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Landfill gas condensate treatment options to eliminate odor issues and to use water for dust control

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Abstract

A large landfill-gas-to-power facility retained the authors to provide process evaluation and development support for a conceptual design of a landfill gas condensate (LFGC) treatment system to eliminate odor issues and reduce organic loads to the sewer or use the water for dust control. Based on the operational observations and water quality data, the source of the LFGC is moisture from gas generated by the decay of waste in the landfill that is transmitted to the power generation facilities by way of the landfill gas (LFG) collection system. As part of this project, the authors reviewed the data, and this presentation includes recommendations for long-term treatment solutions so that a permanent system can be designed, bid, procured, and installed. The purpose of the abstract is to present the findings of this analysis of LFGC treatment system alternatives to identify practical, commercially available solutions with the primary goal to reduce odor issues related to LFGC both on-site and in the sewer system, and to reduce water usage at the site for dust control. The method to evaluate the various treatment options was based on treatment efficiency, and capital and life-cycle costs. The conclusion was to continue with pilot testing of the most suitable options, which was anaerobic treatment followed by polishing with a moving bed bioreactor (MBBR) to reuse the product water in cooling towers or for dust control.

Key words: dust control, landfill gas condensate, odor control, water reuse

Highlights

- Water reuse.
- Waste to energy.
- Anaerobic digestion.
- Landfill gas treatment.

INTRODUCTION

The drought in California is increasing the need to find additional local water sources, and one source is the treatment of industrial wastewater streams. The operator of a landfill-gas (LFG)-fueled power station in California researched and evaluated landfill gas condensate (LFGC) treatment options. The objective was to eliminate odor issues and reduce organic loading to the sewer. The authors analyzed alternatives to reduce water usage in the facility cooling towers (CTs) and potentially use the treated condensate for makeup water in the CT.

Project purpose and scope

The purpose of this project was to conduct a third-party analysis of the LFGC treatment system alternatives and to review the cooling tower water system to identify practical, commercially available solutions to the following:

- Reduce odor issues related to LFGC, both on-site and in the sewer system.
- Reduce municipal water usage in the CTs.

The following activities were performed as part of the analysis:

- Evaluate LFGC treatment options identified by operations staff and additional options identified by the authors.
- Identify data gaps and further testing needs.
- Review, analyze, and rank solution(s) for elimination of odor issues.
- Develop a conceptual design for LFGC treatment.
- Summarize findings and recommendations for next steps.

Wastewater sources and treatment

The source of the LFGC is moisture from gas generated by the anaerobic digestion of waste in the landfill. This gas is typically saturated with water vapor as it enters the fuel processing facility. The majority of the condensate flow was from the chiller and compressors, where liquid vapor in the LFG condenses out and is segregated from the gas stream and separately collected.

The impact of treatment with hydrogen peroxide has been evaluated by the plant operations team over a range of pH values. Approximately 120 gallons per day (gpd) of peroxide has been applied at a pH of 7 to 8 standard units (s.u.).

This treatment has been stopped due to an increase in hydrogen peroxide demand exceeding historical averages in response to observed increases in the general organic content of the LFGC (measured by parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total organic carbon (TOC)).

A proprietary process, involving periodic application of caustic as well as peroxide to inhibit biological activity in the sewer system, was also investigated. The existing treatment system achieves reductions in volatile organic compounds (VOCs) and generally controls odors in the first mile of the sewer system. However, anaerobic decomposition of readily degradable organics in a flat and slow-moving section of the sewer further downstream had caused odors.

Water quality

The LFGC from the chiller and compressors was low in solids, but high in VOCs, hydrocarbons, etc. Water quality data for the untreated LFGC and CT blowdown are shown in Tables 1 and 2, with dust control water quality guidelines for surface discharge included for comparison (RWQCB limits).

The LFGC showed significant concentrations of organics and VOCs including 4-Methyl-2-pentanone (MIBK), Acetone, t-Butyl alcohol (TBA), and 2-Butanone (MEK), as shown in Table 2. It is important to note that these particular organics constituted a small fraction of the total organic content of the LFGC, as indicated by COD or TOC (refer to Table 2). The total VOC concentration was 132 milligrams per liter (mg/L), and the TOC was 1,900 mg/L, which means the VOCs accounted for about 7 percent of the TOC.

Treatment with peroxide resulted in variable levels of reduction, with good removals of Benzenes and modest reductions in Ketones. Some species (such as naphthalene) actually increased as a result of the treatment process, most likely because these species were intermediates or byproducts in the destruction of Benzenes and other aromatic compounds.

The reduction in organics illustrated in Table 2 would not have had a significant impact on the total organic content of the LFGC and, consequently, were not expected to alleviate the odor problem, except for odor specific to VOCs. While VOC-related odors were believed to contribute to odor issues, as discussed below, this was likely not the primary source, because the remaining TOC and COD were still the major food source for anaerobic bacteria in the sewer system.

Table 1 | Wastewater quality of landfill gas condensate and cooling tower water

Parameter	Landfill gas condensate	Cooling tower blowdown	Dust control limits
Barium	0.45	0.6	0.7
Aluminum	0.18	0.3	0.35
Fluoride	1.1	3.8	1.3
Nitrate (as N)	22	48	15
Chloride	310	470	500
Sulfate	1,300	1,542	1,100
Total dissolved solids (TDS)	2,600	3,600	3,000
Alkalinity	370	6	600
Boron	0.52	0.76	1,050
Calcium	305	471	300
Hardness	1,140	1,760	1,300
Magnesium	92	142	150
N-amine	ND	2.9	13.5
Potassium	20	29	25
Sodium	580	480	550
TOC	1,900	9	16
Vanadium	10	16	22
BOD	16,000	–	–
Total suspended solids (TSS)	1,000	–	–
COD	36,000	–	–

Table 2 | Landfill gas condensate treatment with peroxide

Parameter	Units	Raw condensate	Treated condensate	Change (− Reduction/+ Increase)
1,2,4-Trimethylbenzene	ug/L	245	0	−100%
1,4-Dichlorobenzene	ug/L	200	0	−100%
Ethylbenzene	ug/L	199	0	−100%
m and p-Xylene	ug/L	447	0	−100%
Toluene	ug/L	338	0	−100%
o-Xylene	ug/L	209	0	−100%
Xylenes	ug/L	656	304	−54%
4-Methyl-2-pentanone (MIBK)	ug/L	4,550	4,290	−6%
Acetone	ug/L	36,900	34,200	−7%
t-Butyl alcohol (TBA)	ug/L	19,000	18,000	−5%
2-Butanone (MEK)	ug/L	68,300	86,300	+26%
4-Isopropyltoluene	ug/L	616	863	+40%
Naphthalene	ug/L	331	494	+49%
Total VOC	ug/L	132,000		
TOC	mg/L	1,900(1)	NA	NA
Ratio VOC/TOC	%	7%	NA	NA

Note: (1) Data are based on samples collected on 24 June 2015.

The organic content of the LFGC was nearly 100 times that of raw sewage and therefore had a great potential to initiate anaerobic biodegradation and cause the generation of odor-causing gases such as hydrogen sulfide.

No significant permanent relief of the odor issue was expected unless the organic content of the LFGC (as measured by BOD_5, which measures the readily biodegradable fraction of the organics) was substantially reduced. Other treatment methods in the sewer pipe such as caustic flushing have been applied as a periodic maintenance task, but only addressed anaerobic activity for very brief periods or to a limited extent and were not practical or cost-effective measures.

METHODOLOGY

Condensate treatment technologies

Table 3 lists several potential treatment technologies grouped on the basis of their effectiveness in meeting one or more treatment goals: (a) treating VOCs, (b) achieving substantial reductions in total organics, or (c) reducing wastewater volumes sufficiently for off-site disposal (trucking). A reduction in VOCs without a substantial reduction in organics would not have solved the odor problem and technologies that achieve both goals were preferred.

Table 3 | Landfill gas condensate treatment options

Treatment goal	Treatment technologies
Removal of volatile organic carbon (VOC)	• Chemical oxidation • Powdered activated carbon treatment (PACT) • Membrane bioreactor (MBR) • Air stripping and carbon treatment ozone
Reduction of organics (BOD, COD)	• MBR • Moving bed bioreactor (MBBR) for anoxic and aerobic treatment • Aerobic with sequential batch reactor (SBR) advanced oxidation • Electrocoagulation • Anaerobic with upflow anaerobic sludge blanket reactor (UASB) • Anaerobic digester (completely stirred tank reactor (CSTR))
Waste volume reduction	• Evaporation and trucking concentrate off-site

These technologies were considered and compared according to treatment effectiveness, capital costs, operational costs, full-scale treatment experience, and general practicality. Table 4 summarizes the advantages and disadvantages. In these sections the capital costs were estimated by providing a

Table 4 | References to project examples and handbooks and reports from industry groups

Project example #1	Sanitation districts of Los Angeles County – Calabasas landfill located in Agoura, California
Description	Research Permit to Operate the UASB and Air Stripping for Condensate treatment. Design information and VOC removal efficiency.
Source	• South Coast Air Quality Management District (AQMD) • Personal communication with responsible Staff Engineers at Sanitation Districts.
Project example #2	**Scholl Canyon landfill, Glendale, CA**
Description	The collected condensate is treated using an air stripper, then chemically neutralized and discharged to the City of Glendale sewer system and ultimately the Glendale Water Reclamation Plant pursuant to City of Glendale Industrial Wastewater Discharge Permit No. W – 2762.
Source	Internet: http://www.glendaleca.gov/home/showdocument?id=20250

range of equipment costs. The operations costs were based on estimated maintenance and repair costs plus fuel costs (if applicable) to arrive at a dollar per gallon ($/gal) operating cost. The cost estimates were based on Level 4 Engineering Cost Estimates or based on vendor proposals if not noted otherwise.

A local reference for this type of solution is the Calabasas landfill operated by the Sanitation Districts of Los Angeles County (Sanitation Districts), who implemented LFGC treatment using anaerobic treatment with UASB. In this case, use of raw LFGC for dust control was approved and the pretreatment process was no longer utilized. Pilot testing and full-scale treatment at the Calabasas landfill with UASB showed high organic removal efficiency.

Survey of treatment practices in other landfills

Typical condensate management systems will pump the liquids collected by sumps to one or more storage tanks to hold the condensate until it can be treated, reused, or disposed of. Collected condensate is typically combined with leachate for treatment or disposal. A list of typical land fill liquid management practices is presented in Table 4.

Alternatively, combustion in landfill flares is industry practice to reduce the NOx emission by adding moisture to reduce the combustion temperature (thermal NOx formation).

Management and disposal options for LFGC (International Best Practices Guide for LFGC Projects 2012):

- Treatment and return to the Landfill (40 CFR 260).
- On-site treatment (air stripping or aeration).
- Recovery of the hydrocarbon phase (ignitable flashpoint less than 60 degrees Fahrenheit (Deg F) and hazardous waste by the United States Environmental Protection Agency (EPA)) (EPA 2016).
- Hauling and off-site treatment/disposal (depending on quantities the LFGC may be classified as hazardous waste).
- Blending with leachate for treatment.
- Dust control.

Evaluation of condensate treatment alternatives

For the evaluation of the potential treatment processes, Table 5 shows an evaluation of condensate treatment processes ranked based on applicability and advantages over other technologies used in a full-scale treatment at the landfill.

RESULTS

Option 1: pretreatment for sewer discharge with anaerobic UASB treatment and aerobic MBBR

The current variable costs for discharge to the sewer are based on surcharges for BOD and TSS and the daily flow rates. The high BOD concentrations in the LFGC resulted in BOD surcharges, which are expected to be $200,000 per year and flow charges of $100,000, so that the total sewer bill including TSS surcharges is expected to be $360,000 per year. In addition, the costs for chemical treatment for the LFGC prior to discharge would have resulted in an additional operating expense of $250,000 per year.

The proposed treatment with the UASB option would address these operations and maintenance (O&M) costs by reducing the organics (COD and BOD) as outlined below:

- Treatment of the LFGC in an anaerobic or anoxic treatment system followed by aerobic MBBR (one stage or two stage) to further reduce the COD, as illustrated in Figure 1.

Table 5 | Evaluation of condensate treatment processes

Rank	Treatment technologies	Advantages	Disadvantages	Further considerations for implementation
1A	Anaerobic with UASB	Small footprint (reactor dia. 10 ft, 40 ft H), minimal solids, lower energy costs, 15,000 cubic feet (cu ft) per day of digester gas/biogas generation (with 55 – 65% methane content)	With complex waste streams, toxic shock and biological viability are always questions, but bench testing was performed to prove treatability	Yes – proven technology based on the bench testing and full-scale testing at the Calabasas landfill. For confirmation and for specific site, pilot testing is recommended
Alt 1A	Anaerobic with CSTR	As above, but larger footprint than 1A	Larger tank volumes needed with higher capital costs compared to UASB	Could be considered if costs are competitive with UASB technology
1B	MBBR (anoxic and aerobic)	Ideal as 'polishing' after pretreatment with anaerobic process. Lower capital costs than conventional aerobic systems	High COD levels and recalcitrant organics require pretreatment. Aeration energy required	Yes – to polish the effluent from first stage anaerobic treatment process
Alt 1B	Powdered activated carbon (PACT) aeration	Removes wider variety of organics than MBBR	More complex operationally. Higher capital and operating cost (PAC consumable)	Could be considered as an alternative to MBBR if it does not achieve target reductions
NEF	Advanced oxidation processes (AOP)	Can degrade recalcitrant and bio-refractory organics	High organic content of this water will require prohibitively high power and chemical dosages	AOP is not used for very high COD waters such as this – it is a 'clean water' technology
NEF	Chemical oxidation	Low capital investment	High chemical demand, not effective for Acetone and MEK. Cannot achieve high COD reductions	Not recommended due to high chemical usage and low COD impact, as shown during full–scale testing
NEF	Membrane bioreactor (MBR)	Treated effluent reuse water quality	Higher costs, higher solids disposal costs, membrane fouling risk	Not recommended due to operational complexity of MBR
NEF	Electrocoagulation (EC)	Moderate capital costs and no chemical consumption	Insufficient reductions in COD. On-site testing would be recommended	Not recommended – the bench testing did not result in sufficient COD reduction(1)
NEF	Air stripping and carbon	Lower capital costs	Air permits, insufficient COD reduction	Not recommended – only suitable as pretreatment, if allowed by the AQMD
NEF	Ozone	More powerful oxidant than peroxide. Can degrade many recalcitrant compounds	Prohibitively high ozone/electrical demand for this high COD water	Not recommended as a standalone process – could be used in conjunction with bio process, if required
2	Trucking off-site	Low capital cost	High operating costs (per gallons fees)	Potential fallback solution
3	Evaporation and trucking concentrate off-site	Zero liquid discharge	Gas usage 250,000 cu ft per day	Not recommended – air permits for VOCs and off-gas treatment for VOC removal would be required

Key:
1A, 1B: Two sequential technologies required for a complete solution.
Alt: Potential alternatives to the specified technologies – similar but considered to be less desirable.
NEF: Not economically feasible, in comparison with the recommended technologies.
Note:
(1) Electrocoagulation tested on a bench-scale with samples of the LFGC did not achieve an adequate level of COD reduction for it to be an economically viable complement to biological treatment or a standalone treatment process.

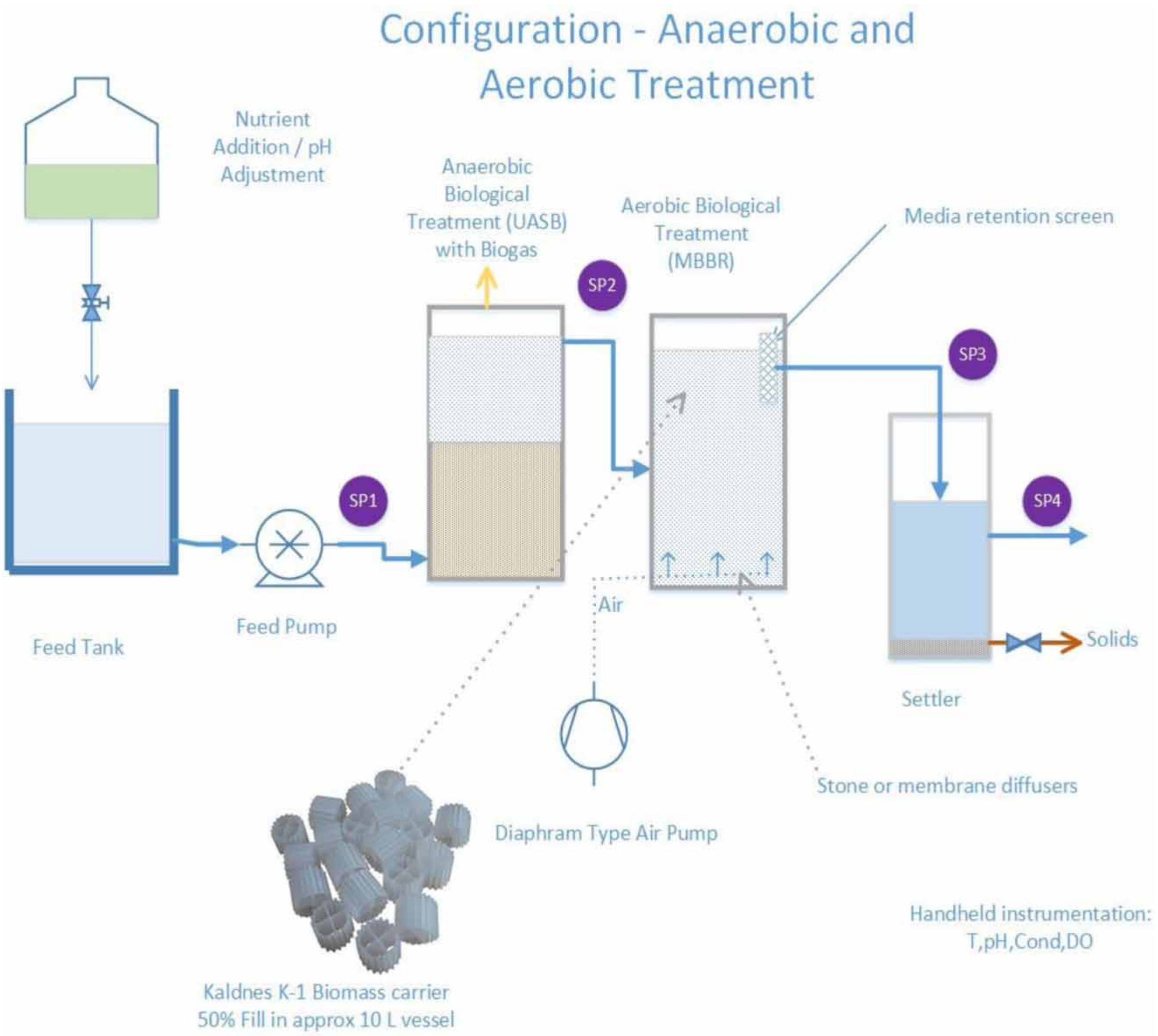

Figure 1 | Proposed process train flow diagram for pilot testing.

- This two-stage treatment approach is commonly used for high-strength wastes where high reductions in organic content are required (e.g. in breweries, soda bottling plants or for yogurt processing).
- Capital costs for UASB digester equipment could range from $1,000,000 to $1,200,000.
- Estimated operating costs UASB: $0.02 per gallon treated (engineer's estimate).
- Capital costs for MBBR could range from $100,000 to $200,000.
- Power consumption for aeration at 500 scfm per 1,000 lbs/day of oxygen with a blower rated at 50 kW: $60,000/year:
  - Estimated operating costs for MBBR for electricity: $0.04 per gallon treated (engineers estimate).
  - Total operating costs for a complete UASB/MBBR system: $0.06 per gallon treated.
- Comparative costs are summarized in Table 6.

Option 2: trucking and off-site disposal

- No treatment would be performed on-site (potentially oil recovery for resale should be considered). The LFGC is hauled off-site and disposed of at a high-strength wastewater receiving facility.
- Minimal capital costs.

Table 6 | Condensate treatment options and costs

Treatment option	Capital costs	Operations costs
UASB and MBBR (Option I)		
UASB[(1)]	\$500,000–\$1,200,000	\$0.02 per gallon
MBBR	\$100,000–\$200,000	\$0.04 per gallon
Combined costs	\$600,000–\$1,400,000	\$0.06 per gallon[(3)]
Hauling (Option II)	–	\$0.35 per gallon
Evaporator (Option III)[(2)]	\$572,000	\$0.23 per gallon

Notes:

Source of costs from Level 4 engineering estimates and:.

(1) Proposal for UASB from Paques: \$1,200,000, excluding heating and digester gas treatment.

(2) Proposal from Ancon Evaporators.

(3) Or \$0.054 per gallon, if the treated LFGC is used as CT make-up water; water savings would be \$21,600 per year (\$6.35 per 1,000 gallon).

- Costs of hauling service: \$1,022,00 per year or \$0.35 per gallon (for maximum 10,000 gpd and average 8,000 gpd)
- Estimated costs: \$0.35 per gallon treated.

Option 3: evaporation and zero liquid discharge

- No wastewater discharge, lower operating costs when using LFG versus NG in the evaporator. Estimated usage is 250,000 cu ft per day of LFG at 50-percent methane (Vendors: Perenniel, Ancon).
- Implementation of this option could complicate or prevent discharge of CT blowdown.
- Capital costs for the evaporator equipment were estimated to be around \$450,000; however, an additional thermal oxidation system will be needed for exhaust treatment to reduce VOC based on the local AQMD regulations; O&M costs are assuming that the value of LFG is \$700,000/year (due to lost electricity generation).
  - Estimated operating costs for fuel: \$0.20 per gallon treated (evaporator fired with LFG as NG is not available on-site. However, the use of LFG as a fuel for the evaporator is not a preferred option because the green power credits provide a higher value and power generation is the core business.
  - Costs for carbon replacement for air stripping: one carbon change-out per month for a 3,000 lb vessel would result in costs of \$72,000 per year (at \$2 per lb of coconut-based activated carbon). In summary, Option 1 will include the following processes and equipment, as shown in Figure 1:
- Hydrocarbons/oil (HC/oil) recovery for sale as fuel (credits not included in above analysis).
- Anaerobic treatment in UASB, with biogas generation (Speece 1995; Tasser & Ferrin 2017).
- Aerobic treatment in MBBR for BOD removal (aiming for overall 80-percent BOD reduction).
- Removing solids from the MBBR effluent and using filtered treated LFGC for dust control where permissible and needed, with the balance of the LFGC discharged to sewer.

DISCUSSION

There are several remaining questions to be resolved before the system design is finalized. Many of these will be answered or at least informed by pilot testing:

- The level of COD/BOD reduction achieved with the selected process (Option 1).
- Overall O&M and capital costs to be refined.

- Air permit requirements for treatment equipment.
- Quality requirements for cooling tower makeup regarding COD/TOC/BOD limits, based on AQMD limits and general recommendations for CTs by American Society of Mechanical Engineers (ASME) or other associations.
- Oil recovery for resale.

CONCLUSIONS

Site testing and treatment with peroxide chemicals are expensive ($250,000 per year) and do not provide a long-term solution in order to ensure compliance with OCSD regarding discharge limits and required odor management from the LFGC.

Sewer discharge of LFGC can only be done in combination with discharge of CT blowdown water to dilute the LFGC in the discharge stream. Reduction of CT blowdown volume is possible, but can only be pursued if it does not prevent LFGC discharge and so is subject to viable LFGC treatment. The hydraulics of the sewer (with the flat sewer sections) requires CT blowdown to convey the relatively smaller volume of LFGC past these flat sections and downstream.

CT water conservation and LFGC treatment must be addressed together. If LFGC is left untreated, the reduction in blowdown flows could exacerbate the odor issues by reducing flow rates in the sewer and increasing LFGC detention times in the sewer. Additionally, although not a requirement to be implemented, water conservation in the CT would be maximized, when the LFGC is treated to a sufficient standard to be suitable for use as makeup water.

Recommendations

The recommended actions to implement the described technologies include pilot testing, review of permitting needs, design, and implementation of the preferred technology.

As a next step, pilot testing is recommended to assess the reduction of the overall COD and TOC after treatment in anaerobic and aerobic processes and to determine design criteria for sizing of the full-scale systems. The following process validation steps need to be undertaken as part of the pilot testing:

- Actual level of COD/BOD reduction achievable by anaerobic treatment.
- Constituent criteria necessary for LFGC to qualify for use as CT makeup water.
- Assess overall O&M and capital costs.
- Determine air permitting needs based on test results.
- Determine raw and discharge water cost reduction based on test results (for grants and credits).

One approach would be to concurrently test the cooling tower water treatment with the LFGC treatment technology, so that the treated LFGC can be potentially added to the CT. The cooling tower water treatment can be pilot tested to investigate if recalcitrant organics can be destroyed using electrochemical treatment.

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