Hazen

GOLETA SANITARY
Water Resource Recovery District

Biosolids and Energy Strategic Plan

FINAL

August 2019

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EXECUTIVE SUMMARY

Goleta Sanitary District (GSD) is committed to being good community stewards of public health, the environment and public funds. This commitment includes a vision for diversifying biosolids beneficial use options and pursuing energy self-sufficiency practices and can only be accomplished by vigilant consideration and planning years ahead.

GSD owns and operates Goleta Water Resource Recovery Facility (WRRF) with an annual current average daily flow of ~5 MGD, and about 6 dry tons per day combined primary and WAS solids currently produced. Figure 1 shows the solids processing flow schematic. The dewatered, Class B biosolids are hauled to King County for beneficial use.

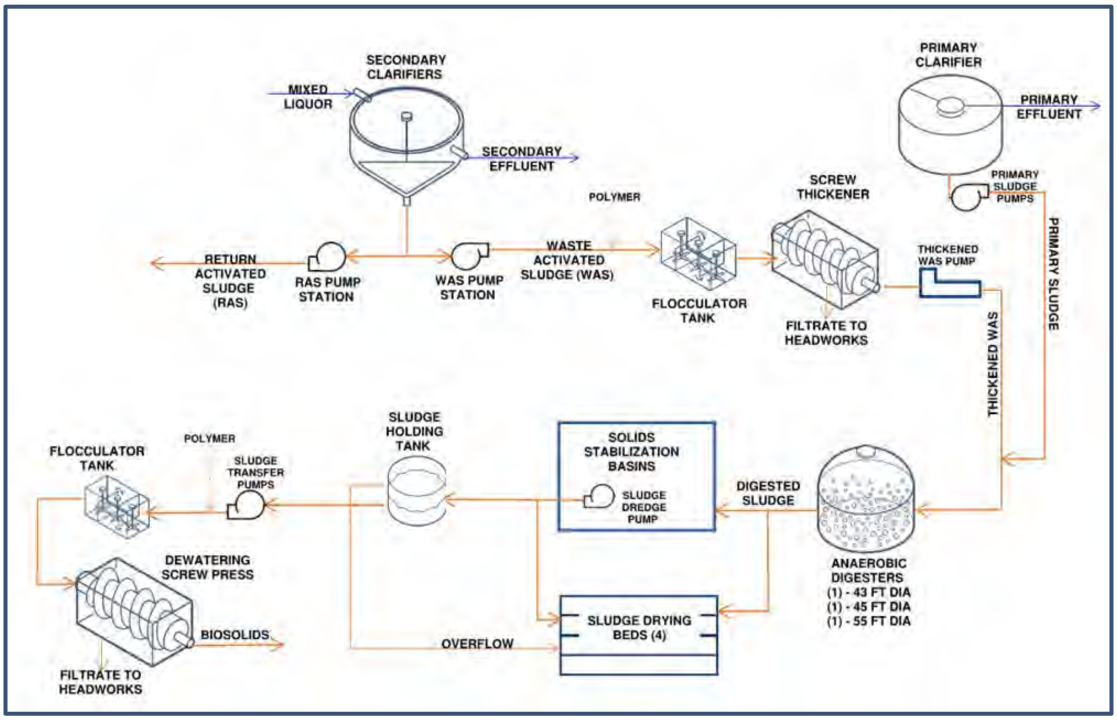


Figure 1. Solids processing flow diagram

Defining clear priorities and risks for GSD and identifying the project drivers are critical in developing a successful plan. Future risks facing the GSD includes significant increase in energy costs, loss of the one existing biosolids beneficial use outlet, increased pressure from the regulatory and environmental stakeholders on beneficial use of biosolids and imposed sustainable practices mandates. To mitigate these future risks, GSD has established several strategic goals for the Biosolids and Energy Strategic Plan (BESP).

- Minimize practice exposure to regulatory uncertainty and future changes.
- Diversify biosolids beneficial use outlets and market options.
- Achieve plant wide energy neutrality through effective use of on-site energy production strategies (i.e., biogas utilization, solar).
- Evaluate the benefits of High Strength Waste (HSW) codigestion.

- Reduce annual operating costs.
- Reduce carbon footprint.

OBJECTIVES

The main objective of the BESP was to provide a biosolids and energy roadmap and strategy for GSD to reach energy-sufficiency by reassessing their biosolids management practices in combination with numerous energy production approaches (energy generation, utilization, storage, and renewable energy sources). The planning horizon is established for year 2043.

Biosolids and energy management strategies cannot be studied separately as they are closely related. Biosolids contain most of the energy that can be recovered from wastewater treatment through anaerobic digestion. Furthermore, the anaerobic digestion process offers the ability to process imported high strength waste material (HSW) for recovering more energy with biosolids processing. Any changes in solids handling processes, especially in digestion have an impact on produced biogas quality and quantity and eventually change the potential energy production.

OVERVIEW OF THE STUDY

Hazen proposed the study be structured in five distinctive phases as shown in Figure 2, for arriving at the BESP that balances future risks and priorities identified. Each phase can be considered as a building block for the subsequent phase.

PHASE I	PHASE II	PHASE III	PHASE IV	PHASE V
Conduct Biosolids End Use Market Study and UCSB HSW Assessment	Identify Biosolids Current and Future Capacity and Potential Energy Production	Evaluate Methods for Increase Digestion Capacity Options and Increased Energy Production	Evaluate Methods for Producing Class A Cake and Dried Material and Associated Energy Production	Biosolids and Energy Strategic Plan Development

Figure 2. Strategic biosolids and energy plan phases

PHASE I: BIOSOLIDS END USE MARKET STUDY

Hazen teamed with Material Matters to conduct a regulatory review and preliminary biosolids market assessment for locally available markets for each of the products, starting the BESP with end use in mind. The Class B products evaluated included anaerobically digested cake (existing product) and selected Class A/EQ products. Class A/EQ products under consideration included: TPAD cake; anaerobically digested and thermally dried biosolids, anaerobically digested and composted biosolids, and thermally hydrolyzed, liquid biosolids (with the Lystek technology). The findings associated with the market assessment indicated that beneficial use of Class B biosolids cake for agriculture and/or reclamation was not a viable outlet for various reasons. Hence, Material Matters did not recommend further consideration of Class B cake beneficial use. However, processing Class B cake into compost at GSD appeared to be a viable option with suitable market partners and local outlets. Other short-term options that were recommended for GSD were identified as offsite composting and thermal drying.

PHASE II: CAPACITY ASSESSMENTS WITH AND WITHOUT HIGH STRENGTH WASTE

Phase II established the biosolids system capacity for the current and future loads. The results showed that existing anaerobic digesters did not have firm capacity if operated at current conditions. Increasing the solids content of combined primary sludge and TWAS by enhancing the performance of screw thickeners, would provide firm capacity to GSD's WWTP. Availability of source separated food waste (FW) from University of California Santa Barbara, and Fats, Oils and Grease (FOG) were evaluated. Taking into account the findings from the current and future biosolids capacity, with and without high strength waste (HSW) stream (including both FW and FOG), and on-site energy generation and storage options, a cost/benefit analysis was performed to understand the value of co-digesting a HSW and the capital required to construct a food waste receiving station. The results indicated that co-digesting HSW was a financially feasible alternative that should be carried forward as a part of the BESP. Co-digesting HSW without a beneficial use for the biogas would not provide a payback for the receiving facility within the 20-year planning period at the projected HSW quantity and tipping fees. However, revenue generated from the additional biogas produced from HSW would provide a payback between 9 to 17 years depending on the biogas utilization strategy used (i.e. CHP) and the long-term tipping fee.

PHASE III: METHODS FOR INCREASED DIGESTION CAPACITY AND ENERGY PRODUCTION

This phase evaluated four different alternative scenarios to increase digestion capacity and enhance biogas production while leveraging existing assets. Although there are a wide variety of technologies available to achieve these two goals, due to the relatively small size of the facility the following four options were selected for GSD: 1) PONDUS thermochemical hydrolysis, 2) Lystek Refeed (LysteMize), 3) Recuperative Thickening, and 4) Construction of a New Digester.

Figure 3 presents the alternative treatment processes that can achieve increased digestion capacity and energy production, (a) PONDUS, (b) Lystek refeed (LysteMise™), and (c) recuperative thickening.

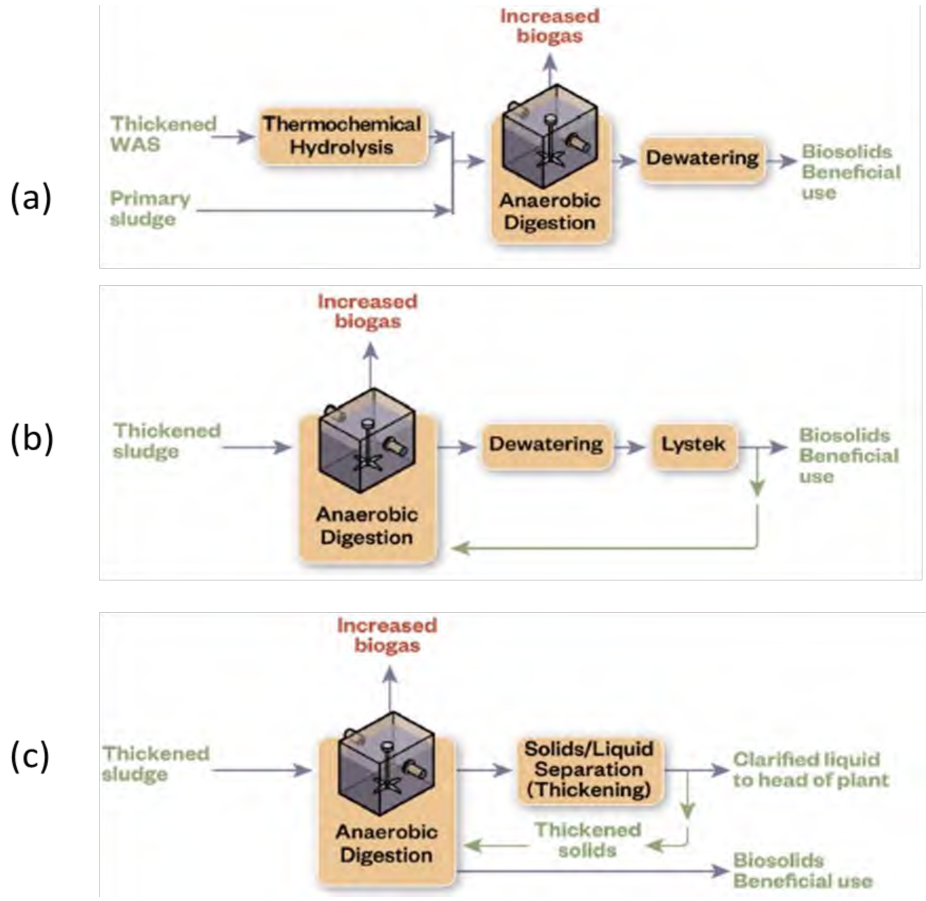


Figure 3. Diagram of the three processes for increased digester capacity and energy production

Thickened Waste Activated Sludge Hydrolysis (PONDUS)

A thermochemical hydrolysis process -PONDUS- can be applied only to TWAS through heating to 65 to 70^{o}C and raising pH to ~ 11 with caustic soda addition. The chemical and heat pretreatment increases the COD solubilization. This results in decreased viscosity, enhanced digestion mixing and increased digester solids loading rate with more biogas production.

Dewatered Cake Hydrolysis (Lystek Re-feed)

In the Lystek process, the hydrolysis is applied on the dewatered cake solids after the screw presses. A portion of the treated biosolids is recycled back to the anaerobic digestion process. GSD is currently housing a pilot Lystek unit that could be used in validating the benefits of this practice where the recycle from the Lystek treatment is increased in a stepwise manner from 10 to 50% of the dewatered cake.

Recuperative Thickening

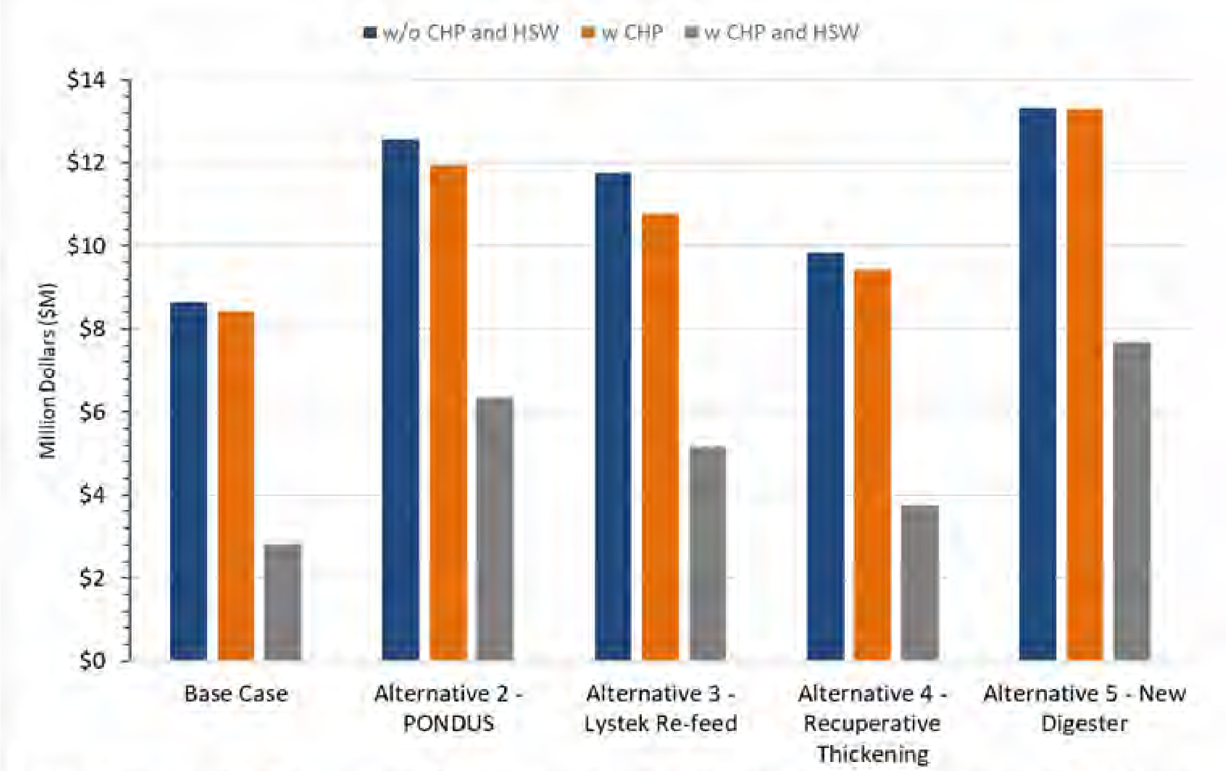
Recuperative thickening is a process, where a stream of the digested biosolids is processed through a mechanical thickening device and recycled to the digester to increase the solids retention time, allowing further solids digestion. This process has been shown and demonstrated to increase digestion capacity. GSD would also benefit by gaining firm capacity by applying recuperative thickening.

Increased Digestion Capacity and Energy Production Evaluation Results

For each alternative, the amount HSW that can be processed, the amount of biogas and energy generated, the impact of the technology on dewatering and solids generation, and construction and operational and maintenance (O&M) costs including Net Present Value (NPV) was evaluated. The results of this evaluation are shown in Figure 4, which summarizes the overall economic benefit of each alternative scenario with biogas beneficial use. Each alternative scenario was modeled with a CHP system included and sized to maximize the utilization of biogas generated by each alternative scenario, with and without HSW addition, at total capacity (i.e., three digesters online). It should be noted that only alternative scenarios 4 and 5 provide firm capacity (i.e., two digesters online) to accept the available HSW. Base Case scenario, alternative 2, and alternative 3 do not have firm capacity for HSW addition. Therefore, the economics provided in Figure 3 are valid for firm capacity except for recuperative thickening and constructing new digester.

Figure 4 shows that Base Case scenario and all the alternatives evaluated in this study resulted in a 20-year NPV cost indicating more than 20 years of payback period. Codigestion HSW as well as beneficial biogas utilization lowers the overall project costs, however, the payback periods would still exceed 20 years.

Table 1 compares the four alternatives for implementation at GSD with the base case scenario, noting that the base case scenario is not a sustainable practice for the future.



Note: Base Case, PONDUS and Lystek Technology alternatives do not meet the firm capacity when practiced and would need to be combined with either recuperative thickening or new digester to meet firm capacity.

Figure 4. 20-Year NPV Digester Capacity and Biogas Increase Alternatives.

Table 1. Advantages and Disadvantages of Each Alternative Scenario

Alternative	Advantages	Disadvantages
Base Case Scenario	• Without implementing codigestion, the Base Case scenario has the lowest NPV compared to the alternatives evaluated. • No additional cost related to solids processing.	• Does not provide firm capacity by 2028. • Does not provide additional capacity. • Does not enhance biogas & energy generation. • Not a sustainable practice.
Alternative 2 PONDUS	• Reduces solids generated and the hauling costs. • Increases biogas and energy generation.	• Does not provide firm digester capacity by 2028. • Does not increase the amount of HSW that can be received. • Additional personnel may be required to operate.
Alternative 3 Lystek Refeed	• Reduces biosolids generated and the hauling costs. • Increases the biogas and energy generation.	• Does not provide firm capacity. • Reduces the amount of HSW that can be received. • Additional personnel maybe required to operate.
Alternative 4 Recuperative Thickening	• Provides firm capacity until 2043. • Enhances the capacity of digestion and would allow GSD to receive higher amounts of HSW • Requires the least space requirement compared to all other alternatives evaluated. • Cost effective compared to other alternatives. • No additional personnel training to operate additional thickener. • Minimal modifications to existing utilities and operation procedure. • Slight reduction in solids generation	• Does not benefit the gas and energy generation as much as PONDUS and Lystek Technologies.
Alternative 5 New Digester	• Provides firm capacity until 2043. • Enhances the capacity of digestion and would allow GSD to receive higher amounts of HSW. • No additional personnel training and the least complex operation among all alternatives evaluated.	• Does not enhance the gas and energy generation. • Solids generation remains the same as Base Case. • Requires significant space.

PHASE IV: METHODS FOR ACHIEVING CLASS A BIOSOLIDS AND ASSOCIATED ENERGY PRODUCTION

The biosolids end use market study found that evaluating Class A/EQ technologies with a focus on producing compost and thermal dried material had the most viable opportunities. GSD was also interested in evaluating the Lystek process. Considering the size and capacity of the facility, four main processes were identified. These are Thermal Drying, Solar Drying, Composting and Lystek Class A – LysteGro™.

Thermal Drying

Indirect thermal drying, such as belt drying or paddle drying, achieves dryness of greater than 90% for Class A biosolids production. Indirect thermal drying is proposed due to the size of the facility and ability to use waste heat from practicing a CHP system.

Solar Drying

Solar drying uses an engineered greenhouse system to dry the dewatered biosolids to greater than 90% and achieve Class A material. GSD currently utilizes drying beds for a small amount of their produced biosolids and could expand to dry all the dewatered biosolids. The high area requirement can be reduced by using waste heat from practicing CHP. More testing and certification may be required to ensure the end product meets EPA Class A requirements.

Composting

A composting unit after dewatering process will generate a marketable, Class A product that can be used as a soil conditioner. In-vessel composting technology was evaluated as it provides a smaller footprint and addresses odor and emission related issues. Composting was assessed based on a preliminary evaluation including the assessment of site restrictions, weather conditions, degree of process control desired, bulking agent availability and ultimately capital and operating cost.

Lystek Class A Process

Another Class A technology identified was the Lystek process to generate liquid pumpable product. Lystek is a physical-chemical process that utilizes low temperature thermal hydrolysis under alkaline conditions that transforms raw or digested sludge into a nutrient rich, Class A multi-purpose product called LysteGro™. High speed shearing, alkali addition, and low-pressure steam is applied simultaneously in a single, enclosed reactor to produce a high solids (15% to 17%) product that remains fully pumpable with conventional liquid handling and application equipment. LysteGro is certified as a fertilizer in the State of California.

Class A Technologies Evaluation Results

Energy and mass balances were conducted for each Class A alternative. Prospective vendors were contacted for sizing and planning level budgetary estimates. The evaluation was conducted with and without considering HSW codigestion. Table 2 summarizes the estimated amount of final material produced (with and without HSW), the solids concentration of the final product and the total footprint required for each alternative. Drying alternatives would generate the least amount of final product, followed by composting. The Lystek Class A alternative would increase the solids to be beneficially used, notably due to lower solids concentration compared to other alternatives. Both solar drying and composting would require significantly higher area in comparison to thermal drying and Lystek Class A alternatives.

Table 2. Evaluation Results of Class A Technologies

Class A Alternatives	Current Operation	Alternative 1 – Thermal Drying	Alternative 2 – Solar Drying	Alternative 3 - Composting	Alternative 4 - Lystek Class A Product (LysteGro)
Final Product	Class B	Class A – dried solid	Class A - dried solid	Class A - compost	Class A - liquid
Final Product Solids, %	18%	90%	90%	65%	15%
Final Product Amount, wtpd w/o HSW	24.5	5.0	5.0	19	30
Final Product Amount, wtpd with HSW	26.5	5.8	5.8	22	31
Required Footprint, ft²	NA	2,400	30,000	33,000	5,300

The economic evaluation for the various alternatives was conducted for three conditions: without HSW (FOG & FW) and biogas beneficial use, with biogas utilization, and with HSW (FOG&FW) and biogas utilization. Thermal drying evaluation was conducted using two options: Alternative 1a, the biogas directly to provide the thermal energy need for drying and Alternative 1b, using the waste heat from using the biogas in a CHP system. Figure 5 shows the economic results. The results conclude that solar drying and composting result in the lowest 20-year NPV costs. The results also conclude that HSW codigestion and biogas utilization (CHP) significantly reduce the 20-year NPV costs.

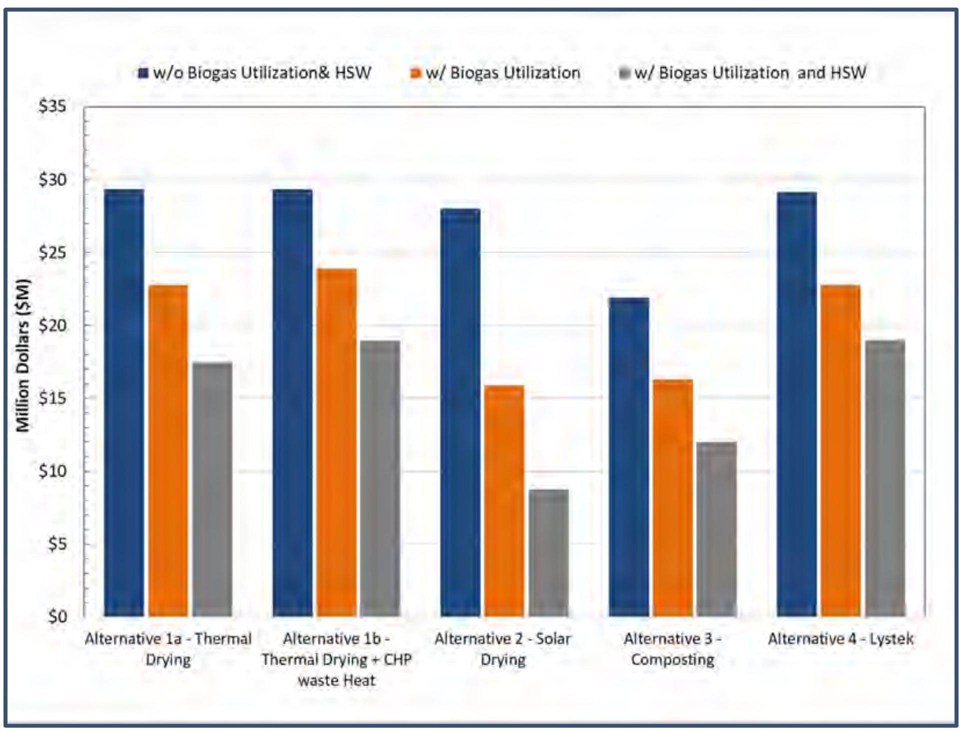


Figure 5. 20-Year NPV for Class A Technologies Evaluated

PHASE V: BIOSOLIDS AND ENERGY STRATEGIC PLAN DEVELOPMENT

In Phase V, shortlisted combinations of technologies from enhanced digestion and increase biogas (Phase III) and technologies for producing Class A were evaluated. The alternative solutions (alternatives) consist of various combinations of technologies discussed in Phases III and IV. Figure 6 shows the process schematic for the GSD solids treatment and the technologies evaluated. The evaluation process was conducted in three steps.

- Step 1 combined all viable alternatives, with each alternative meeting firm digestion capacity and producing Class A material. Where applicable, some alternatives included increased biogas generation and producing Class A material. The combined alternatives were evaluated from a cost perspective to arrive at the top 10.
- Step 2 used non-monetary criteria to evaluate the short-listed alternatives to arrive at the top 6 for detailed evaluation.
- The final step 3 conducted a detailed evaluation of the top alternatives and used the Hazen Converge Multi-Criteria Decision Tool to evaluate the short-listed alternatives in detail.

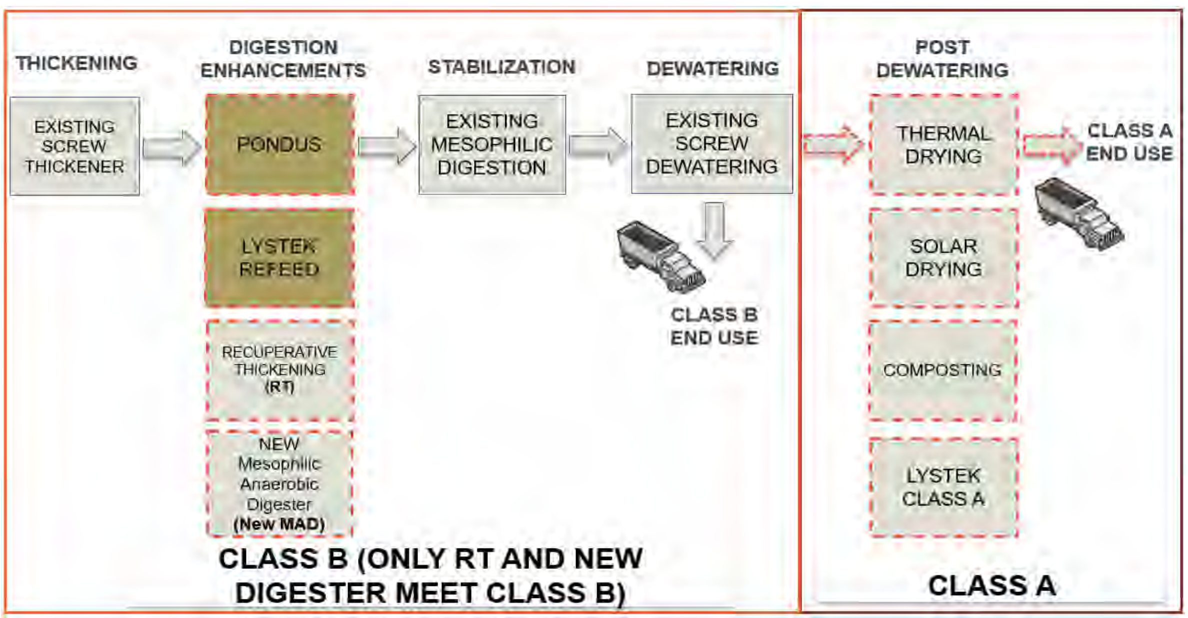


Figure 6. Combination of Biosolids Alternatives Evaluated

<u>Prescreening Results</u>
The combined solutions from Figure 6 resulted in 29 alternatives. The alternatives were combined with HSW codigestion since previous findings showed cost benefits of codigestion. CHP was used as a baseline biogas utilization method.

The cost-based pre-screening evaluation resulted in a shorter list of 10 alternatives presented in Table 3, ranked by lowest to highest Present Worth (PW) value. Interestingly, the pre-screening evaluation resulted in relatively similar results and did not result in the elimination of any technology considered in Phases III and IV. The cost difference between the lowest and the highest cost alternatives was in ± 25%

range. Hence, decision was made to conduct a second step of screening evaluation to include non-economic criteria.

Table 3. Top 10 Alternatives Ranked by PW at 20 years

Ranking	Process	Present Worth at 20 Years
1	RT+ Composting	$25.8 M
2	New MAD + Composting	$28.4 M
3	RT + Solar Drying	$28.6 M
4	PONDUS + Composting	$29.7 M
5	Lystek Refeed + Composting	$29.7 M
6	Lystek Refeed+ Lystek Class A	$29.8 M
7	New MAD + Solar Drying	$31.2 M
8	PONDUS + RT + Composting	$31.7 M
9	LysteMize+ RT+ Composting	$31.7 M
10	LysteMize +RT+ Lystek Class A	$31.8 M

Screening Based on Non-Economic Criteria

In collaboration with GSD staff, the alternatives were evaluated based on the criteria presented in Table 4. These criteria were carefully selected to be in line with the goals defined for the Biosolids and Energy Strategic Plan. Each of technologies (was evaluated and scored separately (raw score) and then multiplied by the weighting factor for a weighted score.

Table 4. Criteria and Weighting Factor

Criteria	Weighting Factor
End use market risk	15%
Technology Maturity	5%
O&M requirement	10%
Space Requirement	10%
Environmental Impacts	10%
Permitting Efforts	10%
Social Community Impacts	10%
Reduce Hauling	15%
Firm Capacity and Reliability	10%
Revenue Generation	5%

For combined alternatives listed in Table 3, the weighted scores were assumed to be additive for this exercise. Furthermore, the total weighted score for each alternative was normalized using the construction cost. The top 6 alternatives results are summarized in Table 5, where the lowest normalized weighted score was considered most favorable. Lystek Refeed combined with RT and Lystek Class A ranked the highest.

The results from Table 5 eliminated solar drying from further evaluation. Due to the large footprint, heat requirement, and the uncertainty of producing Class A product, implementing this process did not appear to be practical. The large footprint requirement for Solar drying could be utilized for solar PV, which could produce a more valuable energy for GSD.

Table 5. Top 6 Alternatives Based on Benefit Cost Analysis

Digestion Enhancement (Increased Biogas and Firm Capacity)	Class A	Capital Cost (Million $)	Total Weighted Score	Normalized Weighted Score Ratio	Ranking
Alternative 1: Lystek Refeed + RT	Lystek	14.7	6.30	2.33	1
Alternative 2: Lystek Refeed + New MAD	Lystek	18.0	5.70	3.15	2
Alternative 3: PONDUS + RT	Thermal Drying	23.4	7.18	3.26	3
Alternative 4: PONDUS + RT	Composting	20.7	6.33	3.27	4
Alternative 5: Lystek Refeed +RT	Thermal Drying	23.7	7.05	3.37	5
Alternative 6: Lystek Refeed + RT	Composting	21.0	6.20	3.39	6

Alternative Solutions Evaluation Methodology

The short-listed alternatives in Table 5 were analyzed in based on detailed mass and energy balances. Figure 7 presents an example of process flow diagrams for Lystek Refeed, Recuperative thickening and Thermal Drying.

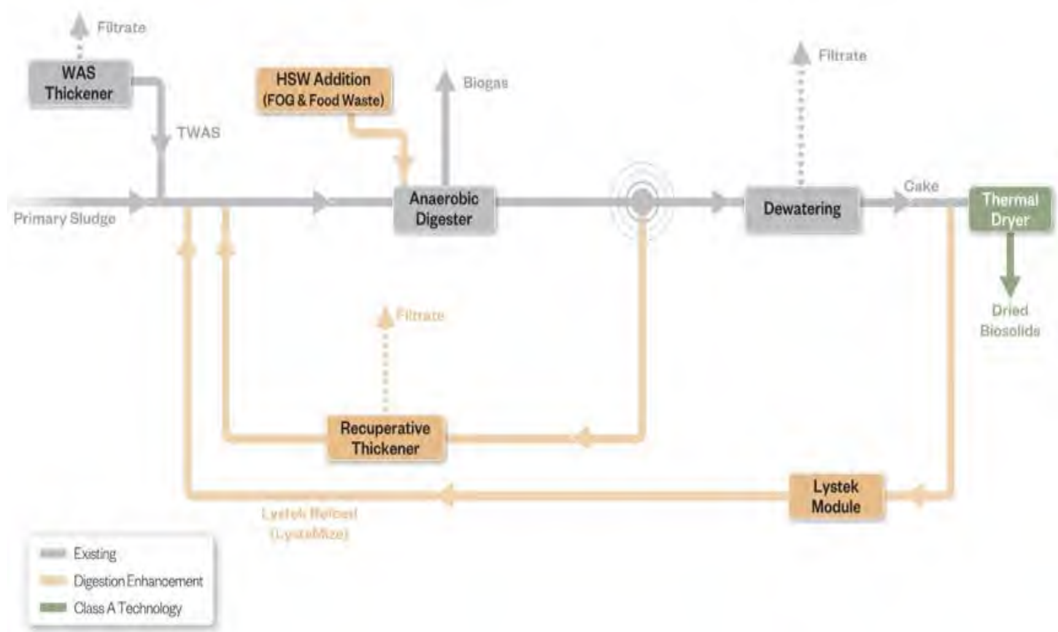


Figure 7. Schematic Diagram with Recuperative Thickening, Lystek Refeed, and Thermal Drying

After conducting an energy balance and considering energy neutrality, implementing Lystek Refeed or PONDUS was found to be not economically viable. Implementation of codigestion to boost energy generation has shown higher benefits than PONDUS or Lystek Refeed. Therefore, Hazen has decided to add the following two alternatives for further evaluation.

- Alternative 7: Recuperative Thickening (RT) + Thermal Drying
- Alternative 8: New MAD + Thermal Drying

After completing detailed mass and energy balances, the results were incorporated in the tool to compare the selected alternatives based on both economic and non-economic criteria. A multi-criteria decision-making tool was used to evaluate the eight alternatives. The identified criteria were grouped into five main categories as shown in Table 6. The weighting for each category, developed in collaboration with GSD staff, is presented in Figure 8.

Table 6. Evaluation Criteria Lumped into Categories

Category	Criteria
Reliability & Resiliency	End Use Market Risk
	Firm Capacity/Reliability
Technical Performance & Simplicity of Design	Technology Maturity
	Process Footprint
	Complexity of Operation and Maintenance
Economic	Capital Costs ($Million)
	O&M Costs ($Million)
	Revenue Generation
	Hauling Cost ($Million)
Environmental	Vector Pathogen Reduction
	Permitting Efforts
	Greenhouse Gas Emissions
Community	Odor Impacts
	Traffic Impacts
	Public Perception and Visual Appearance

Figure 8. Weights for Evaluation Categories

Alternative Solutions Evaluation Results

The results from multi-criteria decision-making tool are shown in Figure 9 for eight alternatives. Higher scores are indicative of higher favorability. As shown in graphical output:

- Recuperative thickening is favored as the process to sustain digestion firm capacity. However, Digester #1 require demolition and constructing a new digester. The remaining life span of the Digester #1 will dictate implementing RT or new digester. Accordingly, both RT and New MAD where considered in the energy neutrality evaluations.
- Either Pondus or Lystek Refeed can be used for increased biogas production.
- Thermal drying is the preferred Class A technology for GSD.

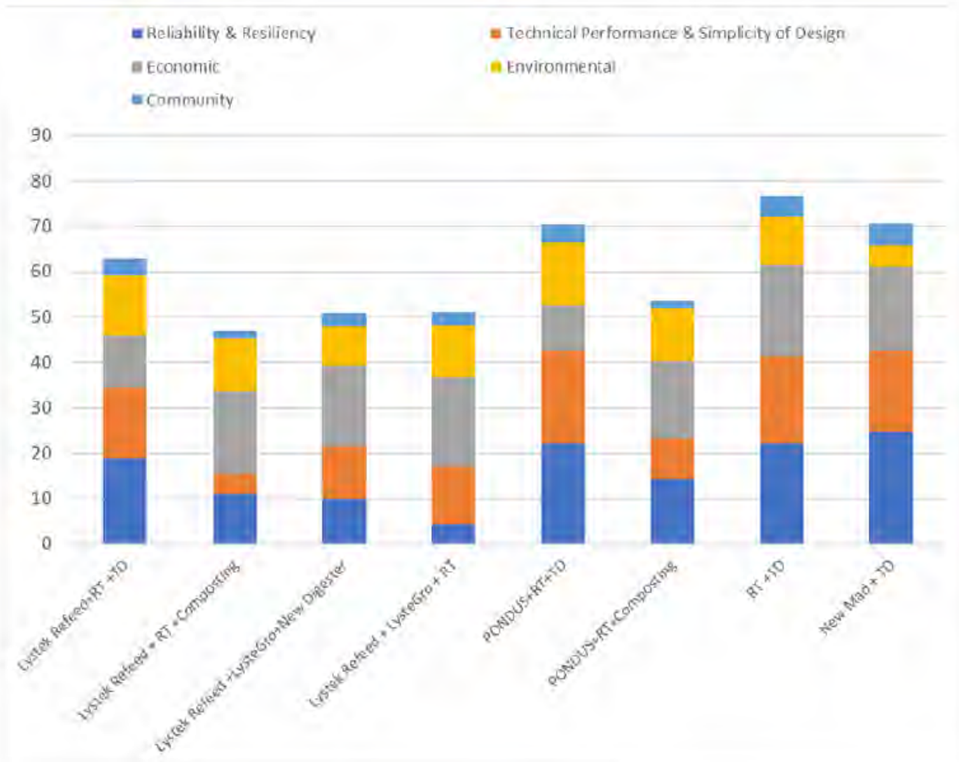


Figure 9. Multi-Criteria Decision-Making Tool Output

Composting and Lystek Class A (LysteGro™) alternatives were eliminated during the May 29, 2019 workshop with GSD. Composting and LysteGro™ will not be considered for the final roadmap for GSD's Biosolids and Energy Strategic Plan for the following reasons:

- Composting would need significant amounts of bulking material continuously.
- The marketing efforts for the compost could be substantial. Currently, GSD does not have the resources to implement an onsite composting program.
- The footprint requirement for composting and storage of finished product requires a much larger area than can be accommodated at GSD's facility.
- The Lystek process produces a high solids pumpable Class A product (LysteGro™) which could be challenging and expensive to haul. In addition, GSD will be dependent on only one outlet to beneficially use the biosolids.

Energy Neutrality Evaluation Methodology

Achieving energy neutrality by implementing technologies and strategies to maximize biogas production and recovery and implementing on-site renewable energy (solar) and energy storage were evaluated. While energy neutrality is a desirable goal, the economic benefit must be in alignment with GSD's economic goals. The technologies focused on energy neutrality explored are:

- Co-digesting FOG/HSW – Increase biogas production and gain FOG/HSW receiving tipping revenue
- PONDUS – Increase biogas production
- Lystek Re-feed – Increase biogas production
- Photo Voltaic (Solar) – On site energy production
- Energy Storage – Manage demand to increase value from on-site energy production (solar).

The energy neutrality evaluations were performed by calculating the ratio between purchased energy and energy recovered/produced onsite. Purchased energy sources included electric and natural gas. GSD currently purchases approximately 3,200,000KWH per year for the WWTP and ~400,000KWH per year for the GSD lift station.

The energy neutrality evaluation results presented here assumes the plant and GSD lift station utility services will be combined for an average annual plant load of 3,600,000 KWH/year.

Energy Neutrality Evaluation Results

Since Thermal Drying was identified as the preferred option for GSD to achieve Class A product, the following energy neutrality evaluations were conducted for the thermal drying option. Tables 7 and 8 summarize the level of energy neutrality for thermal drying without and with CHP, respectively. The results are presented for meeting digester firm capacity with either RT or a New Digester and with increased biogas production using either Lystek Refeed or Pondus. The tables present the results with various combinations for FOG/HSW and Solar PV. Scenarios under 100% are net energy consumers. Scenarios over 100% are net energy producers.

Table 7. Energy Neutrality Summary (Biosolids Drying)

	No FOG/ No Solar		With FOG/HSW No Solar		No FOG/HSW With Solar		With FOG/HSW With Solar	
Process Scenario	Elec Neutrality	Total Energy Neutrality	Elec Neutrality	Total Energy Neutrality	Elec Neutrality	Total Energy Neutrality	Elec Neutrality	Total d Energy Neutrality
Lystek Refeed + RT	0%	45%	0%	57%	21%	55%	21%	66%
New Digester	0%	27%	0%	67%	21%	34%	21%	74%
PONDUS + RT	0%	44%	0%	60%	21%	53%	21%	69%
RT	0%	29%	0%	64%	21%	37%	21%	71%

Table 8. Energy Neutrality Summary (Biosolids Drying & CHP)

	No FOG/ No Solar		With FOG/HSW No Solar		No FOG/HSW With Solar		With FOG/HSW With Solar	
Process Scenario	**Elec Neutrality**	**Total Energy Neutrality**	**Elec Neutrality**	**Total Energy Neutrality**	**Elec Neutrality**	**Total Energy Neutrality**	**Elec Neutrality**	**Total Energy Neutrality**
Lystek Refeed + RT	87%	43%	148%	93%	108%	55%	170%	106%
New Digester	68%	26%	129%	60%	89%	35%	150%	69%
PONDUS + RT	85%	41%	146%	87%	106%	51%	168%	99%
RT	72%	30%	133%	68%	95%	39%	154%	79%

Table 7 shows that Pondus and Lystek Refeed decrease energy neutrality with FOG/HSW codigestion which can sound counterintuitive. The reason for the decrease is described in TM5.

The results presented in Tables 7 and 8 show that without practicing CHP, there is no need to implement either Pondus or Lystek Refeed. However, these biogas enhancement technologies are needed to achieve energy neutrality when implementing CHP.

Energy Neutrality Cost Considerations

It is important to point out that energy neutrality does not result in zero energy costs. An energy cost evaluation using a billing rate model was performed to evaluate the relationship between energy neutrality and energy costs. This evaluation concluded that achieving ~100% energy neutrality results in approximately 65% energy cost reduction. This limited cost reduction is due to the electric utility's billing rate configurations and was accounted for in the economic evaluations.

Energy Recovery Economic Evaluations

The total project 20-year net present (NPV) cost was calculated for each biosolids process scenario and biogas utilization alternative combination (Table 9). The 20-year NPV includes all biogas utilization and biosolids process capital costs, O&M costs, energy revenue, and tipping revenue to account for the total project 20-year NPV cost.

Table 9. 20-year NPV Cost Summary (With FOG/HSW Codigestion)

Process	CHP 20 Year NPV Cost	RNG 20 Year NPV Cost
Lystek Refeed + New Digester + Lystek Class A	$22,100,000	$16,630,000
Lystek Refeed + RT + Composting	$17,670,000	$12,560,000
Lystek Refeed + RT + Lystek Class A	$19,000,000	$13,890,000
New Digester +Composting	$14,400,000	$10,790,000
PONDUS + RT + Composting	$17,770,000	$12,650,000
RT + Composting	$12,030,000	$8,130,000
Process	**Sludge Dryer w/o CHP 20 Year NPV Cost**	**Sludge Dryer + CHP 20 Year NPV Cost**
Lystek Refeed + RT	$22,530,000	$23,360,000
New Digester	$19,720,000	$21,470,000
PONDUS + RT	$22,870,000	$23,880,000
RT	$17,460,000	$18,940,000

Table 9 shows that the sludge drying alternatives have a higher overall cost compared to the CHP and RNG alternatives. This is driven primarily by the dryer capital costs. Table 10 shows the 20-year NPV revenue for each biogas utilization technology without the biosolids process equipment costs to better compare the value of each technology. The revenue data shown in Table 10 includes the energy production revenue, tipping revenue, construction and O&M costs for the biogas utilization and HSW systems only. The costs associated with biosolids process modifications are omitted so that the benefit for each biogas utilization alternative can be observed.

Table 10. 20-year NPV Biogas Utilization System Revenue Summary (With FOG/HSW Codigestion)

Biogas Utilization Alternative	CHP 20-Year NPV Revenue*	RNG 20-Year NPV Revenue*	Dryer 20-Year NPV Revenue*
Lystek Refeed + RT	$4,152,000	$9,264,000	5,901,000
New Digester	$4,310,830	$7,947,000	$6,963,000
PONDUS + RT	$4,144,000	$9,258,000	$6,170,000
RT	$4,205,000	$8,105,000	$6,494,000

* Positive number = revenue

Table 10 shows that producing RNG has the highest 20-year NPV benefit. This is due to a strong market for renewable fuel commodities (RINs and LCFS Carbon Credits), however, as described in the Phase V TM the commodities markets for renewable fuels are also more volatile and uncertain when compared to electric energy markets (CHP). Given the recent renewable fuel market trends and long term uncertainty, RNG was eliminated from consideration as a feasible long term biogas utilization technology.

Fueling the sludge dryer with biogas has the second highest 20-year NPV revenue. This is driven primarily by the low capital and O&M costs for this alternative. Under this alternative, the dryer capital and O&M costs are driven by the need to achieve Class A biosolids and not for biogas utilization. Therefore, the dryer capital and O&M costs are not included in the biogas revenue calculation.

If GSD elects to implement a sludge dryer, the logical use for the biogas would be to fuel the dryer. However, the timing of the dryer installation will impact this decision. An evaluation of the CHP and Dryer 20-year revenues showed that the Dryer and CHP revenues would be similar if the dryer installation was delayed 5 years. In other words, if the dryer is installed within a 5-year window after GSD begins accepting HSW, then fueling the dryer with biogas will be the recommended biogas utilization strategy. If the dryer installation is expected to exceed the 5-year window, GSD should consider moving forward with CHP to start gaining revenue from the biogas.

To expedite the beneficial use of the biogas resource, the CHP installation can be completed in two (2) phases. The first phase will install a single CHP engine and heat recovery systems with provisions for a second future engine. The first phase should be completed with the construction of the new mesophilic digester to immediately begin the beneficial use of digester gas. The second phase would add the second engine after the HSW/FOG acceptance and co-digestion facilities are in place and the increase in biogas production is known.

Solar and Energy Storage Considerations

The results in TM 5 show that solar results in a net cost over a 20-year period. These results do not take into account any renewable/green energy funding. Solar should be re-evaluated if GSD can secure funding or incentives for the solar array. It should also be noted that if implementing CHP results in net energy production, the surplus energy produced would be purchased back at the surplus energy buyback rate (~$0.03/KWH) thus reducing the value from being energy neutral. To maximize the value from solar, solar should not be implemented if CHP will bring the plant at, or close to, energy neutrality. Solar funding and incentives as well as a partnership with a private solar entity should be explored after the biogas utilization alternative and FOG/HSW amounts are known.

The energy storage evaluations show that energy storage does provide some benefit, however, the benefit is limited due to the utility billing rate facility demand charge structure. The estimated energy storage costs ($/MWH of storage) currently exceed the benefit gained, however, energy storage prices are falling, and GSD should track energy storage prices for consideration in a future installation.

CONCLUSION: ROAD MAP TO BIOSOLIDS AND ENERGY PLANNING

The key findings of the Biosolids and Energy Strategic Plan are summarized below:

- Beneficial use of Class B biosolids cake for agriculture and/or reclamation is not a viable outlet for GSD moving forward.
- HSW codigestion increases the biogas generation and with codigestion GSD will benefit from increased energy production and anticipated tipping fee revenue.
- UCSB can provide source separated food waste for codigestion.
- There is an interest in the local market to supply FOG/HSW to GSD.

- Recuperative Thickening (RT) can provide a cost effective, short term solution to achieve firm capacity. However, Digester #1 might need to be replaced due to the results from condition assessment. GSD has indicated that the new mesophilic digester is the preferred alternative to achieve increased flexibility and firm capacity.
- Although the end use market assessment indicated composting as a viable option, due to the large footprint, bulking agent requirement, truck traffic involved and market risk, composting is not found to be a viable option for GSD.
- Thermal Drying reduces the amount of biosolids generated significantly and generates Class A cake. Considering other non-monetary criteria, in combination with cost and energy balance, thermal drying alternatives scored the highest of the alternatives.
- If GSD pursues thermal drying in the near term (within 5 years of implementing FOG/HSW program) then using biogas to fuel the dryer provides the highest level of economic benefit. If the thermal dryer implementation exceeds 5 years after the FOG/HSW program, GSD should consider implementing CHP at the same time as the FOG/HSW program. GSD has indicated that a thermal dryer will likely not be installed within the 5 year window and the timing will be driven by future biosolids regulations and increased hauling costs.
- CHP is the most desirable biogas utilization technology. It is recommended that a single engine CHP system with provisions for a second engine be installed with the new mesophilic digester so GSD can begin beneficially using digester gas as soon as possible (Phase 1). The second CHP engine should be installed after the FOG/HSW acceptance program is operational.
- A ~500kW (rated) on-site solar photo voltaic system will supply ~20% of GSD's annual energy usage. Solar does not provide a 20-year payback without funding and/or incentives.
- Using energy storage (battery system) to shift loads to off peak periods provided a marginal level of financial benefit. The level of benefit will not cover the cost of the battery system at the current estimated costs. Recommend GSD continue to re-evaluate energy storage as prices continue to fall.

Two biosolids and energy roadmaps were developed for GSD as shown in Figures 10 and 11. Figure 10 presents a roadmap with triggers for changing direction, adapt a new strategy, and implement technologies. Figure 11 presents a roadmap with a proposed phased timeline for implementing the biosolids and energy plan.

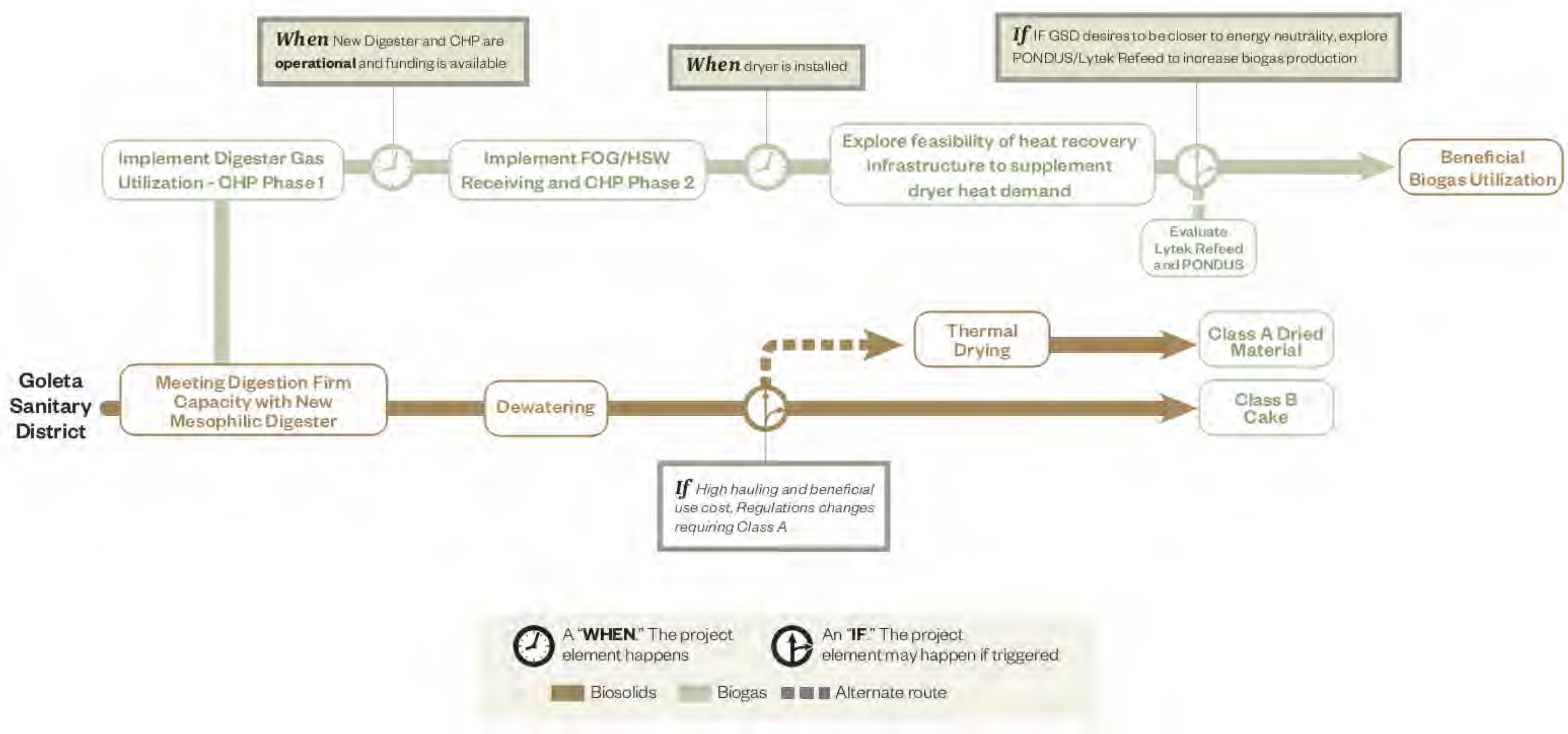


Figure 10. Roadmap for Biosolids and Energy Strategic Planning

Figure 11. Proposed Phased Timeline Roadmap for Biosolids and Energy Strategic Planning

An interactive energy balance and economic model (EBAT) was developed as a part of this BESP (Figure 12). EBAT is calibrated to the specific energy balance and energy market/cost conditions for the GSD plant. EBAT has adjustable parameters for HSW receiving, capital costs, biogas production, energy consumption, solar PV, hauling costs, and energy market conditions. This model calculates the 20-year net present value for all biosolids process and biogas utilization alternatives included in this plan. It is the intent that GSD use this model to refine the economic and energy outcomes as capital costs are refined, funding/incentives are finalized, and market conditions evolve. This capability will enable GSD to make more informed decisions as future conditions change.