Evaluation of Energy Recovery Options for Conversion of Aerobic Digesters to Anaerobic Digestion

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This article discusses a case study in Florida for evaluating the conversion of an aerobic digestion system to anaerobic digestion with a focus on energy recovery. The 'threshold' facility size for implementing anaerobic digestion has been debated and depends on several factors, including process considerations.

By utilizing a cost model developed for the baseline project, we can examine the economic viability of various sized projects. The benefits of implementing a biosolids energy recovery project depend on several factors that include facility size, sludge composition, digestion process selection, and the energy recovery method.

The Hillsborough County *Digester System Improvements Evaluation* was completed in May of 2009. The study presented a review of the Hillsborough County Biosolids Management Facility (BMF) aerobic digester operations.

The BMF is a centralized sludge processing facility that produces Class A biosolids. Dewatered biosolids from the county's South/Central Region are contract hauled to the BMF, while liquid sludge is pumped from the Northwest Region's plants directly to the BMF.

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This conceptual level evaluation focused on the liquid component of the sludge received at the BMF from the four wastewater treatment plants located in the Northwest Region: River Oaks Advanced Wastewater Treatment Plant, Dale Mabry Advanced Wastewater Treatment Plant, the Northwest Regional Water Reclamation Facility, and Van Dyke Wastewater Treatment Plant. There is no sludge stabilization provided for the biosolids prior to pumping from these treatment plants to the BMF. Table 1 summarizes the type of sludge and delivery method for each plant.

Table 1 - Wastewater Treatment Plants – Northwest Service Area

No.	Plant Name	Type of Sludge	Delivery Method
1	River Oaks Advanced Wastewater Treatment Plant	Primary and Secondary	Pumped 6 miles
2	Dale Mabry Advanced Wastewater Treatment Plant	Secondary	Pumped 6.5 miles
3	Northwest Regional Water Reclamation Facility	Secondary	Pumped 0.5 miles
4	Van Dyke Wastewater Treatment Plant	Secondary	Trucked

The Hillsborough County Biosolids Management Facility.

Objectives

The objectives of this article are to present a summary of the evaluation performed for the county and to extrapolate the findings for other treatment plants of various sizes. As part of the evaluation, the existing digestion and solids handling processes were summarized. The primary focus was to determine what steps could be taken to improve the digestion process by converting the existing aerobic digestion process to anaerobic digestion so the biogas produced by that process could be utilized as a fuel.

To evaluate the solids processing and provide feasibility level costs, several tasks were required, including:

- Documenting the historic and current wastewater and sludge quantities, and determining projections for further analyses.
- Determining the viability of gas production through analyzing the volatile suspended solids (VSS) content of the sludge received at the BMF.

Table 2 - Comparison of Two-stage Mesophilic Anaerobic Digestion to Aerobic Digestion

Alternative Description	**Advantages**	**Disadvantages**
Two-stage Mesophilic Anaerobic Digestion	✓ No aeration blowers required compared with aerobic digestion ✓ Gas generated can be used as an alternative energy source; heating, power production, supplemental gas for dryer system ✓ Substantial savings on energy costs and lower operations costs ✓ Greater VSS destruction reduces natural gas capacity requirement of the downstream process units	✓ Initial capital costs are high ✓ Must improve GBT performance to thicken sludge up to 5–6% solids ✓ Very sensitive to the adverse effects of lower temperatures ✓ Increased potential of odors and corrosive gas production ✓ New process – will require staff training ✓ High foaming potential ✓ Potential for struvite formation (dependent on bio-P removal)

- Establishing the capacity of the existing digesters based on historic flows and performance.
- Identifying reasonable process alternatives and performing an economic analysis.

Existing Digestions Process

The existing wastewater flows for the county's Northwest Service Area equaled about 20 million gallons per day (mgd) for 2009. This wastewater flow rate represents a sludge production of approximately 17 dry tons per day (dtd). As mentioned previously, the liquid sludge is pumped to the BMF and thickened prior to transfer to the aerobic digestion system.

The sludge is partially stabilized in the four aerobic digesters. Each tank is sized at 1.5 million gallons for a total volume of 6 million gallons.

After digestion, the sludge is pumped to centrifuges and dewatered to approximately 18 to 20 percent dried solids. The dewatered sludge then is conveyed and pumped to the BMF's dryer facility where it is dried to approximately 92 percent dried solids. The fuel source for the two rotary drum direct dryers is natural gas.

The final Class A dried pellet product is stored and then transported for beneficial reuse. Because the dryer equipment relies totally on purchased natural gas, the study looked at the viability of utilizing biogas for process heating and fuel for drying.

Process Alternatives

Currently the liquid sludge received at the Hillsborough County BMF is partially stabilized in four aerobic digesters operated in a "draw and fill" mode. To understand the available process technologies, several types of anaerobic digestion processes, including mesophilic (single-stage and two-stage high rate processes), thermophilic, temperature phased digestion (TPAD), and enhanced digestion processes were reviewed.

Some of the processes reviewed were considered "leading edge" technologies because they have been applied in relatively few plants or as prototypes; however, the growing interest in the biosolids industry suggests that these technologies may become more common in the future. Other processes reviewed can be costly or not reliable in some cases, or they may have operational or maintenance issues, while still others may not be adaptable for certain locations and conditions.

The enhanced digestion processes generally include high temperatures and/or pressures to accelerate the hydrolysis biochemical reaction in the anaerobic digestion process. These processes are attractive because of their potential for increased gas production capabilities; however, they may be best suited for larger installations because of their relatively high capital costs and complex operations.

While each process has its merits and limitations, a straightforward comparison was completed in an effort to select an anaerobic digestion process to conduct a conceptual-level economic analysis. The process comparison included the following criteria, which were scored with respect to Hillsborough County's objectives:

- Project Capital Costs
- Operation and Maintenance Costs
- Volume Reduction
- Potential for Supplemental Gas Production
- Risk Factors (health and safety)
- Complexity of Operation

It is important to note that each facility will have its own unique requirements and the scoring and evaluation of potential process changes must consider these. Based on the scoring for this project, and considering the county's existing facilities, two-stage anaerobic digestion (mesophilic) was selected to complete the economic analysis.

Table 2 presents some of the advantages

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and disadvantages for the selected process modifications:

Once the anaerobic digestion process was selected, capital costs and operations and maintenance (O&M) costs were developed using a spreadsheet model. This evaluation of the County's BMF provided the 'baseline' project, which represents an approximate wastewater flow of 20 mgd.

In an attempt to focus on the feasibility of anaerobic digestion with gas recovery, the study made the following general assumptions:

- Conversion from existing aerobic digestion to anaerobic digestion (two-stage mesophilic process).
- Utilize existing digestion tanks for conversion to anaerobic process.
- Existing tank volume is adequate for 20+ days solids retention time (SRT).

The recommended modifications for the county's sludge digestion process, as well as the respective design criteria, are discussed below. Conceptual level costs for capital and O&M are presented as annual costs for comparison.

Baseline Project Definition: 2-Stage Mesophilic Anaerobic Digestion

Information from the county's *Digester System Improvements Evaluation* project was used as the baseline project for estimating the capital and O&M costs, as well as potential gas production and revenues. Information and data gathered for this report was extrapolated for a range of facility sizes using the cost model developed for the baseline project.

The various components that are required for conversion from aerobic to anaerobic process (two-stage mesophilic process) are outlined in the following paragraphs. For this project, it is assumed that the existing aerobic digestion process would be changed to an anaerobic process by modifying three of the four existing digester tanks. The modifications would include rehabilitation of the existing tanks to include additional piping and gas draw-off connections, mixing systems, yard piping modifications, and other items. To meet stabilization requirements, two process tanks are required with a third tank used for storage and flexibility in a "fill and spill" configuration.

The process hydraulic retention time (HRT) required for this alternative is used for stabilization and gas production. The gas produced by the system could be used for heating the proposed anaerobic digestion system and potentially for supplementing the existing heat drying process.

Here are the conceptual level design criteria for the baseline project:

<u>CONCEPTUAL LEVEL DESIGN CRITERIA</u>

- Thickened Sludge Flow: approximately 121,000 gallons per day (gpd)
- Design Thickening Requirements: 5.5 percent
- Solids Retention Time/Process Configuration with two tanks + one storage:
  - ✓ First Stage = 26 days
  - ✓ Secondary Digester = two to four days
- VSS destruction: 30 to 50 percent (varied for economic evaluation)
- Sludge Average Temperature: 70° Fahrenheit
- Treatment Process Temperature: Mesophilic (85° to 100° Fahrenheit)
- Heat exchanger heat transfer coefficient: 0.9 to 1.6 KJ/meter2
- Mixing pumps: 0.025-.04 horsepower/1,000 gallons of digester volume
- Mixing Pumps per tank: two pumps
- Turnover Time of tank contents: 20-30 minutes
- Velocity Gradient (G): 50-80 S-1

The process and equipment changes described for the following areas are required for conversion from aerobic to anaerobic digestion for the baseline project developed for the county; however, the overall requirements for a digestion process change at a typical aerobic digester facility would be similar and may include, but may not be limited to, the following:

<u>PROCESS/EQUIPMENT CHANGES</u>

Area 1 – **Sludge Holding Tanks**

Sludge holding tanks structural rehabilitation – repairs.

Replacement of the sludge holding tanks aeration blowers – same capacity.

Area 2 – **Sludge Pumping and Thickening**

Replace/rehabilitate sludge thickener feed pumps.

Area 3 – **Sludge Digester**

Modify three existing aerobic digesters to anaerobic digesters. Two process tanks and one storage tank for operational flexibility. Modifications to tanks will include gas collection piping, vacuum relief valves, and flame traps.

Overflow piping from primary/process digesters to secondary digester.

New pump mixing system for three tanks (two process tanks and one storage tank). Modifications will include piping to transfer sludge between digester tanks.

Feed piping additions and control valves for sludge feed control and other appurtenances required to control and monitor the process.

Area 4 – **Gas and Heating Management Area**

Sludge heating equipment including heat exchanger and boiler system. This system would be heated by gas generated by the anaerobic digestion process.

Addition of gas management system including storage, gas treatment, gas monitoring equipment, etc.

Heat exchanger equipment and excess waste heat sink.

Area 5 – **Combined Heat and Power (CHP)**

Addition of engines for electrical power production and waste heat recovery.

As mentioned previously, the Hillsborough County BMF includes sludge drying using purchased natural gas as fuel. For this analysis, it is assumed that new CHP systems would utilize the biogas for electricity production and the waste heat would be used for digester heating. For this analysis, CHP is se-

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lected based on its reliability and common use. In addition to CHP, direct-drive systems are also an alternative for utilizing biogas. Direct-drive applications have relatively high efficiencies and include directly using biogas to run the primary mover, such as pumps or blowers. While this technology has been used at wastewater treatment plants, it is not evaluated here for the sake of simplicity, and because of its less-than-dependable results.

The economic analysis for the 'baseline' project includes the following items, considerations, and assumptions:

- Thickening equipment must be added or upgraded.
- Utilization of waste activated sludge (WAS) only.
- Biogas is used by the CHP system for electricity production with waste heat used to heat the digestion process.
- Excess heat produced by the CHP system is wasted.
- Digested WAS has a 70-percent VSS fraction.
- VSS destruction between 30 and 50 percent.
- Electricity costs, 10 cents/kilowatt-hour
- Gas cost, $1.10/therm
- Electrical efficiency, 30 percent (1)
- Power-to-heat ratio, 64 percent (1)
- CHP capital cost, $2,000/kilowatt-hour (1)
- IC engines maintenance cost, $15/kilowatt-hour/year (2)
- No land acquisition is required.
- Existing aerobic digester tanks can be renovated for use as anaerobic digesters.
- Yard piping complexity must be examined for each facility.
- Cost for supernatant treatment is included because of its return effect on the liquid treatment process.
- Costs for treatment of concentrated return waste streams are included.

Figure 1

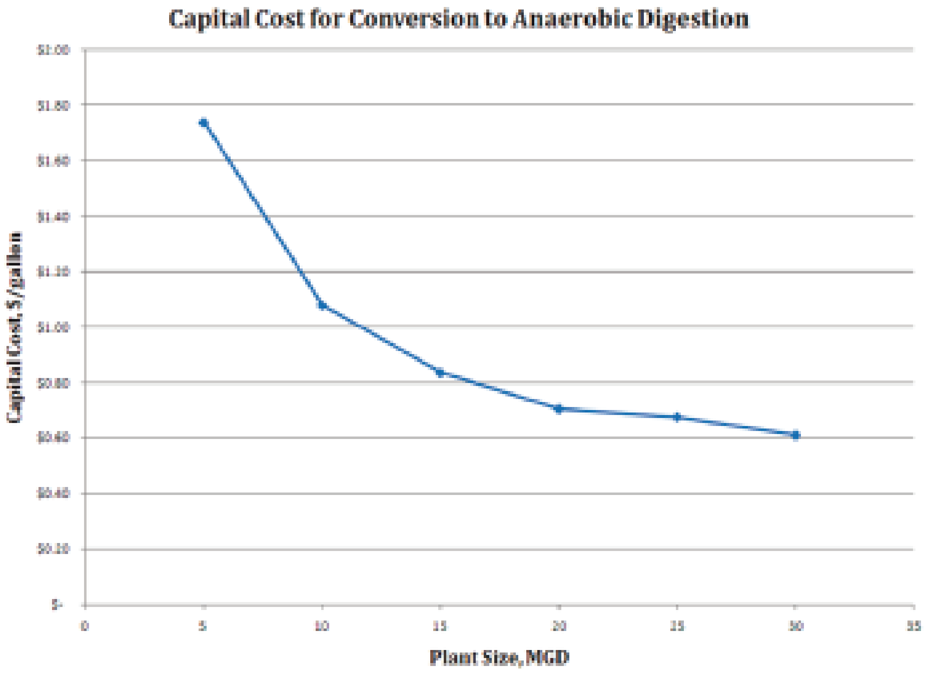
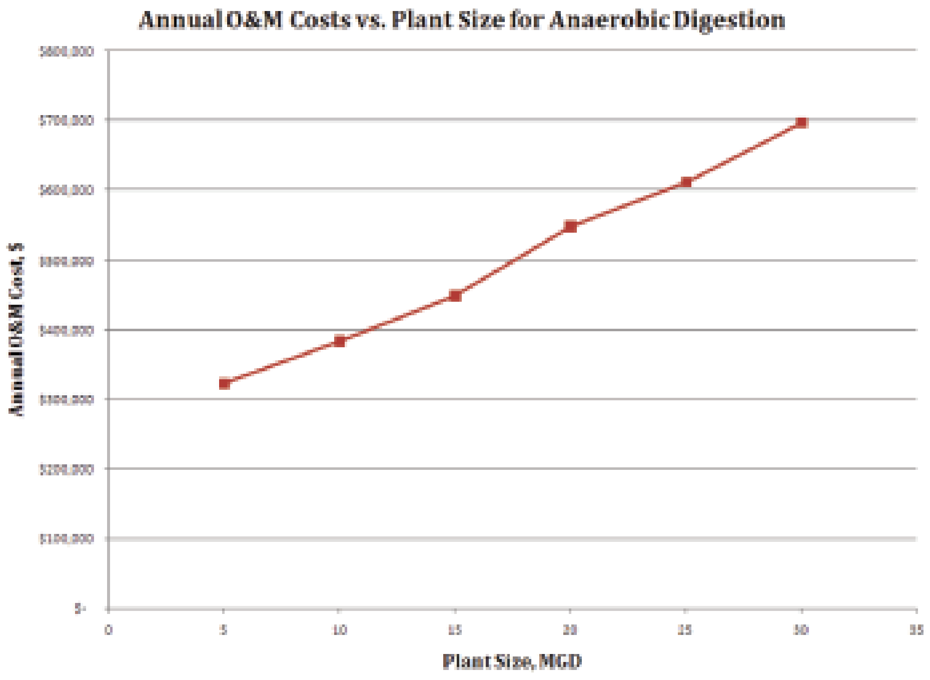


Figure 2



Sources:

(1) EPA: CHP Opportunities and Benefits of Combined Heat and Power at Wastewater Treatment Facilities – April 2007

(2) WERF: An Assessment Tool for Managing Cost-Effective Recovery from Anaerobically Digested Wastewater Solids – 2006

Economic Analysis

The cost model and input data used to determine the costs for the baseline project (approximate 20-mgd treatment plant) were used to develop costs for the 5-mgd and 30-mgd digestion projects.

The capital costs were determined by adjusting the equipment sizes (horsepower and capacity) as well as the number of units necessary for the appropriate sized anaerobic digestion facility. Other capital costs for items such as digester modifications and piping were scaled based on the treatment plant sizes and expected sludge volumes.

The operation and maintenance costs were also input for the 5- and 30-mgd treatment plants based on the cost model used for the 20-mgd baseline project. Once again, the input data was scaled based on the required equipment size/capacity, horsepower, and equipment runtime for that plant size.

For this evaluation, facility sizes for 5 through 30 mgd were selected in 5-mgd increments to determine the practicality of converting to anaerobic digestion with gas recovery. Using the capital and O&M costs developed in the cost model for the 5-, 20-, and 30-mgd treatment plants, trend lines were used to estimate the costs for the remaining sized plants (10, 15, and 25 mgd).

Figure 1 presents the estimated capital

costs for conversion from aerobic to anaerobic digestion. The estimated capital cost in dollars per gallon for the plant sizes show the expected 'economy of scales' for the various sized facilities. The approximate costs for the 5-mgd and 30-mgd treatment plants are $1.75 per gallon and $0.60 per gallon, respectively.

Figure 2 presents the annual O&M costs for anaerobic digestion versus plant size.

For anaerobic digestion with gas recovery to be successful, the VSS fraction and VSS percent destruction are critical. For this evaluation, only WAS is assumed to be digested, which is a worst-case scenario because it is well known that WAS has a much lower gas production potential than primary sludge. Tables 3-5 present the biogas production with resultant energy production and estimated revenues for 30-, 40- and 50-percent VSS destruction.

Based on the preliminary estimates for power and heat revenues generated from the recovery of the biogas, it is evident that the VSS fraction in the digested sludge is critical. The straight-line increase in revenues from 30 percent to 50 percent VSS fractions results in a 67 percent increase in revenues.

It should be noted that additional heat is available and must be wasted if not used. This analysis assumes that much of the excess heat

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Table 3 - Energy/Heat Production and Revenues for 30% VSS Destruction

Plant Size (AADF MGD)	Energy potential per day	Gas usage for digestion	Electricity produced-using an IC Engine	Heat recovered from CHP system	Excess heat Available	Electrical revenue	Heat generation revenue
	(BTU/day)	(BTU/day)	(kW)	(BTU/day)	BTU/Day	($/year)	($/year)
5	16,077,852	3,215,570	59	7,536,493	4,320,923	$ 51,598	$ 30,259
10	32,155,704	6,431,141	118	15,072,986	8,641,845	$ 103,196	$ 60,518
15	48,233,556	9,646,711	177	22,609,479	12,962,768	$ 154,794	$ 90,777
20	64,311,408	12,862,282	236	30,145,973	17,283,691	$ 206,392	$ 121,036
25	80,389,260	16,077,852	295	37,682,466	21,604,614	$ 257,990	$ 151,295
30	96,467,112	19,293,422	353	45,218,959	25,925,536	$ 309,588	$ 181,554

Table 4 - Energy/Heat Production and Revenues for 40% VSS Destruction

Plant Size (AADF MGD)	Energy potential per day	Gas usage for digestion	Electricity produced-using an IC Engine	Heat recovered from CHP system	Excess heat Available	Electrical revenue	Heat generation revenue
	(BTU/day)	(BTU/day)	(kW)	(BTU/day)	BTU/Day	($/year)	($/year)
5	21,437,136	4,287,427	79	10,048,658	5,761,230	$ 68,797	$ 40,345
10	42,874,272	8,574,854	157	20,097,315	11,522,461	$ 137,595	$ 80,691
15	64,311,408	12,862,282	236	30,145,973	17,283,691	$ 206,392	$ 121,036
20	85,748,544	17,149,709	314	40,194,630	23,044,921	$ 275,189	$ 161,381
25	107,185,680	21,437,136	393	50,243,288	28,806,152	$ 343,987	$ 201,727
30	128,622,816	25,724,563	471	60,291,945	34,567,382	$ 412,784	$ 242,072

Table 5 - Energy/Heat Production and Revenues for 50% VSS Destruction

Plant Size (AADF MGD)	Energy potential per day	Gas usage for digestion	Electricity produced- using an IC Engine	Heat recovered from CHP system	Excess heat Available	Electrical revenue	Heat generation revenue
	(BTU/day)	(BTU/day)	(kW)	(BTU/day)	BTU/Day	($/year)	($/year)
5	26,796,420	5,359,284	98	12,560,822	7,201,538	$ 85,997	$ 50,432
10	53,592,840	10,718,568	196	25,121,644	14,403,076	$ 171,993	$ 100,863
15	80,389,260	16,077,852	295	37,682,466	21,604,614	$ 257,990	$ 151,295
20	107,185,680	21,437,136	393	50,243,288	28,806,152	$ 343,987	$ 201,727
25	133,982,100	26,796,420	491	62,804,109	36,007,689	$ 429,984	$ 252,158
30	160,778,520	32,155,704	589	75,364,931	43,209,227	$ 515,980	$ 302,590

Figure 3

CHP Revenue for Various VSS Destruction Percentages

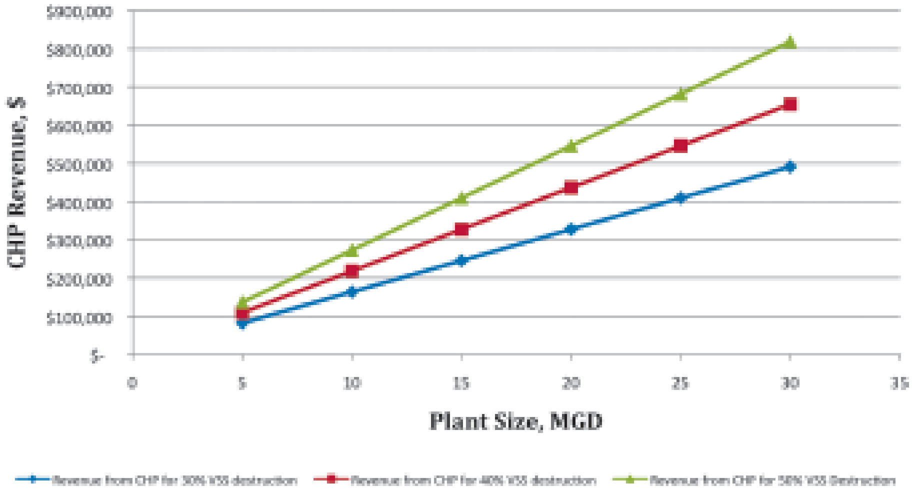
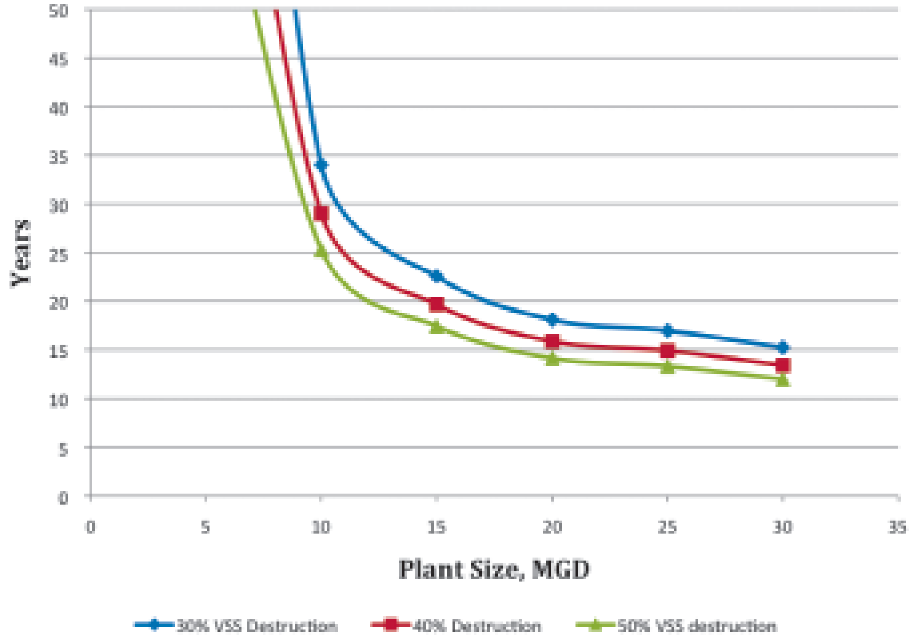


Figure 4

Plant Size vs. Payback Period



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available is wasted and no revenue is recovered, which is typical for Florida, but there are options available for additional heat recovery, such as chillers, HVAC units, etc., that were not evaluated as part of this study.

Figure 3 presents the revenues expected from CHP systems based on electrical power production and waste heat recovery for 30, 40, and 50 percent VSS destruction. As expected, the revenues increase substantially for larger plants with greater VSS destruction.

Figure 4 presents the payback periods expected for the various sized projects for the three VSS destruction percentages. While the preferred short payback periods are not evident, the figure does show that there is a clear economic tipping point for treatment plants of about 12 to 15 mgd and larger, based on the assumptions presented herein. This seems to validate the perceived view of treatment plant size for anaerobic digestion, although the VSS fraction and destruction percentage are critical.

By implementing an anaerobic digestion process the following benefits can be realized:

- Reduced biosolids mass and better stabilization of the biosolids.
- Reduced power requirements through the elimination of the large aeration requirements for the aerobic digestion process.
- A reduction in hauling costs, if applicable, due to reduced biosolids mass from anaerobic digestion.
- A sustainable energy source (digester gas) to reduce the facility's carbon footprint and offset natural gas and power usage.

Before a digestion process change can be implemented, several items must be evaluated for the specific facility considered for the process change. A preliminary design scope of work should include the following items:

- Confirm the sludge VSS fraction for the influent sludge.
- Structurally inspect the existing digester tanks to ensure that they can be retrofitted for use as anaerobic digesters.
- Confirm energy balances and heat transfer efficiencies to validate cost savings form gas production.
- Determine the best configuration and location of the proposed equipment and facilities, including process and electrical.
- Perform an evaluation of the existing equipment's condition and need for replacement.
- Perform an economic evaluation for capital and O&M costs to verify the recommended project's viability.