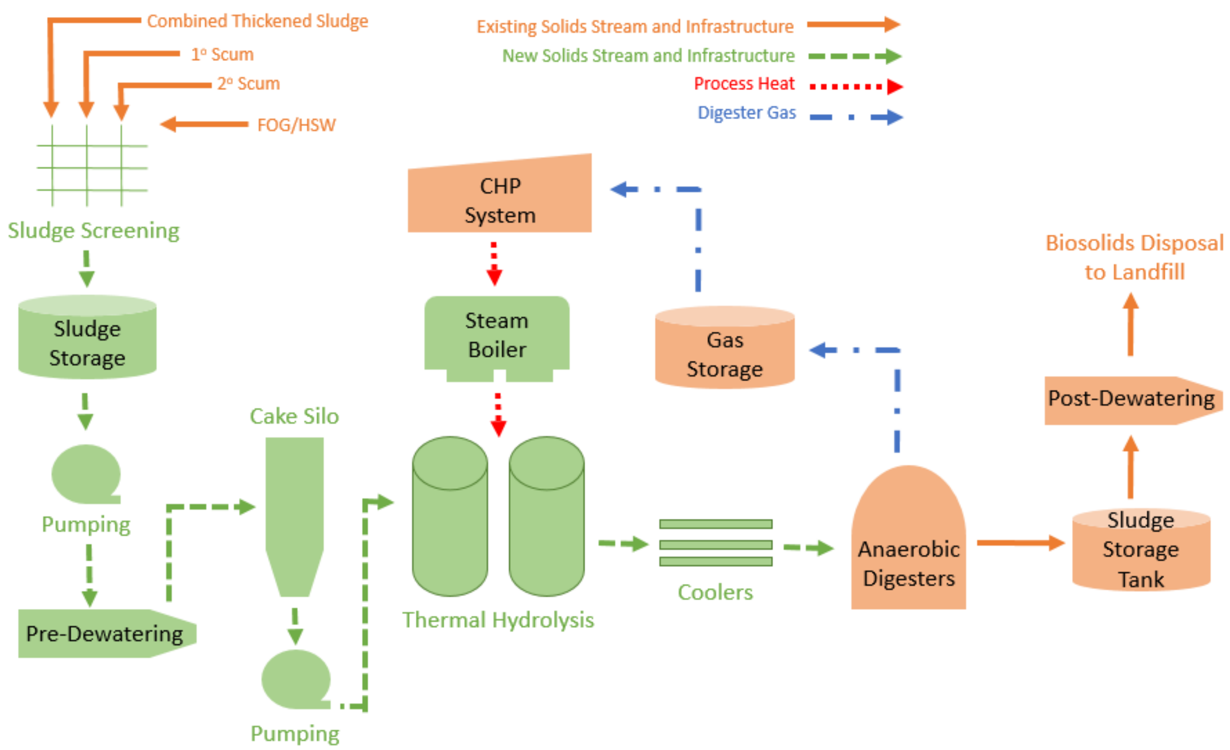

Figure 4. Process Flow Diagram for a Thermal Hydrolysis Process Implementation at the FWHWRC.

Current Biogas Calculations

Biogas and Methane Calculations of Current AD System

Below are the calculations regarding the biogas produced from the current anaerobic digestion system at FWHWRC. Data from the digesters show that the percent total solids averaged across the five total digesters is 3.47% (3.47 g total suspended solids (TSS)/L). Similar data taken from FWHWRC shows that the flow rate from both primary sludge (1°) and waste activated sludge (WAS) is 832.79 m^3/d and 1,627.73 m^3/d, respectively. Equations 1 and 2 are used to calculate the mass rate of each sludge [35]. For both, it is assumed that the percent total solids are the same for both 1° and WAS.

$$TSS_{1^o} = \frac{(832.79 m^3/d) * (34{,}700\ g\ TSS/m^3)}{1000\ g/kg} = 28,897.81\ kg\ TSS/d \tag{1}$$

$$TSS_{WAS} = \frac{(1{,}627.73\ m^3/d) * (34{,}700\ g\ TSS/m^3)}{1000\ g/kg} = 56,482.23\ kg\ TSS/d \tag{2}$$

Once a mass rate is achieved, Bali Consulting calculated the number of volatile solids (VS) destroyed per day. First, it was assumed that there is 0.75 kg VS/kg TSS. Next, for 1^{o}, the group assumed that there is 0.6 kg VS destroyed/kg VS. For WAS, it is assumed to be 0.2 kg VS destroyed/kg VS. The conversions for both 1^{o} and WAS can be seen below in equations 3 and 4 [35].

$$TSS_{1^o} = (28,897.81\ kg\ TSS/d) * (0.75\ kg\ VS/kg\ TSS) * (0.60\ kg\ VS\ dest./kg\ VS) \qquad (3)$$

$$TSS_{1^o} = 13,004.02\ kg\ VS\ Destroyed/d$$

$$TSS_{WAS} = (56,482.231\ kg\ TSS/d) * (0.75\ kg\ VS/kg\ TSS) * (0.20\ kg\ VS\ dest./kg\ VS) \qquad (4)$$

$$TSS_{WAS} = 8,472.33\ kg\ VS\ Destroyed/d$$

After the mass rate of VS destroyed was computed, Bali Consulting converted how much of the VS was destroyed to methane produced for the whole anaerobic digestion process for the combined thickened sludge. Here the group assumed that 0.70 m^3 CH_4 are produced for every kg VS destroyed. The two values from equations 3 and 4 can be summed together because they are now in the same units. This brief conversion can be seen below in equation 5 [35].

$$\Sigma 1^o + WAS = 21,476.35\ kg\ VS\ dest. * (0.7\ m^3CH_4/kg\ VS\ dest.) = 15,003.5\ \ m^3CH_4/d \qquad (5)$$

$$Methane\ Produced\ via\ 1^o + WAS = 15,003.5\ \ m^3CH_4/d$$

Assuming that the biogas is composed of 62.5% methane, Bali Consulting calculated equation 6, shown below.

$$Biogas\ Produced\ from\ \ 1^o + WAS = \frac{15{,}003.5\ \ m^3CH_4/d}{0.625\ \ m^3CH_4/\ m^3biogas} = 24,053.5\ m^3\ biogas/d \qquad (6)$$

The value from equation 6 is from our combined thickened sludge and does not take into account the FOG/HSW that arrives at the plant daily. Therefore, the group took into account the added values on a yearly average (60,730 gal/d). Bali Consulting assumed that the percent total solids in the FOG/HSW is 3.47 g/L. But with a new waste stream, the group assumed that 0.85 kg VS destroyed/kg VS and that 0.71 m^3 of methane is produced per kg VS destroyed. The volume of methane produced is calculated in equation 7 [30].

$$Biogas = \frac{(229.89\ m^3/d) * (3.47\ g/L) * (0.85\ kg\ VS\ dest./kg\ VS) * (1.56\ m^3 CH_4/kg\ VS\ dest.) * (1000L/\ m^3)}{(1000\ g/kg)} \tag{7}$$

$$Biogas\ Produced\ from\ HSW = 1,057.78\ m^3 biogas/d$$

Therefore, the sum of total biogas produced per day is in equation 8.

$$Biogas = 24,053.5\ m^3 biogas/d + 1,057.78\ m^3 biogas/d = 25,111.28\ m^3 biogas/d \tag{8}$$

$$Total\ Biogas\ Produced = 615.92\ ft^3 biogas/min$$

This calculated value of 615.92 ft^3 biogas/min is very close to the measured value of 608.20 ft^{3}biogas/min. This second value stems from the average biogas volume produced by summing the five digesters average taken over a three month interval. This percent difference between the calculated and measured value is only off by 1.27%.

Therefore, the total amount of methane produced per day can be seen below in equation 9.

$$Methane = \Sigma 1^o + WAS + HSW = 15,003.5\ m^3 CH_4/d + 1,057.78\ m^3 CH_4/d \bullet 0.65 \tag{9}$$

$$Total\ Methane\ Produced = 15,721\ m^3/d$$

Heat Requirements for Current AD with Jenbacher Engine

Once the amount of methane produced is calculated based on the current solids capacity, the amount of energy produced from the process can be found. This is seen in equation 10 [30].

$$E_{ANER,pro.} = (15,721\ m^3 CH_4/d) * (35,846\ kJ/m^3) = 563.5\ x10^6\ kJ/d \tag{10}$$

Heat loss must be accounted for in the digesters during this process due to insulation in the walls, external ambient temperature, and many more factors. The heat loss from these processes can be seen below in equation 11. Some assumptions made here are as follows: the influent wastewater is 20°C and it needs to be brought up to 35°C; the specific heat of water is 4.2 kJ/(°C * kg); and the fraction of heat available after losses from the vessel and heat exchanger is 0.80. For Q, the average sum of combined thickened sludge and HSW, is 1,016 m^3/d [30].

$$E_{ANER,lost} = -(Q)(\Delta T)(C_P)(10^3\ kg/m^3 water)(\tfrac{1}{Eff_{heat}}) \tag{11}$$

$$E_{ANER,lost} = -(1,016\ m^3/d\ )(15^oC)(4.2\ kJ/{}^oC \bullet kg)(10^3\ kg/m^3 water)(\tfrac{1}{0.80})$$

$$E_{ANER,lost} = -80.0\ x10^6 kJ/d$$

Hence, the total net energy created from the five current anaerobic digesters is 483.5 x10^6 kJ/d. This value is found from equation 12 below.

$$E_{ANER,net} = E_{ANER,pro.} - E_{ANER,lost} \tag{12}$$

$$E_{ANER,net} = 563.5\ x10^6\ kJ/d - 80.0\ x10^6 kJ/d = 483.5\ x10^6\ kJ/d$$

This gas and net energy is utilized to heat up the current digesters to their mesophilic operating temperature of around 37°C. Any additional biogas not utilized from the Jenbacher engine used to heat up the sludge will be burned off as flare gas.

New Gas Balance with THP

Biogas Calculations of THP System

Similar to the current biogas calculations, Bali Consulting looked into the amount of biogas and methane that will be produced from the implementation of the new THP system. The current solids loading rate of 3.47% (3.47 g total suspended solids (TSS)/L) taken from the average of the five digesters will be utilized for the THP calculations to ensure uniformity. But, this value will be increased to 16.5% from the dewatering step needed before [36]. This value stems from what is needed to operate the CambiTHP B6 unit (the unit that we will be selecting).

Bali Consulting first needs to select a time-temperature relationship on methane production. The selected one is 150°C for 60 min. This may not be the one chosen in the end, but from a peer-reviewed academic study it was proven to yield the most methane per input of chemical oxygen demand (COD). The methane yield comes out to be 273.3 mL CH4/g COD [40]. Therefore, Bali Consulting calculated the methane produced under anticipated conditions for THP in equation 13 below. The total flow rate of combined thickened sludge plus HSW is combined here to give a value of 3,476.5 m^3/d.

$$Methane = \frac{(273.3 mL\ CH_4/g\ COD) \cdot (16.5\ g\ TSS/L) \cdot (1.2 g\ COD/g\ TSS) \cdot (1.2 g\ COD/g\ TSS) \cdot (3{,}476.5\ m^3/d) \cdot (1000\ L/m^3)}{(1000000\ mL/m^3)} \tag{13}$$

$$Methane\ Produced\ via\ THP = 18,812.6\ m^3 CH_4/d$$

$$Biogas\ Produced = 18,812.6\ m^3 CH_4/d\ /\ 0.625 = 30,100.2\ m^3 Biogas/d$$

Heat Requirements for New THP System

Similar to the above calculations for the current capable production of energy, the same for THP follows in equation 14.

$$E_{ANER,pro.} = (18,813\ m^3 CH_4/d) * (35,846\ kJ/m^3) = 674.4\ x10^6\ kJ/d \tag{14}$$

Heat loss will be the same for the digesters as above, with a value of -80.0 x10^6 kJ/d. This is because of the same digesters and system being in place. Therefore, the net energy produced due to the increased biogas production is as seen below in equation 15.

$$E_{ANER,net} = E_{ANER,pro.} - E_{ANER,lost} \tag{15}$$

$$E_{ANER,net} = 674.4\ x10^{6}\ kJ/d - 80.0\ x10^{6} kJ/d = 594.4\ x10^{6}\ kJ/d$$

Additional heat loss factors will stem from the THP system itself and its accompanying piping. But, this will be more empirically driven and Cambi will have the answers to this if this is further pursued. Finally, **Table 3** below highlights the overview of gas and energy production from both the current and THP system.

Table 3. Overview of calculated gas and energy production from pre and post THP implementation.

	Conventional AD + CHP	**THP + AD + CHP**
Biogas Production	25,111 m^3/d	30,100 m^3/d
Methane Production	15,721 m^3/d	18,813 m^3/d
Energy Production	483.5 $x10^6$ kJ/d	674.2 $x10^6$ kJ/d

Steam Demand of THP System

For THP to operate properly, steam must be produced via the Jenbacher addition from its heat and electricity output. The amount of steam needed for the THP is based on the assumption that there needs to be 1 ton of steam at 175 psi for every ton of solids that is going to be treated. Hence, equation 16 below shows the simple unit conversion. This also assumes that there is 16.5% total solids coming in due to the pre-THP dewatering step.

$$Steam = (16.5\ kg\ TSS/\ m^{3}) * (1016\ m^{3}/d) * (2.21\ lb/kg) * (ton/2000\ lb) = 36.96\ ton/d \tag{16}$$

The current Jenbacher engine cannot produce this amount of steam per its specifications. Therefore, the implementation of an additional steam boiler will be needed to help produce more steam from captured biogas. This will then allow the THP system to operate at peak efficiency.

Economic Analysis

There are numerous costs that need to be considered when implementing THP for FWHWRC. As previously stated, a 5 millimeter screen, two cake silos, a steam boiler, and an oxidation catalyst need to be installed in addition to the four trains of THP. The cost of the 5 millimeter screen is $1.7 million as referenced from the 60 MGD Neuse River WWTP in Raleigh, North Carolina. The screen will be an in-line coarse screen that will remove grit and large solids prior to THP treatment [25]. Two cake silos are recommended to the County to ensure steady flow of solids through THP and ample storage for biosolids after processing. The cost to purchase and install a single cake silo is $500,000 estimated from Jim Myers & Sons Inc [31], a wastewater equipment manufacturer, and Cambi [27]. However, as two of them are recommended, the total cost will be $1 million. The B6-4 THP units themselves will cost a total of $6.5 million as stated by Cambi through Black & Veatch. To power the THP units, a steam boiler will be purchased at a cost of $420,000 reported by Cambi [27]. To ensure the steam boiler is not emitting toxic pollutants, an oxidation catalyst will be installed to clean the CHP exhaust gas. The oxidation catalyst will cost around $850,000 per the Combustion Turbine Work Group of the Industrial Combustion Coordinated Rulemaking [32]. After the sludge is cooked during THP, the temperature is reduced by coolers before digestion to prevent the destruction of the microbes. A single cooler unit costs $33,000 [33], however, referencing the Trinity River Authority Central Regional Wastewater System in Texas, two coolers are recommended for every digester at the plant [34]. Therefore, 10 coolers are suggested for a total cost of $330,000. To account for construction, installation, piping, electrical, overhead, contingency, and engineering costs, typical scaling factors were used to estimate the costs associated with each as seen in **Table 5**. It should be noted that the costs for reconfiguration, pumps, and conveyors are included in the construction and civil costs. The percentages were reported and referenced from THP vendor, Cambi [27].

The costs associated with certain types of equipment, construction materials (including installation), contractor overhead, and engineering fees are listed below for a Cambi B6-4 unit (THP) in **Table 4** and for a mesophilic anaerobic digester, consisting of 5 digesters, in **Table 5**. The group referenced an article comparing

Cambi's THP treatment to Exelys THP treatment and conventional anaerobic digestion in order to draw inspiration and learn more about costs that must be accounted for in Cambi's THP treatment train [27]. Even though THP is initially slightly more expensive compared to the anaerobic digestion design, **Figure 5** shows how that over twenty years, the THP process will have a higher value at the end of the twenty year period due to the return on investment (ROI) from increased biogas production (offsetting the energy demand for THP, cutting out cost of heating and cooling) and production of Class A biosolids that are able to be sold as a land-applicable fertilizer [29]. **Figure 6**, as seen below, represents a comparison of Cambi's B6-4 unit to the five digester set up of mesophilic anaerobic digestion over a twenty year period. For both present and future worth scenarios, an interest rate of 8% was assumed.

Table 4. The Cost Analysis for Implementing THP Treatment, a Cambi B6-4 Unit

Cost Estimates	Quantity	Factor [27,28]	Cost (Total)
Capital Equipment Costs			
5 mm Screening	1		$1,700,000.00
Cake Silo	2		$1,000,000.00
THP Units (B6 X 4)	4		$6,500,000.00
Steam Boiler/HRSG	1		$420,000.00
Coolers/Heat Exchangers	10		$330,000.00
Oxidation Catalyst System			$850,000.00
Total Equipment Cost			**$10,800,000.00**
Construction & Civil Costs		20%	$2,160,000.00
Installation		25%	$2,700,000.00
Piping		5%	$540,000.00
Electrical		15%	$1,620,000.00
Subtotal 1			**$17,820,000.00**
Contractor or Overhead & Profit		20%	$3,564,000.00
Subtotal 2			**$21,384,000.00**
Contingency		25%	$5,346,000.00
Subtotal 3			**$26,730,000.00**
Engineering, Admin, & Legal		20%	$5,346,000.00
Total Project Cost			**$31,226,000.00**

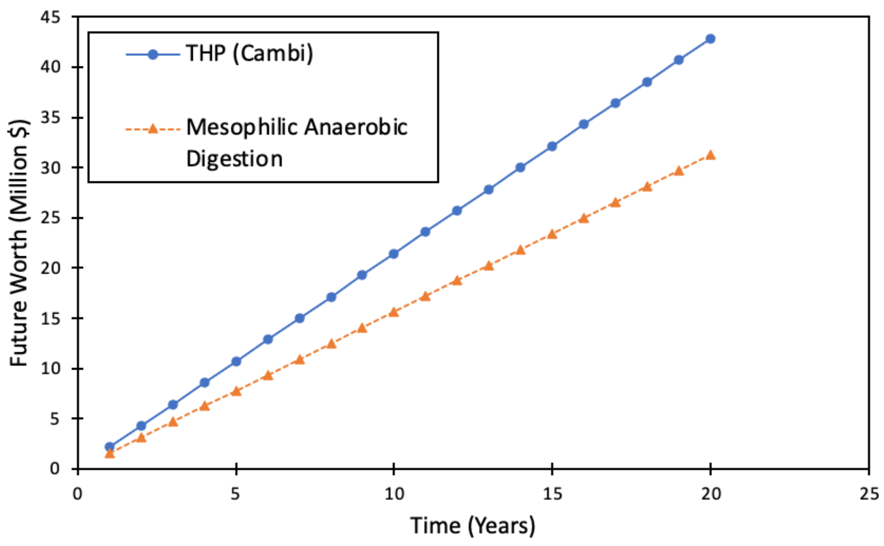

Figure 5. A 20-year future worth (FW) cumulative cost estimate for Mesophilic Anaerobic Digestion versus Thermal Hydrolysis Process.

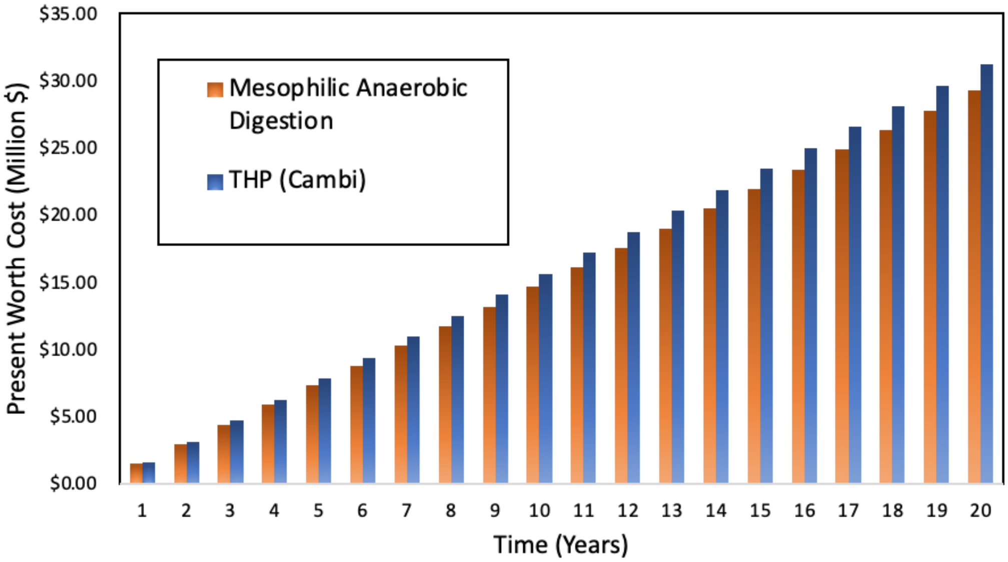

Figure 6. A 20-year bar graph representing the present worth (PW) for both Mesophilic Anaerobic Digestion and Thermal Hydrolysis Process.

Energy and Ecological Analysis

In addition to THP creating Class A biosolids and decreasing digester capacity, the treatment technology also produces more biogas than conventional anaerobic digestion. However, the increase in biogas yield does not necessarily correlate to an overall net increase for the plant as THP demands high inputs of high-grade heat and electricity [39]. For instance, conventional anaerobic digestion typically requires an input of 135 kWh of electricity and 400 W of low-grade heat to produce 1920 W of biogas. With THP implementation, it is estimated that the process will require an input of 179 kWh of electricity and 537 W of high-grade heat to produce 2680 W of biogas [39]. Still, the inputs and outputs of THP are estimated to produce a net gain of energy, although less than that of conventional anaerobic digestion. Baseline energy inputs and outputs for both conventional anaerobic digestion and THP are compared in **Table 5**.

Table 5. Energy inputs and outputs for conventional digestion and THP [39].

	Conventional AD + CHP	**THP + AD + CHP**
Typical Energy Flow (1 kgDS/h)		
Post-AD Sludge	2720 W	2330 W
Biogas	1920 W	2680 W
Heat	400 W (low grade)	537 W (high grade)
Outputs		
CHP Maximum Electricity	2185 kW	3061 kW
Biogas Yield	25,111 m^3/d	35,155.4 m^3/d
Inputs		
Electricity	135 kWh	179 kWh
Nat Gas	0 kWh	370 kWh
Diesel	7.3 kg	3.7 kg
Polymer	9.2 kg	14 kg
THP Process Assumptions	-	
Thickening - Electrical Demand	-	60 kW h/TDS
THP- Electrical Demand	-	50 kW h/TDS
Pre-Dewatering Polymer Demand	-	5 kg/TDS
THP Steam Demand	-	1 kg/kgDS at 174 psi

Another consideration in plant improvements is the ecological footprint. The THP technology has been reported to decrease greenhouse gas emissions by roughly 40% while decreasing grid energy purchases by about 30% [38]. The reduced biosolids hauling and energy production from the increased biogas yield will contribute to the reduction in greenhouse gases and ultimately enhance the overall air quality in Gwinnett County. From various studies of implemented THP technology, data has determined that THP for an anaerobic digestion and CHP plant will produce an overall global warming potential (GWP) score of 3 out of 5 while conventional digestion is concluded to have a score of 2 [39]. The scores are based on a scale of 1 to 5 with 5 deemed the best scenario with the least amount of impacts.

Figure 7. Ecological impacts of THP implementation.

Therefore, it is reasonable to conclude that although THP will require higher energy and electricity inputs, a positive net yield of energy for the plant can be accomplished while reducing FWHWRC's overall emissions, energy purchases, and ecological footprint.

Capacity Considerations

Suppose Gwinnett County delays the construction of Class A biosolids production technology at FWHWRC and primarily focuses efforts on capacity expansion alone. In that case, it will be vital for the County to add two new additional digesters to the solids processing to ensure the treatment plant can withstand predicted solids inflow due to expected population growth. There are currently five digesters with a combined maximum volume of 5 million gallons that are typically filled. As Gwinnett County's population continues to increase, FWHWRC will have to accommodate increased solids flow rates. The digesters have an average of 60,730 gallons per day of FOG, as well as HSW. It is important to note that FOG/HSW flow does not change as the plant changes flow rate. This is because the FOG/HSW is brought into the plant via trucks and stored in a separate storage container [17]. Operating at an average of 35 MGD, the plant also has 207,740 gallons per day (gpd) of thickened sludge coming from the rotary drum thickeners. With an average SRT of 20.73 days, there was a combined total of approximately 5.55 million gallons in the digesters [18]. This value was calculated by adding the FOG/HSW flow rate to the thickened sludge flow rate and multiplying the sum by the SRT. This is not feasible as the digesters can only hold up to 5 million gallons. To account for the maximum volume of the digesters, the SRT of the digesters can be decreased to ensure that they are not overloaded at times of higher flow rates. It was also calculated that the population of Gwinnett County is growing at an approximate rate of 20.5% per decade. This value was found by averaging the population growth rate from 2000 to 2010 and 2010 to 2019 [19]. At this rate, the plant will be handling about 42 MGD, and the digesters will need to accommodate over 6.5 million gallons of waste by 2030. Therefore, Bali Consulting is recommending the addition of two additional digesters for a combined digester volume of 7 million gallons. **Figure 8** illustrates the impact of SRT values on digester volume. The red lines represent the total volume and SRT that the FWHWRC currently operates at.

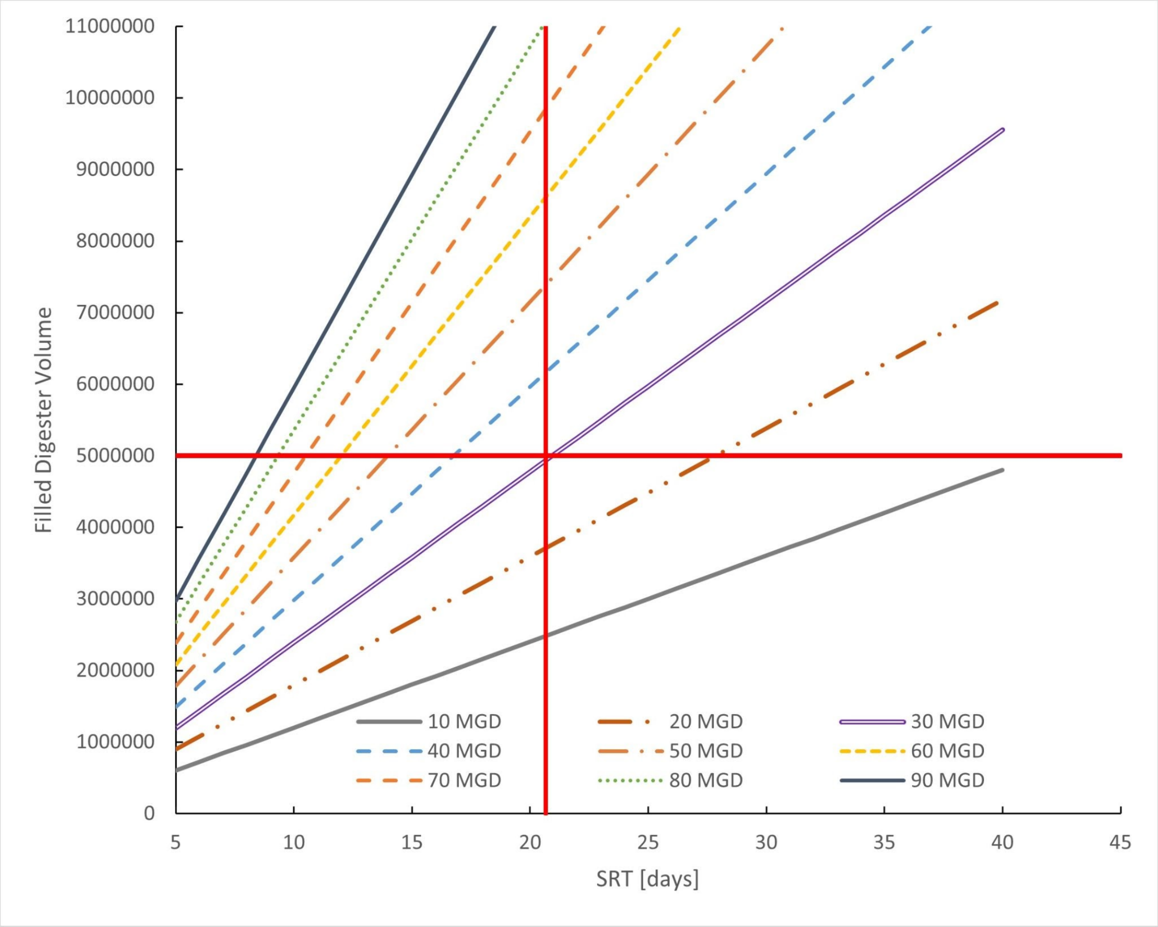

Figure 8. The Impact of SRT on the Total Digester Volume at Various MGDs.

To determine the predictions in **Figure 8**, several steps were executed. Since the average volume at the plant is 35 MGD, the value of thickened sludge was divided by 35 and then multiplied by the MGD of interest. The resulting value was added to the HSW flow and the sum then multiplied by the SRT. The number of digesters required can be determined by taking the filled digester volume and dividing it by 1 million. By incorporating two additional digesters, FWHWRC will be able to handle the current average flow rate of 35 MGD and the increased flow rate of 42 MGD due to population increase over the next decade, assuming that the average SRT of 20.7 days does not change [20]. The capital cost and O&M cost of the two additional digesters will be the same as the existing digesters. It can be predicted that while adding two digesters will allow the plant to handle flows in the next few years, Gwinnett County's population will continue to increase past 2030 resulting in the need for more digesters to be built.

Conclusion

The design objectives set forth by Black & Veatch and Gwinnett County include quality enhancement of biosolids cakes to a Class A designation, the decrease of biosolids volume, and the accommodation for future growth of solids influx into the plant. To address the objectives, Bali Consulting has analyzed the current solids processing flows at FWHWRC and considered three design options: thermophilic anaerobic digestion, temperature-phase anaerobic digestion (TPAD), and thermal hydrolysis process (THP) treatment. After conducting a KT comparative analysis of the three design implementations using eight different criteria, it was concluded that THP will be the most viable option. THP treatment guarantees the production of Class A biosolids, an increase in biogas production, a decrease in the anaerobic digester space required, and stable, odor-free, compactable, biosolids cakes capable of being land applied. Therefore, the THP treatment design is predicted to fulfill the biosolids classification and volume objectives at a total cost of $31.3 million. If the County delays the construction of Class A biosolids technology at FWHWRC, it will be vital for the FWHWRC to add two new anaerobic digesters to successfully meet the future needs of the plant in regards to a rise in solids inflow.

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Appendix

Table A1. A summary of the six alternatives for meeting Class A pathogen requirements.

In addition to meeting the requirements in one of the alternatives listed below, the requirements in Table A3 must be met for all six Class A alternatives.

Alternative 1: Thermally Treated Biosolids

Biosolids must be subjected to one of four time-temperature regimes.

Alternative 2: Biosolids Treated in a High pH-High Temperature Process

Biosolids must meet specific pH, temperature, and air-drying requirements.

Alternative 3: Biosolids Treated in Other Processes

Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after pathogen reduction demonstration is completed.

Alternative 4: Biosolids Treated in Unknown Processes

Biosolids must be tested for pathogens --- *Salmonella* sp. or fecal coliform bacteria, enteric, viruses, and viable helminth ova --- at the time the biosolids are used or disposed, or, in certain situations, prepared for use or disposal.

Alternative 5: Biosolids Treated in a PFRP

Biosolids must be treated in one of the Processes to Further Reduce Pathogens (PFRP)

Alternative 6: Biosolids Treated in a Process Equivalent to a PFRP

Biosolids must be treated in a process equivalent to one of the PFRPs, as determined by the permitting authority.

Table A2. The Four Time-Temperature Regimes for Class A Pathogen Reduction Under Alternative 1.

Regime	Applies to:	Requirement	Time-Temperature Relationship*
A	Biosolids with 7% solids or greater (except those covered by Regime B)	Temperature of biosolids must be 50°C or higher for 20 minutes or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
B	Biosolids with 7% solids or greater in the form of small particles and heated by contact with either warmed gases or an immiscible liquid	Temperature of biosolids must be 50°C or higher for 15 seconds or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
C	Biosolids with less than 7% solids	Heated for at least 15 seconds but less than 30 minutes	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
D	Biosolids with less than 7% solids	Temperature of sludge is 50°C or higher with at least 30 minutes or longer contact time	$D = \frac{50{,}070{,}000}{10^{0.14t}}$

*D = time in days; t = temperature in degrees Celsius

Table A3. Pathogen requirements for all Class A alternatives.

The following requirements must be met for *all* six Class A pathogen alternatives
Either: The density of fecal coliform in the biosolids must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis). or The density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis). Either of these requirements must be met at one of the following times: - When the biosolids are used or disposed - When the biosolids are prepared for sale or give-away in a bag or other container for land application; or - When the biosolids or derived materials are prepared to meet the requirements for EQ biosolids Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation option are met.

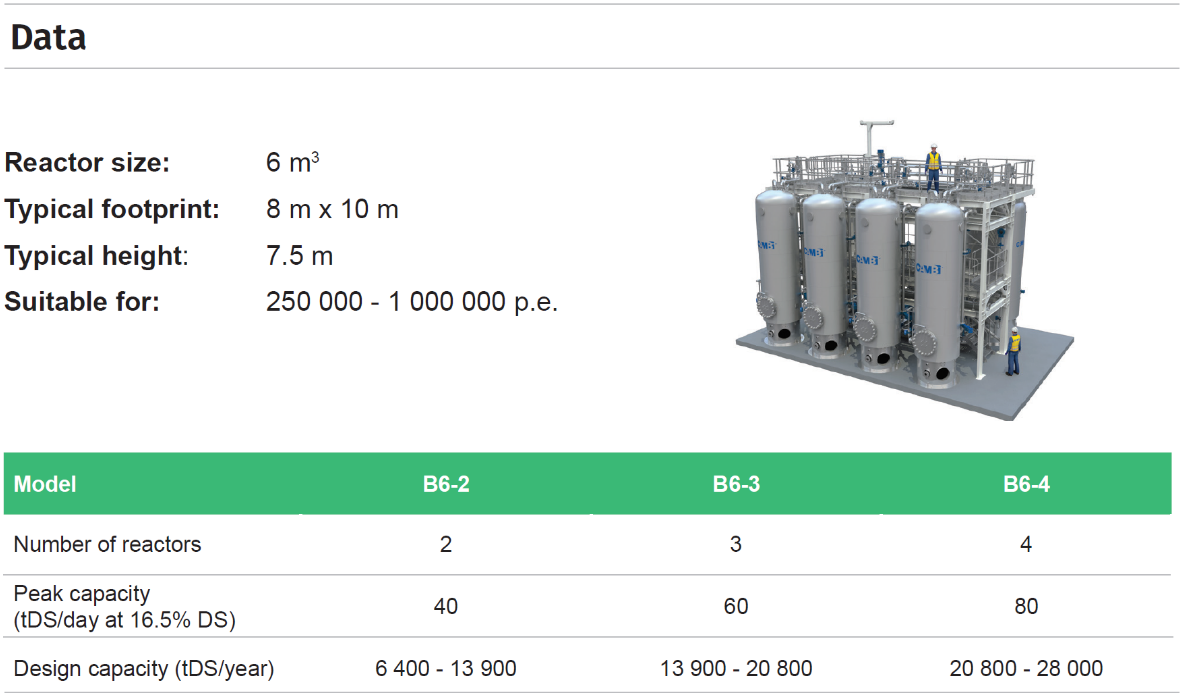
Table A4. A table showing the detailed parameters for the Cambi THP system planning to be implemented at FWHWRC.

Parameter	Detail	Unit
Solids Input to THP	7.6	% TS
Number of THP Trains	4	
Model Number	B6 X 4	
THP Footprint	3,715	ft^2
Steam Requirement	422.7	lb/ton DS input
Steam Requirement	1	ton steam per ton DS input
Digester Feed Solid Content	9.46	%
Total Digestion Volume	668,405	ft^3
Total System VSR	50	%
2nd Stage Dewatering DS%	21	%
Total Solids Produced	16	dtpd
Dewatered Cake Hauled	71	wtpd
THP Gas Production	577,843	ft^3/day
% of Gas to CHP	94%	%
Electricity Production	1,482	kW
Low Temp Waste Heat Available	4,347	MBTU/hr
Electricity Consumption	216	kW/hr

*dtpd = dry tons per day; wtpd = wet tons per day

Table A5. The Cost Analysis for Implementing Mesophilic Anaerobic Digestion

Cost Estimates	Factor [27,28]	Cost (Total)
Capital Equipment Costs		
Total Digestion Cost ($5/gal)		$6,551,712.00
Total CHP Cost ($2500/kW)		$3,300,000.00
Total Equipment Cost		**$9,851,712.00**
Construction & Civil Costs	20%	$1,970,342.40
Installation	25%	$2,462,928.00
Piping	5%	$492,585.60
Electrical	15%	$1,477,756.80
Subtotal 1		**$16,255,324.80**
Contractor or Overhead & Profit	20%	$3,251,064.96
Subtotal 2		**$19,506,389.76**
Contingency	25%	$4,876,597.44
Subtotal 3		**$24,382,987.20**
Engineering, Admin, & Legal	20%	$4,876,597.44
Total Project Cost		**$29,259,584.64**

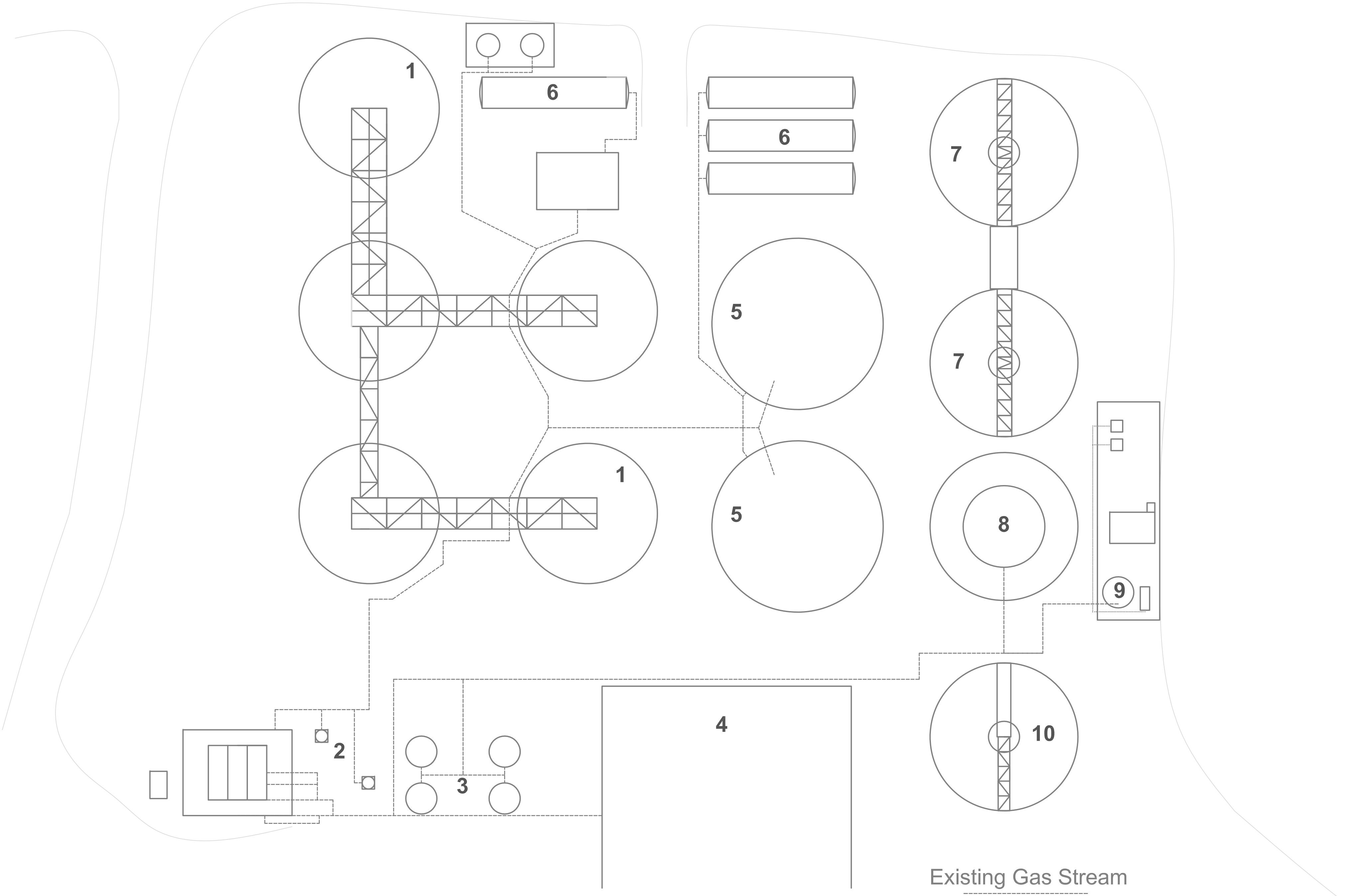


Data

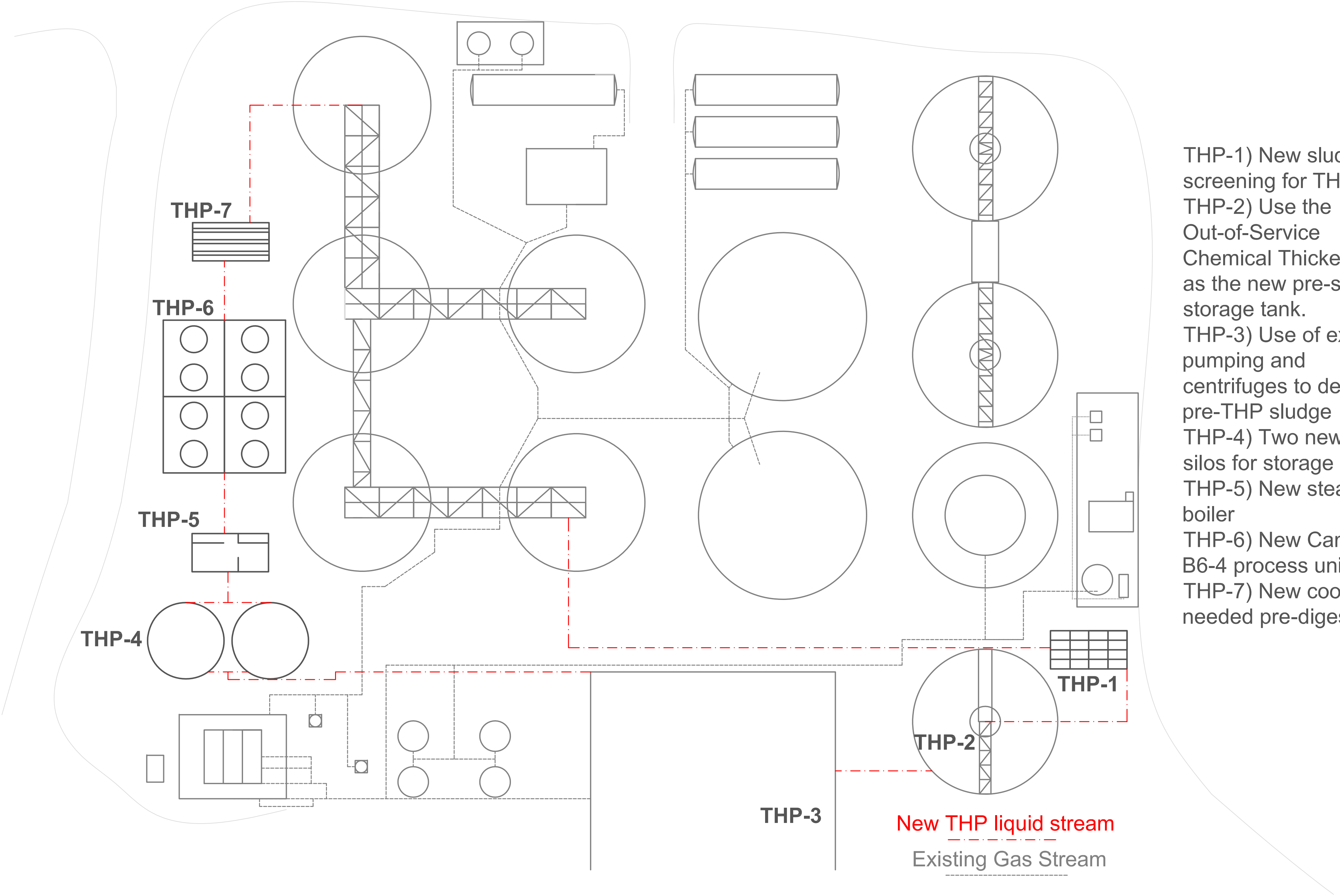
Reactor size: 6 m^3
Typical footprint: 8 m x 10 m
Typical height: 7.5 m
Suitable for: 250 000 - 1 000 000 p.e.

Model	B6-2	B6-3	B6-4
Number of reactors	2	3	4
Peak capacity (tDS/day at 16.5% DS)	40	60	80
Design capacity (tDS/year)	6 400 - 13 900	13 900 - 20 800	20 800 - 28 000

Figure A1. Detailed Parameters on the Cambi THP system [36].



1 - Anaerobic Digester (5)
2 - Waste Gas Flare (2)
3 - FOG Receiving Tank (4)
4 - RDTS, Centrifuges, Boilers, etc.
5 - Sludge Storage Tanks (2)
6 - Pressurized Gas Storage Tanks (4)
7 - Chemical Thickeners (2)
8 - WASSTRIP Tank
9 - Odor Scrubber
10 - Out-of-Service Chemical Thickener



THP-1) New sludge screening for THP
THP-2) Use the Out-of-Service Chemical Thickener(10) as the new pre-sludge storage tank.
THP-3) Use of existing pumping and centrifuges to dewater pre-THP sludge
THP-4) Two new cake silos for storage
THP-5) New steam boiler
THP-6) New Cambi B6-4 process unit
THP-7) New coolers needed pre-digester