OPTIMISING BIOGAS AND BIOSOLIDS ENERGY RECOVERY AND REVENUE GENERATION

J. Witherspoon, J. Surti, R. Forbes, P. Burrowes

ABSTRACT

The Life Cycle Assessment Manager for Energy Recovery (LCAMER) Tool by Water Environment Research Foundation for on-site energy recovery system (ERS) evaluation using biogas was used. Two case studies are presented, including a FOG facilities. LCAMER is a spreadsheet based model that uses a life cycle assessment approach to compare relative economic benefits of one ERS to another over the life of the system.

Different anaerobic digestion technologies were reviewed, ranging from single stage / multiple stage mesophilic digestion, acid phase digestion in combination with mesophilic anaerobic digestion and, temperature phased anaerobic digestion. LCAMER estimates biogas production based on feed sludge quality and quantity, digester -type, SRT, and volatile solids destruction. It estimates sludge heating and mixing energy requirements based on digester volume and geometry. Digester Capital and O&M cost is estimated using LCAMER life cycle tool.

A large energy recovery systems range is assessed based on performance, capital and O&M cost for engines cogeneration, gas turbines, microturbines and fuel cells. Financial outcome is expressed as simple payback period. Life cycle assessment considers electricity and natural gas cost for each option and estimates onsite greenhouse gas emissions and relative emission rates of common criteria air pollutants.

KEYWORDS

Biogas, Energy Recovery, Biosolids, Life Cycle Assessment Tool, Digestion, Carbon Emissions, Fat, Oils and Grease (FOG) Recovery Facility

1 INTRODUCTION

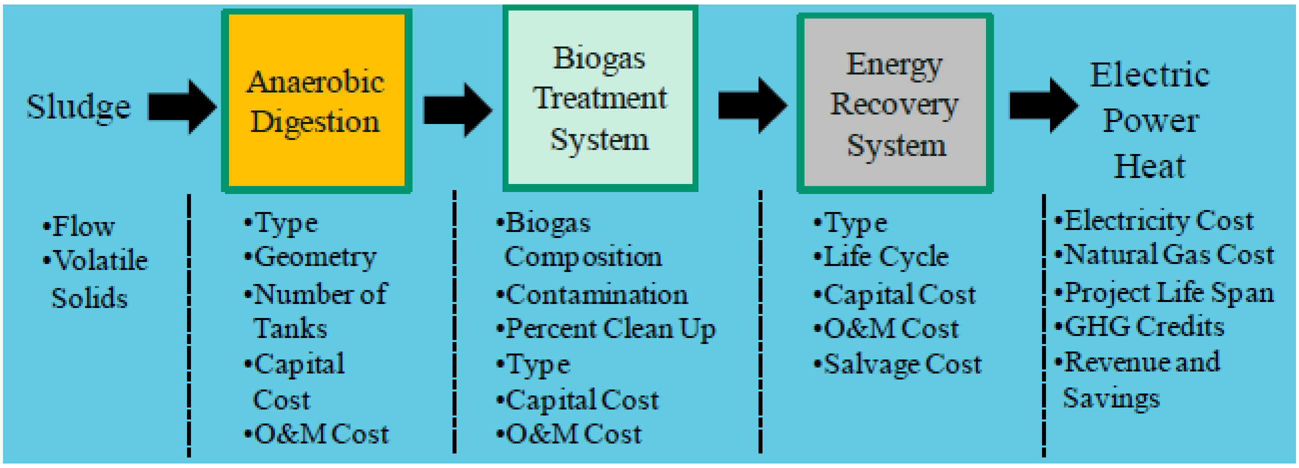
The paper's objective is show a high level business case related evaluation that supports decision making for an Energy Recovery System (ERS) using biogas. In the two case studies presented by WERF (WERF et al., 2011 and Forbes et al., 2011), biogas is generated in digesters. In one case study, the cost benefits of using fats, oils, and grease (FOG) recovery facility to enhance biogas production in their existing digesters is explored. Both case studies were looking for innovative resource management strategies focused on water-energy-carbon nexus solutions.

The Life Cycle Assessment Manager for Energy Recovery (LCAMER) Tool developed by the United States (US) Water Environment Research Foundation (WERF) (WERF et al., 2011) for the purpose of on-site ERS evaluation using biogas was used for this assessment. Other tools exists that cover various physical, economic, and emissions generation sections and segments found in LCAMER. However, LCAMER is the only tool that combines and incorporates biogas quality and quantity; biogas generation; digester-type options; energy recovery options; life cycle costs analyses; and, by-products-of combustion emissions in a single tool.

WERF is a large, non-profit applied and academic research and development foundation funded by members and US EPA. Members include international private and publicly owned wastewater treatment works, US EPA and other US-based government agencies, private and public universities, global consultants, and other public funding sources. WERF has members globally, including in New Zealand.

LCAMER is a spreadsheet based model that uses a life cycle assessment approach to compare the relative economic benefits of one ERS to another over the life of the system. Figure 1.1 shows the municipal sludge to ERS lifecycle, as captured by the LCAMER Tool, as well as the tool's flexibility in energy recovery systems decision making and side benefits (carbon footprint, power, efficiencies, and other air pollution emissions) using biogas.

Figure 1.1 Municipal Sludge to Energy Recovery Scheme Overview (Forbes et al., 2011)



Different anaerobic digestion technologies can be selected in LCAMER, ranging from single stage / multiple stage mesophilic digestion, acid phase digestion in combination with mesophilic anaerobic digestion and, temperature phased anaerobic digestion (TPAD). LCAMER Tool is capable to estimate the quantity of biogas production based on the input quality and quantity of feed sludge, type of digester, SRT in digester and volatile solids destruction associated with it. It also estimates the sludge heating and mixing energy requirements based on digester volume and geometry. The digester Capital and O&M cost can be estimated by using LCAMER life cycle tool.

The quality of biogas including methane, carbon dioxide, hydrogen sulphide and total siloxanes is a user defined function based on biogas sampling data. It determines the characteristics of a gas pre- treatment required prior to use in onsite energy recovery system. LCAMER includes costs and performance information for a wide range of biogas pre-treatment technologies such as Iron sponge, iron salts, carbon filters etc. The tool estimates the Capital and O&M cost for selected biogas pre-treatment technology.

Range of energy recovery systems can be assessed based on their performance, capital and O&M cost using LCAMER such as Boiler, engine cogeneration, steam turbine, gas turbine, microturbine fuel cell, etc. The financial outcome of a model is typically expressed as simple payback period. The life cycle assessment also considers the electricity and natural gas cost for each option. It also estimates onsite greenhouse gas emissions for selected ERS technologies so that relative emission rates of common criteria pollutants such as NOx, SOx, CO etc are estimated for any ERS investigated.

2 BACKGROUND

This section provides summary information on the two US wastewater treatment works studied using the new, WERF LCAMER tool (WERF et al., 2011; Forbes et al., 2011; and Witherspoon et al., 2011). Both facilities were used to pilot test the LCAMER tool by CH2M HILL, under a WERF grant (WERF et al., 2011). Both facilities were looking at ERS to optimize their biogas production because of rising electrical power costs, opportunities to achieve sustainability policies and laws, and for potential revenue generation schemes. Another key reason was to simplify the daunting task of life cycle analysis for optimized energy recovery systems using biogas as a renewable fuel source. The life cycle analysis needs to look at anaerobic digestion options, biogas pretreatment and energy recovery equipment options, today's and future casting costs for electricity and natural gas, population growth projections, loan discount rates and potential monetary grant schemes, and to meet air emissions and carbon footprint counting reductions and standards (WERF et al., 2011; Forbes et al., 2011).

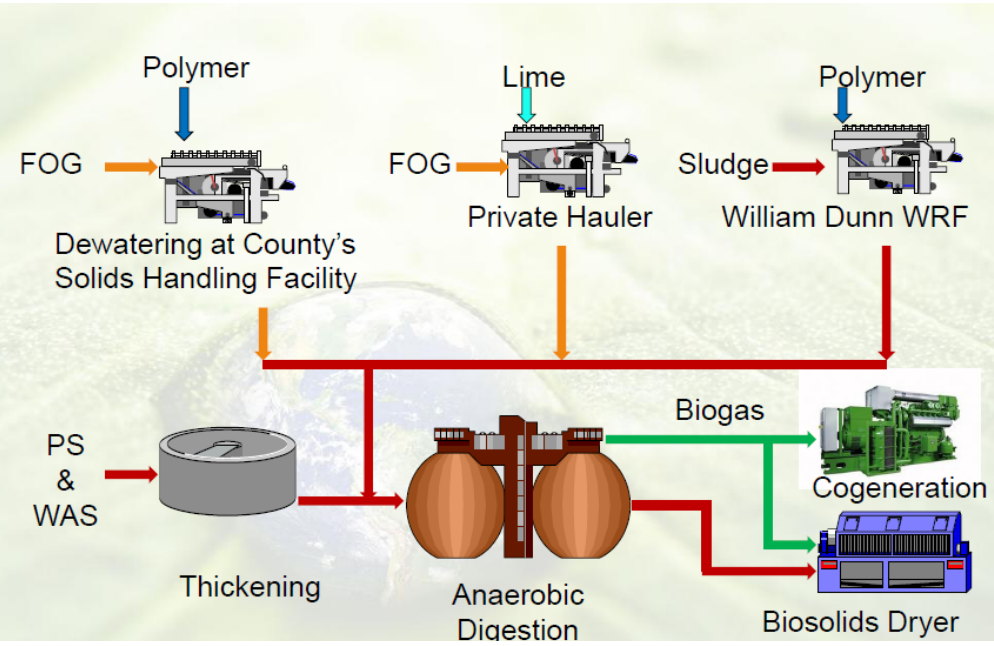
2.1 CASE STUDY FACILITIES GENERAL INFORMATION

Two US, publically owned treatment works (POTWs) were studied using the LCAMER tool. Together the two POTWs provide a range of flows, digester types, biosolids handling facilities, and biogas generation levels. One POTW is also looking at adding fat, oils, and greases (FOG) recovery facility on-site to generate additional biogas flows beyond rates generated by "traditional" biosolids management practices. The other POTW was looking at upgrading their current biogas recovery system due to aging infrastructure and end of life equipment concerns. Both utilities use high strength wastes together with wastewater solids to enhance biogas production to be used to generate electric power (WERF et al., 2011; Witherspoon et al., 2011).

2.1.1 PINELLAS COUNTY UTILITIES, CLEARWATER, FLORIDA, USA

Pinellas County WWTP is located in Clearwater, Florida, USA and is an 113,550 cubic wastewater meters/day (30 MGD) traditional wastewater treatment plant that captures wastewater solids and FOG from two main sources – the County's Solids Handling Facility and from private FOG waste haulers under contract with local restaurants and other sources of FOG. The latter contractor diverts FOG from municipal landfills, is paid a tip fee, as well as the County receives a waste handling fee from discharger sources that adds revenue to their budget after subtracting operational costs for handling, treating, and using the FOG. The plant was looking to upgrade or change their current energy recovery system – cogeneration engines and biosolids dryer with the latest, best practices approaches since these facilities were at the end of their useful life. WERF's LCAMER tool was used to evaluate potential digester and energy recovery schemes that optimize life cycle costs and return on investments (ROI) over the next 20 year period. Figure 2.1.1 provides an overview of their current sludge to energy recovery scheme (WERF et al., 2011).

Figure 2.1.1 Pinellas County's Sludge to Energy Recovery Scheme Overview (WERF et al., 2011)

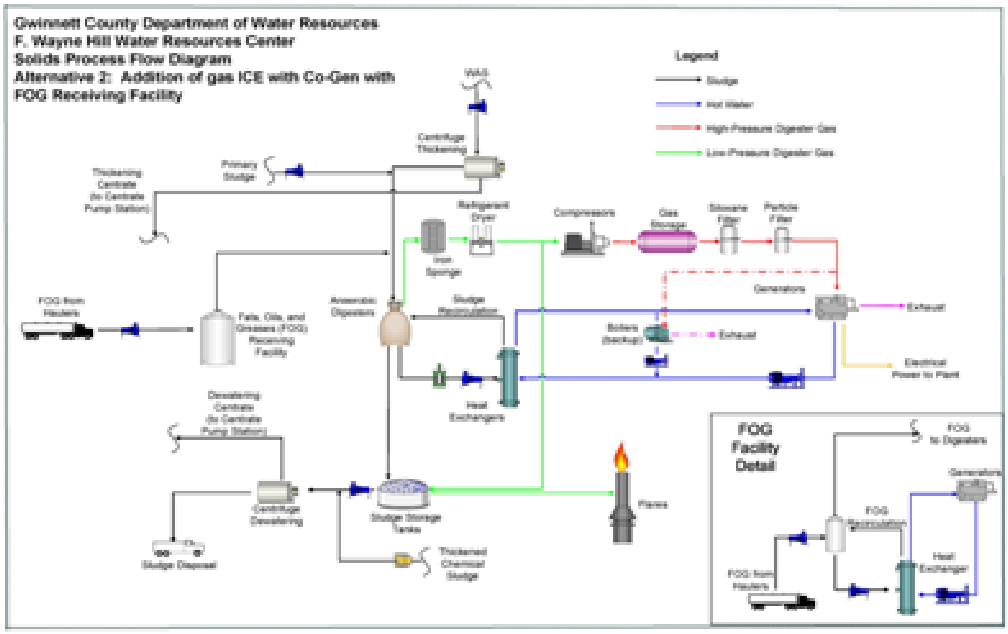


Currently biogas generated in their digesters is used for both cogeneration and biosolids drying. Analysis by LCAMER continues to include the biogas mixed usage and rates available for electrical power generation, since biosolids drying products are still viable recycle/reuse scheme and potential revenue stream for the County (Forbes et al., 2011).

2.1.2 GWINNETT COUNTY DEPARTMENT OF WATER RESOURCES, LAWRENCEVILLE, GEORGIA, USA

Gwinnett County is located in Georgia, USA, and is a 227,100 cubic wastewater meters/day (60 MGD) wastewater reclamation treatment plant. Main difference with Gwinnett County compared to Pinellas County facilities and operations are plans for treating FOG onsite rather than offsite. Also, there is no biosolids dryer at Gwinnett County, so all of the biogas energy can be used for cogeneration, with waste heat sufficient for digester heating and possibly for a new on-site, FOG treatment and handling needs. Figure 2.1.2 provides an overview of Gwinnett County's sludge to energy recovery scheme, including a new, on-site FOG facility (WERF et al., 2011).

Figure 2.1.2 Gwinnett County's Sludge to Energy Recovery Scheme Overview



This facility currently receives FOG from private contractors into the influent headworks and this project looked at the County setting up a separate FOG, on-site facility to optimize energy recovery and to better control air emissions and odours. Costs for this new facility were included in the LCAMER analysis.

3 METHODOLOGY

The following tasks were used to evaluate both plants:

3.1 DATA COLLECTION, REVIEW AND ANALYSIS

This task included gathering data regarding current and future wastewater treatment plant's (WWTP's) anaerobic digestion and biogas operation scenarios, biogas usage and production rates, and current energy recovery system (IC engines) data that was used in the LCAMER Tool.

An initial kick-off meeting helped organise and aligned key operational, maintenance, and engineering staff with the project, provided an overview of the LCAMER Tool benefits and to establish actions and delivery dates for needed information, data, and inputs by both owner and consultant.

3.1.1 DATA AND INFORMATION REQUIRED

The following data and information was required to complete LCAMER evaluations for existing WWTP operating conditions:

- Biogas quality, composition and BTU value.
- Biogas generation rates under annual average, maximum month, maximum week and maximum day operating conditions.
- Capacity of existing biogas treatment system and IC engines (and biosolids dryer).
- Quantity of biogas flared – daily, weekly, monthly and annual averages.

This information came from several of the following planning, operational and engineering documents. This information was combined to set up and evaluate potential, future operating scenarios using the LCAMER Tool.

- Waste Management/Biosolids/Biogas Master Plans and Replacement Scheme reports.
- Cogeneration energy supply output and WWTP total energy demand.
- O&M records for existing IC engines and projected life of existing facilities.

- Capital assets and useful life of biogas related infrastructure, equipment and facilities.
- IC Engines replacement options needed Return on Investment (ROI) calculations and costs.
- Energy recovery supply requirement level (100%, 50%, etc. of energy supply to meet WWTP demand or become net energy producer and sell energy).
- Miscellaneous operational, population projects, and planning data and information needed for input into the LCAMER Tool so that future operating scenarios can be modelled.
- Acceptable ROI period needed to meet planning level inputs and considerations.
- Revenues generated or saved by current energy recovery facility – after addressing costs tied to O&M.
- Current and projected costs per kWh for grid energy.
- FOG Receiving Facility Capital, O&M, projected Revenue, and add-on costs for odour control and other needs.
- Discount cash rate and costs for natural gas.

3.2 LCAMER SET-UP & OPTIMISATION

This task took data and inputs developed above to set-up the LCAMER Tool and run various energy recovery options and equipment schemes. LCAMER Tool was run for the base case (current conditions) and up to 5 energy recovery scenarios for future operations (100% usage of generated biogas) based on agreed biogas generation and energy costs levels over a 20 year useful life of the "new" energy recovery scheme.

The base case and the most beneficial future scenario were optimised based on best international practices, CH2M HILL's US biogas recovery and LCAMER experts, and lessons learned from our extensive energy recovery database and peer experiences (WERF et al., 2011; Forbes et al., 2011).

3.3 LCAMER WORKSHOP

Results from the LCAMER demonstration were presented to each WWTP during a workshop (WERF et al., 2011). A sensitivity analysis for life cycle costs and simple payback period was conducted by modifying values for variables (biogas quantity, price of electricity, and so on) that allowed future-proofing and fine-tuning of the tool and results that are of particular interest to each WWTP for their upcoming planning needs.

This workshop provided the WWTPs an opportunity for hands-on experience with the LCAMER Tool, allowing an educational opportunity for WWTP staff about its capabilities, and provided life-cycle analysis results that can be applied to advance respective cogeneration projects.

4 RESULTS

A final technical memorandum report were provided to each WWTP that summarises the LCAMER evaluation results, and recommended modifications to the WWTP's biogas energy recovery schemes and options (WERF et al., 2011, Forbes et al., 2011). The recommendations were based on results from the LCAMER Tool evaluation, cost analysis and conclusions from the workshop with each WWTP, and their planning and future-proofing needs. Results assisted in each WWTP's decision making and/or selection risk reduction schemes to meet their short- and long-term ERS needs and/or sustainability objectives and County Board Policies.

The following results provided the basis for long-term biogas planning as well as provided ROI comparison of energy recovery options and other supporting information to ensure that a sustainable biogas energy recovery solution for the next 20 years is in place for each WWTP.

4.1 PINELLAS COUNTY WWTP LCAMER RESULTS

Results of the LCAMER optimised scheme is seen in Table 4.1.1. All monetary figures are in $ USD (which is approximately equal today to $1.0 USD = $1.2 NZD). This table reflects current international best practices and all CapEX would need to be adjusted to local costs and conditions. LCAMER does provide parametric CapEX and OpEX costing library that can be adjusted to any location. Also, additional scenarios were run, but not provided in this paper that future-casted technology breakthroughs that would result in lower CapEX and O&M costs. Focus on these runs were for technology innovations that lower costs as some of the newer ERS options in the future as these innovations are built, optimised, and become more commercially viable. An example is Stirling engines and Fuel cells, as they age and become more commercially viable or not.

Table 4.1.1: Pinellas County LCAMER Results (WERF et al., 2011)

	Internal combustion engines	Stirling engines	Gas turbines	Micro-turbines	Fuel cells
Total Capital Cost, $	3,255,000	5,608,000	7,482,000	5,674,700	7,956,000
Total O&M Cost, $	353,500	157,200	284,800	294,500	412,600
Annual savings, $	958,970	787,000	835,400	907,000	805,700
Net annual savings, $	605,470	630,000	550,568	611,900	393,000
ERS service life, years	20	15 (1)	20	9.5	20
GPS service life, years	20	20	20	20	20
Discount rate, %	4	4	4	4	4
Payback, years	5.4	8.9	12	8.9	17.1
Payback including replacement capital, yrs	5.4	12.6	12	13.8	17.1
20-yr lifecycle savings, $	5,000,000	636,000	-845,000	-445,000	-1,228,000

(1) Using the LCAMER default of 15 years, there is no service life data above 10 years for Stirling engines

Table 4.1.1 shows CapEX, OpEX, annual energy savings per today's energy costs, predicted service life and payback period (in years) and 20 yr lifecycle savings. For today, the County selected internal combustion engines while watching biogas turbines to become more cost effective in the next 5 to 10 years. Gas turbines have an additional side benefit to the County because its waste high heat temperature and exhaust rates that can be better used in biosolids dryers than current engines exhaust. This would reduce the current biosolids dryer O&M costs due to supplementary fuels being used to meet drying temperature requirements.

4.2 GWINNETT COUNTY WWTP LCAMER RESULTS

LCAMER results in Tables 4.2.1 and 4.2.2, for Gwinnett County WWTP were presented in two ways – technical and financial feasibilities for with and without the proposed on-site's FOG facility. The FOG facility greatly helps ROI and payback periods (even after factoring in the FOG facilities' CapEx and OpEx) vs. no facility because of the extra biogas generated and their ability to capture the extra electrical power generated on-site. As seen in these tables, for today, the internal combustion engine provides the lowest capital costs and has the lowest payback period of the options reviewed. Payback depends on revenue from the FOG receipts, unit cost of electricity and the biogas quantity, with the biggest difference in the energy recovery options is in their current unit costs of electricity (Forbes et al., 2011). Again, as technology innovations and breakthroughs and electrical costs raise in the future, this result could change. However, for the planning period needed by the County they were happy with their decision to use engines and install an on-site FOG facility (Forbes, et al 2011).

Table 4.2.1: Gwinnett County WWTP LCAMER Results for Technical Feasibility (WERF et al., 2011)

	Internal Combustion Engine		Gas Turbine	Micro Turbine	Fuel Cell
	(W/O FOG)	(With FOG)	(With FOG)	(With FOG)	(With FOG)
Net Power Generation (KW) per Unit	1,428 KW	1,902 KW	1,183 KW	250 KW	1,000 KW
Number of Units	1	1	1	5	2
Total Power Generation Capacity (KW)	1,428 KW	1,902 KW	1,183 KW	1,250 KW	2,000 KW
Electrical Efficiency(%)	39.7%	38.6%	24%	26%	43%
Thermal Efficiency (%)	43%	44.7%	42.3%	43%	19%
Total Efficiency (%)	82.7%	83.3%	66.3%	69%	62%
% Biogas Used	100%	100%	100%	93.9%	94.4%
% of the Avg. FWH-WRC Electric Load	28.3%	38%	23.5%	24.8%	39.7%

Table 4.2.2: Gwinnett County WWTP LCAMER Results for Economical Feasibility(WERF et al., 2011)

	Internal Combustion Engine		Gas Turbine	Micro Turbine	Fuel Cell
	(W/O FOG)	**(With FOG)**	**(With FOG)**	**(With FOG)**	**(With FOG)**
CAPEX ($) for Cogen (including replacements)	**$5.54M**	**$6.91M**	**$6.41M**	**$8.85M**	**$25.39M**
CAPEX ($) for FOG Receiving Facility	**0**	**$4.08M**	**$4.08M**	**$4.08M**	**$4.08M**
OMEX ($/yr) for Biogas System & Natural Gas	**$562K**	**$762K**	**$536K**	**$572K**	**$1.32M**
OMEX ($/yr) for FOG Receiving Facility	**0**	**$145K**	**$145K**	**$145K**	**$145K**
Revenue ($/yr) from Electricty Savings(1)	**$870K**	**$1.17M**	**$723K**	**$766K**	**$1.23M**
Revenue ($/yr) from FOG Receipts	**0**	**$850K**	**$850K**	**$850K**	**$850K**
Payback Period (years)	**18**	**9.9**	**11.8**	**14.4**	**47.9**

(1) - Estimated @ $0.07/KWh

5 CONCLUSIONS

WERF's LCAMER Tool was very beneficial in two WWTP's ERS evaluations, as well as it simplified the decision process to select an energy recovery scheme that matches needs and sustainability requirements. The tool provides flexibility in setting up schemes and "what if" scenarios to match a given ERS goal, process data, population projections, or revenue generation needs from either receiving FOGs or producing on-site electrical/thermal energy. The tool allows the realm of Water-Energy Nexus Solutions for WWTPs that provides green renewable energy for on- and off-site beneficial use. This tool also helps reduce fossil based fuel usage by allowing WWTPs to see potential payback periods and reduction of electrical grid demand by producing their own power – electrical and thermal.

LCAMER tool provides future casting scenario planning needs, as well. Planning includes needs to address population projections, new revenue streams to meeting existing operational or capital planning needs, and how innovations in ERS can play in the future, as they become more commercially viable. Payback periods are highly dependent on the cost of electricity which is projected to double over any given 6 – 10 year period due to demand increases cause by population group and fossil fueled supplied electrical infrastructure aging and needing significant upgrades or carbon footprint abatement. As electricity costs rise, other renewable innovations become more cost effective. However, industry will start to optimize several of today's current technology innovations to reduce their costs and to optimize their beneficial usages.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge WERF and the two participating WWTPs for their contributions and testing of the LCAMER Tool which is available to all WERF members.

REFERENCES

Water Environment Research Foundation (WERF), (2011), Fillmore, L., Pramanik, A., Surti, J., Kabouris, J., Forbes, B., WERF Project - *Life Cycle Assessment Manager for Energy Recovery,* Alexander, VA, USA.

Forbes, B., Surti, J., Kabouris, J. Shea, T., Fillmore, L., (2011) LCAMER Presentation at a WERF Research Forum, held in Washington D.C, USA in August 2011.

Witherspoon, J., Forbes, B., Surti, J., Kabouris, J. Shea, T., Fillmore, L., (2011), LCAMER & BORR Presentation at the Water Services Association of Australia's Managing Assets, water Quality and Energy in a Carbon Constrained Future Conference, in Sydney, Australia on October 25th, 2011.