Commerce Energy Biogas/PV Mini-Grid Renewable Resources Program

Making Renewables Part of an Affordable and Diverse Electric System in California

Contract No. 500-00-036

Enhanced Energy Recovery Through the use of Microturbines & Optimization of Anaerobic Digestion Evaluation Report

Project No. 2.2 Enhanced Energy Recovery through the use of Microturbines & Optimization of Anaerobic Digestion

Task 2.2.8a Deliverable

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Introduction

In June 2001, the Commerce Energy Team (previously the Commonwealth Energy Team) was awarded a programmatic contract under the California Energy Commission's Public Interest Energy Research (PIER) Program to develop and carry out research strategies for making renewable energy more affordable in California. The Commerce Energy (Commerce) approach involved assessing the combined potential of biogas and photovoltaic (PV) resources in a defined study area and identifying how these resources could be developed in a complementary and cost-effective manner. The Commerce Energy Team conducted this research in a real world setting so that the findings could be applied in other parts of California. The Chino Basin, an area centered southeast of Los Angeles that is rich in PV and biogas resources, was the selected location for the Commerce program.

An important element of the Commerce PIER Renewables Mini-Grid Program is a project devoted to implementation of research and demonstration activities for improving energy recovery through anaerobic digestion. Measurement and evalution (M&E) of this Commerce project, often referred to as "Project 2.2", is the subject of this evaluation report. Approximately 20 individuals employed by the regional waste water and electric utilities, dairy, renewable energy, and environmental industries were interviewed about their experience with the Commerce Project 2.2 and other similar projects related to anaerobic digestion, biogas cleaning, and microturbine operation. Commerce PIER project participants, as well as non-participants, were interviewed for this assessment to determine if there are differential views of the outcome of Project 2.2 by those who were directly involved relative to those who were not.

The purpose of this assessment is to determine how well the Project 2.2 objectives were met and how effective this project has been in meeting the overall goals of the PIER Program. This M&E effort focuses on the following waste water treatment (WWT) enhanced digester gas to energy systems issues:

- Were the *pilot system performance* and *reliability testing criteria* appropriate and sufficiently comprehensive? The focus here is on the evaluation of environmental, economic, and process efficiency/energy production performance.
- Were *Technology Transfer* effectiveness goals met?
- How well did the Project perform in meeting its *Market Impact* goals?

1.1 Purpose of the Enhanced Energy Recovery through Optimization of Anaerobic Digestion and Microturbines Pilot

The objectives of the Commerce Project 2.2 were to:

- Increase and optimize digester gas production through ultrasound (mechanical hydrolysis) processes,
- Develop and optimize gas cleanup systems,
- Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants fueled by biogas, and
- Evaluate performance and cost during operation so sewage treatment plants have greater certainty on cost and reliability of using microturbines.

Based upon the research, a number of key findings were reached. Ultrasound technology did not lead to a significant increase in solids destruction unless it was used in systems where there was not adequate time for digestion (also referred to as “stressed systems”). In the testing of ultrasound systems, it was determined that systems with larger sonic horns (those with a size range of greater than 6 kW) were less reliable than those with smaller horns. Additionally, the ultrasound systems with larger horns required more energy to operate without resultant benefits.

Gas cleaning technologies did contribute positively to the economics of biogas projects. They facilitated the use of lower emitting energy generation technologies, such as microturbines, and they improved the overall life cycle costs for other generation systems, like reciprocating internal combustion engines. Biological scrubbers, in comparison to iron sponges or other standard control technologies, reduced the life cycle cost of H_2S removal systems by reducing the need to purchase chemical media and generating less solid waste.

Conducting tests on energy recovery through anaerobic digestion and the use of cleaned biogas in microturbines resulted in additional data related to the costs of biogas production, gas cleaning, and the reliability of operating microturbines with the cleaned biogas. These data provide additional information to sewage treatment plants that might consider this form of renewable energy.

1.2 Project 2.2 Relationship to Overall Goals of the Commerce PIER Program

The overall goals of the Commerce Energy PIER Program are to:

- Develop and implement an approach for tailoring resource development to the specific needs and resources of local areas, or mini-grids;
- Develop means of increasing landfill gas production, accelerating biodegradation and decreasing landfill generation lifecycle costs;
- Improve the affordability of renewable energy produced from digester gas at sewage treatment plants;
- Improve the economics of producing energy from animal waste;
- Demonstrate the potential for the use of advanced gasification processes to reduce the cost of residual or sludge disposal;
- Demonstrate the use of proper systems integration to enhance the performance of photovoltaic systems;
- Demonstrate and update the application of a performance evaluation rating system for building integrated systems; and to improve the transfer of this information on system and module performance to consumers and the supply channel stakeholders; and
- Illustrate the potential for demonstration applications that add substantial value to building integrated PV technology, and simultaneously take advantage of economies of scale by installing larger PV systems under various targeted arrangements (i.e., dual/tri-use facilities, common ownership and ESP power purchase/billing, PV/Biogas hybrid facilities, DC direct drive applications, etc).

The work conducted under Project 2.2 directly relates to the goal of improving the affordability of biogas production at sewage treatment plants. Ultrasound and thermal hydrolysis were both reviewed as methods of optimizing gas production at municipal waste water treatment plants (WWTP). After a review of both processes, ultrasound was deemed superior given the greater potential for its application in southern California. Test results of two ultrasound systems at the City of Riverside WWTP demonstrated that ultrasound only enhances energy recovery when there was inadequate digester capacity, as stated earlier. While the tested ultrasound systems did not result in increased biogas production, gas cleanup systems did produce more favorable results.

Three different gas cleaning technologies were tested at the Inland Empire Utilities Agency (IEUA) Regional Plant No. 1 and all three performed well by cleaning biogas that could then be used for electric generation purposes. One technology, the biological scrubber, was the most cost-effective as it eliminated the need to use chemicals in the gas cleanup system. The positive results from the evaluation of gas cleaning systems moves towards the goal of increased affordability of generating renewable energy from biogas at sewage treatment plants.

In addition, Project 2.2 also furthers the goal to develop and implement an approach for tailoring resource development to the specific needs and resources of local areas. Tests of alternative ultrasound and gas cleanup systems were performed to provide WWTPs and other potential producers of biogas with choices related to enhanced energy recovery. The current processes employed and the layout of equipment at one sewage treatment plant may make one type of ultrasound system and/or gas cleanup system more appropriate than the others.

1.3 Organization of the Report

The remainder of this report is organized as follows:

- **Section 2** presents economic and engineering assessments of ultrasound and gas cleanup systems used to improve biogas production and usability. PIER and non-PIER participants were interviewed about the economic and environmental drivers, project costs and funding, and equipment installation, operation, and performance. An evaluation of the test plan is also included.
- **Section 3** describes the success of technology transfer activities by presenting feedback from groups and communities on the Project 2.2 data and results, how this information was communicated with the WWTP community specifically, and the awareness of the WWTP community with the PIER project.
- **Section 4** assesses the market impacts of Project 2.2. The influence of available information about ultrasound and biogas cleaning systems, the effect of the PIER program on addressing obstacles to implementing ultrasound and biogas cleaning systems, and the effect of future waste gas emission standards on implementing these projects are described.
- **Section 5** examines whether this project has contributed to producing affordable electricity and increased reliability, how well this project met the overall goals of the PIER program, and whether this project will help to increase market penetration.

2

Project 2.2 - Pilot Design, Performance, and Economics

This section evaluates the performance of the effectiveness of enhancing energy recovery at the host WWT facilities, as indicated by the specific performance metrics. The primary emphasis is on the increased output of energy, the effects on cost-effectiveness, and the environmental impacts relative to conventional approaches. Initially developed estimates of environmental and economic performance will be compared to those based on actual pilot project results. Data on these aspects of performance have been collected and analyzed by the project team under Task 2.2.5, and these results are further assessed here.

This evaluation examines how effectively the test sites were monitored for performance. Included is an assessment of 1) how well-designed the monitoring system was in capturing all relevant aspects of system performance, 2) how well the monitoring was executed, and 3) how thoroughly the performance data were analyzed and evaluated.

2.1 Evaluate Test Plan

This section evaluates how well the Task 2.2.5 *Test Plan* was carried out at both the Riverside Wastewater Treatment Plant (Riverside) for the pilot ultrasound pretreatment and at Inland Empire Utilities Agency Regional Plant No.1 (IEUA RP-1) for biogas cleaning.

Ultrasound Test Plan

The aim of the enhanced anaerobic digestion test was to evaluate the cost-effectiveness of using ultrasound to increase digester gas production at sewage treatment plants. The test was being conducted at the City of Riverside sewage treatment plant, as this has primary and secondary treatment processes that are typical of those found in California. Two different ultrasound systems were to be tested side-by-side to compare several different approaches to the application of this technology for enhanced digestion.

To achieve this, the objectives of this test were:

- Establish robust baseline performance data for the test digesters

- Evaluate performance of two digesters, each with a different ultrasound system
- Evaluate operability of the two ultrasound systems (availability/downtime, energy draw, etc.)

To achieve the test plan objectives, the test will be conducted in four phases, briefly described below, and results summarized in Table 2-1.

- <u>Pretest Phase</u> - During this phase, a number of checks were to be carried out at the City of Riverside sewage treatment plant, to ensure that the data collected during the test will be robust and reliable. This includes calibration of all flow meters (sludge flows and gas flows), evaluation of mixing systems on the test digesters, tracer tests to determine digester operating volume, and collection of plant data for the previous year.
- <u>Baseline Phase</u> - During the first three months of the test, detailed baseline data was to be collected with newly calibrated instrumentation.
- <u>Ultrasound Test Phase</u> - Once the two ultrasound systems were installed, the ultrasound systems and digesters' performance were to be monitored.
- <u>Continuation Phase</u> – After the ultrasound systems had been shut down at the end of phase three, the digesters were to be monitored for another two to three months, to follow the change in digester performance back to the previous baseline. This would confirm that improvements seen during the ultrasound testing phase can truly be attributed to the use of the equipment.

The principle tasks for satisfying these objectives were the sampling and analysis of sludge and biogas.

<u>Sludge & Biogas Sampling & Analysis at Riverside</u>

Four project participants answered questions about the sludge and biogas sampling and analysis that took place at Riverside. All respondents replied that the sampling rate was adequate and that no other biogas or sludge constituents needed to be measured. One participant added that there was a good balance between sampling frequency and budget and that the sampling was very well planned. Riverside and CH2M Hill employees collected the samples and three respondents reported that the sampling plan was not modified from the original Task 2.2.5 *Test Plan*. The fourth respondent indicated that the sampling frequency was too expensive initially. The plan was modified so that the constituents that took longer to react to changes were sampled less frequently. All respondents reported that the samples were consistently taken on time. One respondent stated that the samples were sent to three laboratories for analysis: Western Analytical, Environmental Management Services, and Environmental Analytical. Another respondent stated that some samples were sent to Edward S. Babcock & Sons, while the rest were analyzed internally. The Riverside operator checked the data for quality control before it was given to the CH2M Hill team for analysis. The ultrasound systems will no longer be used and sampling will continue as before this project was implemented.

Gas Cleaning Test Plan

The test plan for gas cleaning had two main objectives for this pilot program. One was to obtain the necessary data to determine the contaminant removal efficiency for each of the technologies. The principle activity under this objective was the sampling and analysis of sludge and biogas. The other objective was to obtain the necessary data to determine the cost-effectiveness of operating each of these technologies. The principle activity was the collection of operating and maintenance costs associated with each technology.

Sludge & Biogas Sampling & Analysis at IEUA

Three project participants answered questions about the sludge and biogas sampling and analysis that took place at IEUA. All respondents replied that the sampling rate was adequate and that no other biogas or sludge constituents needed to be measured. IEUA collected siloxane samples using the Impinger method and CH2M Hill employees collected siloxane samples using the Summa canister method and hydrogen sulfide samples. The sampling plan was not modified from the original Task 2.2.5 *Test Plan*. The samples were sent to three laboratories for analysis: Western Analytical, Environmental Management Services, and Environmental Analytical. One respondent stated that samples were consistently taken on time, while the another respondent stated that the samples were generally taken on time, however, plant operators sometimes had higher priority tasks that needed to be addressed before collecting the samples. There were no other problems with collecting the samples. When asked if they could recommend standardizing one of the sample collection methods for siloxanes, one respondent replied that the same sample was not collected by both methods, except during the baseline period. These samples had very different siloxane concentrations and they were unsure which value was more accurate. The second respondent indicated that one method may be more cost-effective, although he was unsure which method was more accurate. The third respondent was also unsure which method was more accurate and mentioned that the impinger method used by IEUA was three hours long while the Summa canister method used by CH2M Hill was shorter. Although use of the gas cleaning system will continue, internal lab analyses will be less frequent and IEUA has purchased gas quality meters. Samples will no longer be sent to an outside lab. The data was analyzed by a team at CH2M Hill.

2.2 Engineering Assessment

This section evaluates the performance of the ultrasound systems, the gas cleaning systems, and the microturbines tested by the PIER Program participants and the performance of hydrogen sulfide removal systems and microturbines used by non-participants.

Ultrasound Pilot

Table 2-1 presents the ultrasound data as tested and as estimated at full scale. The data shows that biogas production was not increased, digestion was not enhanced, and the units were unreliable. Dewaterability slightly improved with one of the units.

Table 2-1: Technical performance of Ultrasound units – As tested and expected at full scale at Riverside WWTP

Engineering/Economic Consideration	Baseline - each digester, as tested, no ultrasound	Ultrasound - Sonico Unit (as tested)	Ultrasound – IWETec Unit (as tested)	Baseline - full scale (all Riverside WWT digesters)	With Ultrasound - selected unit (Sonico) at full scale
Operational Parameters					
Volatile Solids Reduction (VSR), %	54 - 57%	52 - 58%	54 - 58%	54 - 57%	52 - 58%
Biogas Production Yield (cfd/lbVSR)	14 - 16	13 - 15	13 - 15	14 - 16	13 - 16
Increase in biogas production	N/A	0	0	N/A	0
Reliability of Unit	N/A	66%	21%	N/A	75 - 85%
Dewaterability					
TS% of dewatered cake from belt filter press	13%	14 - 17%	13%	13%	14 - 17%
Polymer use at belt filter press (lb/ton)	26	20 - 27	26	26	20 - 27

Four project participants answered questions about the performance of the ultrasound systems. Two ultrasound manufacturers were tested, and both companies provided valuable onsite assistance while installing the units. There was a language barrier with the first company and this unit also had many operational problems due to the fact that it was a new technology, required a higher pumping horsepower than they had used before, and would only accept a narrow sludge thickness range. One respondent stated that this type of installation was unusual for this company. Also, the first company was located in Europe and was not able to provide good tech support, which was frequently needed. The second unit had operational problems and was down approximately 50 percent of the time, but was more reliable than the first unit. This could have been due to its design which included smaller and more horns than the first unit and would continue operating even if one horn was down. The first unit required that all horns be operating in order for the system to continue operating; if one horn was down, the entire system would stop operating. The second unit was the largest horn size unit that the company manufactures and was also a new technology.

Overall the respondents preferred the second unit, which was more reliable; however, neither unit increased biogas production.

A tank was installed to hold the thickened waste activated sludge (TWAS) before it was pumped through the ultrasound units. Two respondents reported initial problems with the TWAS holding tank, including overflows and a shortage of instrumentation; however, these problems were eventually resolved by managing the process to prevent over-pumping.

Operational problems were ranked by two respondents. The biggest reported problems were controlling the TWAS because the sludge was getting too thick. Keeping the two units balanced with a similar loading rate was difficult so that the results could be compared. The second biggest reported problems were pumping issues and the sensitivity of the ultrasound units, which needed to be protected from the environment. The third biggest reported problems were the lack of increased biogas production by the ultrasound units and the complicity of getting spare parts because they had to go through customs. A third respondent reported that the biggest problem was the larger horns. Two respondents added that the ultrasound units may enhance digestion and increase biogas production at a plant that is operating under non-ideal digester conditions. One respondent expressed that he was disappointed with the ultrasound units and hopes that they will work better in the future because it makes sense that they should improve digestion and biogas production. Due to the numerous operational challenges experienced at Riverside, ultrasound manufacturers are no longer recommending the larger horn units.

An employee of the company that manufactures the second ultrasound unit responded to questions about the operational problems. When asked what the biggest operation problems were, he replied that the first problem, from his company’s perspective, was that Riverside brought a third digester online which lengthened the hydraulic retention time and decreased the benefits of the ultrasound systems. The second problem was that it was a very wet winter, which served to flush the primary solids out of the primary tanks and affected the key ratio of primary solids to secondary solids. The third problem was that it was hard for Riverside to calculate a good mass balance due to the wide variation in sludge concentration and volumes being pumped, and difficulties with their meters reading different values. Riverside attempted to solve this problem by reviewing meter readings on a regular basis and by attempting a number of polymer dosing regimes. The fourth problem was that the power input to the unit drifted down overtime due to the manual control of the back pressure. This could have been solved by installing automated controls.

Gas Cleaning Systems & Microturbines

The reported gas cleaning systems’ operation and performance data is shown in Table 2-2.

Table 2-2: Summary of Gas System Operation and Performance

					With Project SagPak HOX-Based		With Project SagPak C-Based		With Project Chiller		With Project H2S Scrubber		
		Baseline			Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	With Project Iron Sponge
	Units	(July/04 - May/05)	12-Oct-04	16-Nov-04	(July/05 - Aug/05)		(July/05 - Aug/05)		(July/05 - Aug/05)				
Operational Parameters													
Biogas Production Total	cfd	707,000	230,000	640,000									
Biogas Production Digester 4	cfd	107,000	97,000	116,000									
H2S [1]	ppmv	-	77	26	-	-	-	-	-	-	1,263	14	19 [6]
Moisture	ppmv	-	209 [2]	8,900 [3]	0.012	0.014	0.012	0.018	0.013	0.011	-	-	-
Siloxane	μg/L	518	36	5	-	-	-	-	2,885	1,223	-	-	-
Siloxane	μg/L	518	36	5	5,480	1,520	5,480	2,660	5,480	2,450	-	-	-
Environmental Benefits													
SOX Reduction		-	-	-					[8]				
Reliability													
Percentage of Days Operated	%	NA	NA	NA	47%		47%		47%		100%		

NA: Not applicable

[1] Digester 4 data; with FeCl3 addition for H2S control during baseline, and without FeCl3 addition after project implementation

[2] Combined gas at the flare

[3] Combined gas after the compressors

[4] Price of media replacement

[5] Price of one complete unit

[6] No change from baseline gas loop measurements. Field test period was insufficient to determine useful life of test unit.

[7] Price of modifications to existing system and media addition

[8] Assumes chiller saves 1 changeout per year of SagPak media

Biological Hydrogen Sulfide Removal System

Three project participants answered questions about the performance of the biological hydrogen sulfide removal system. Two respondents reported that the unit was easy to install, while the third replied that there were initial problems only because this was a new technology in the U.S. and European specifications had to be modified to design the tank. Also the initial tank that they were planning to use was dirty and was not cost-effective to clean, so a new tank was purchased. Another respondent added that the biological removal system was easier to operate than the conventional method of ferric feed combined with an iron sponge, and that future systems will be easier to implement now that the first system has been put in place and the initial problems have been worked out. The two respondents who were familiar with the data reported that the biological system had reduced the hydrogen sulfide concentrations as predicted. When asked if the biological system reduced the need for ferric feed and the use of an iron sponge, all three respondents replied yes, however some ferric feed will still be required because it also acts as a thickening agent. Two respondents said that the biological system could completely eliminate the need for an iron sponge, however, one respondent added that when it is used for biosolids and food waste co-digestion, the iron sponge will be needed, but the media life will be much greater. All three respondents reported that there were no problems with oxygen concentrations or pH levels. When asked to compare the biological system to the chemical system, all three respondents replied that the biological system is preferred because the use of chemicals is greatly reduced and this reduces costs, reduces labor, and is beneficial to the environment. All respondents were happy with the performance of the biological gas cleaning system and one respondent noted that it may be expanded to treat gas from the biosolids digesters.

Siloxane and Moisture Removal Systems

Three project participants answered questions about the performance of the refrigerated dryer and the siloxane removal media. All three reported that the refrigerated dryer was easy to install and operate. When asked about operation issues with the refrigerated dryer, only one respondent replied that there were issues with the liquid when it drained out of the chiller and the piping was redone to solve this problem. The one respondent who was familiar with the data reported that the refrigerated dryer had reduced moisture and siloxane concentrations as predicted. When asked to give their overall opinion of the refrigerated dryer, one respondent said that it is an important part of an optimal gas cleaning system; however, more tests need to be done to determine the temperature at which the refrigerated dryer should be operated. A lower temperature will further reduce siloxane concentrations, but will increase power usage, and further testing is needed to find the balance between the savings from the increased life of the siloxane removal media which follow the refrigerated dryer and the increased cost from the increased power usage of the unit when run at a lower temperature. Another respondent added that chillers are now being installed at IEUA RP-1 and RP-2.

Two different media, polymer and graphite, were tested for removing the remaining siloxane from the biogas after it had been through the refrigerated dryer, and the media were not difficult to install or operate. When asked if each media had reduced the siloxane concentrations as predicted, the one respondent who was familiar with the data replied yes, although breakthrough had not yet occurred and so it is uncertain if the lifetime of the media will be increased and it is uncertain which media will have the longest lifetime. Two respondents reported that there were operational problems with the media because the microturbines were not continuously running. This restricted the air flow and a recirculation loop had to be constructed. This delayed the start of testing and shortened the testing period. Two respondents replied that they expected the graphite media to perform better, only because it has been frequently used in the past and the polymer media has been used less often. One respondent added that the polymer media may be used more frequently in the future because it is less expensive.

Overall Biogas Cleaning System

Two respondents expressed that the tested biogas cleaning systems had been successful and that they would recommend these systems be implemented elsewhere. Three respondents reported that the biggest problems with the overall biogas cleaning system were that the biological scrubber had initial problems with water entering the biogas line, the airflow was restricted to the siloxane removal media, the operators were not open to new procedures and technologies, and the biogas cleaning system added extra work for the operators. All respondents recommended that IEUA continue to use all components of the biogas cleaning system and would recommend the technologies to other plants. One respondent recommended that the refrigerated dryer should be used for the removal of both moisture and siloxanes, as opposed to only moisture.

Microturbines

One project participant answered questions about the performance of the microturbines during the testing period. He reported that the microturbines had historically had a lot of operational problems due to impurities in the biogas, especially siloxanes. There were no problems with any other compounds that were not removed by the biogas cleaning system, and the biogas cleaning system reduced the siloxane, moisture, and hydrogen sulfide concentrations to meet the manufacturer’s input fuel specifications. The respondent also mentioned that IEUA only uses the microturbines as a back-up because they have a lower efficiency than internal combustion engines. He would recommend microturbines for smaller-scale applications because of air quality regulations, but they are not as beneficial for larger-scale applications because of their poor operating fuel to electricity efficiency.

An employee of a company that manufactures microturbines responded to questions about the operational problems. He replied that there are rarely problems with compounds that are not removed by the biogas cleaning system, although there have been rare reports of damage from arsenic when used with landfill biogas. His company recommends their siloxane and moisture removal system and a commercial iron sponge system for cleaning the biogas. He added that their systems are reliable and that maintenance costs are about the same as compared to internal combustion engines.

PIER Non-Participants

Three PIER non-participants were surveyed and had used a gas cleaning system to reduce hydrogen sulfide concentrations. One respondent had used biological, chemical, and physical systems. One respondent had good success with an iron sponge. The third respondent stated that there had been problems with the iron sponge system he had used.

Four project non-participant respondents had used microturbines. All had unsatisfactory experiences with the microturbines and found them unreliable. One commented that they had so many electrical and mechanical problems that they only ran about 10 percent of the time. He was sometimes able to fix the problems himself, but often he had to call in a consultant. Another respondent found that they frequently shut down due to impurities in the fuel.

2.3 Economic Assessment

Enhanced Biogas Production

The economic objective of the ultrasound test was to increase bio-solids destruction thereby increasing biogas production and ultimately increase electric production all in a cost effective manner. In interviewing staff from the City of Riverside Department of Public Works who were directly involved in the project, the conclusion was that these systems did not provide the results that had been hoped for. The economics of these systems could not be assessed under the conditions in which ultrasound pretreatment of WWT sludge is believed to be most effective (i.e., stressed anaerobic digestion systems). However, the one operational system did provide insights into the costs and associated benefits such that an estimate of the cost effectiveness of such a system could be developed by the project team. The published results from the tests are summarized in Table 2-3.

Table 2-3: Economic performance of Ultrasound units – As tested and expected at full scale at Riverside WWTP

Economic Consideration	Baseline - each digester, as tested, no ultrasound	Ultrasound - Sonico Unit (as tested)	Ultrasound – IWETec Unit (as tested)	Baseline - full scale (all Riverside WWT digesters)	With Ultrasound - selected unit (Sonico) at full scale
Environmental Benefits					
Anticipated to be zero, since no measurable increase in gas production was observed, so additional energy generation					
Capital Costs					
TOTAL INVESTMENT	**N/A**	**$231,500**	**$205,500**	**N/A**	**$1,876,000**
O&M Costs (Annual)					
TOTAL ANNUAL O&M	**$680,539**	**$673,382**	**$856,691**	**$1,837,455**	**$1,673,655**
TOTAL O&M SAVINGS	**N/A**	**$7,157**	**($176,152)**	**N/A**	**$163,801**
Lifecycle Analysis:					
Present Value of O&M savings at 6 % discount rate, 15 year project life	N/A	$69,512	($1,710,832)	N/A	$1,590,872
Net Present Value of Investment	N/A	($161,988)	($1,916,332)	N/A	($285,128)
Simple Payback period (years)	N/A	32.3	N/A	N/A	11.5
Rate of return (percent)	N/A	-8%	N/A	N/A	4%

It was initially anticipated, as reported in the Process Selection Report for Wastewater Treatment Plants under Task 2.2.1, that ultrasound systems would have a simple pay back period of two to five years, depending on factors such as:

- • Site-specific improvements in gas production, reduction in biosolids production – this will depend on factors such as baseline performance, ratio of secondary to primary solids, digester retention time;
- Value of energy, whether measured in terms of natural gas off-set or purchased electricity costs;
- Actual impact on dewaterability – there may be a potential for savings on polymer and for production of drier biosolids cake;
- Cost of reusing or disposing the biosolids

- Thickness of feed secondary sludge - the more dilute, the larger the size of ultrasound system and the lower the increase in gas production per installed ultrasound unit
- Site-specific installation costs, such as surge tanks, pressure regulating systems, installation on the secondary sludge line or on the digester recirculation line, etc.

These expectations clearly did not happen. Even with the partial operating data from one unit, the simple payback was over 11 years.

Preliminary installed ultrasound cost for a 34 mgd plant were estimated to be in the range of \$1.3 to \$1.6 million, and would depend on what ancillary equipment, such as holding tanks that might be required at the site. These costs estimates were slightly lower than predictions based on actual data.

The actual rate of return was only calculated for the Sonico unit as it was the only unit to be at least partially operational. As tested, the Sonico unit cost more to operate than it ultimately saved. The rate of return for a functional full scale ultrasound pretreatment system is estimated to be four percent based on the project results. The underlying assumption behind this estimate is that the digester is not stressed (i.e., digestion retention times are sufficient for significant solids destruction). These economic results suggest that it is not economical to apply ultrasound pretreatment at a WWT digester facility that is not stressed.

PIER Participants Ultrasound

Three project participants answered questions about the ultrasound pilot. All indicated that under the conditions that existed at the Riverside facility, ultrasound pretreatment was not beneficial. They all indicated that the primary driver for using ultrasound pretreatment was to increase biogas production to feed the onsite cogeneration facility. One individual stated that the environmental drivers all link to the economic. If you generate more biogas you’re going to generate more energy so there’s a saving in overall purchased energy. There would be a reduction is chemical costs because of a decrease in the use of polymer to assist dewatering the post digester sludge. This in turn should reduce trucking costs associated with hauling away the dewatered sludge because of the reduced volume and weight.

When asked about the amount of match funds, the respondents indicated that it was difficult to track the labor costs associated with the pilot project. Riverside’s operating and maintenance costs associated with the thickened waste activated sludge (TWAS) tank were estimated to be over \$10,000 for the test period. The total Riverside match funding for the purchase of the TWAS, labor and electricity was estimated to be between \$80,000 and \$100,000.

PIER Non-Participants Ultrasound

Gas Cleaning

The economic objective of the gas cleaning pilot was to reduce contaminants (i.e. moisture, hydrogen sulfide, and siloxane) in the biogas which cause emissions and maintenance issues and thereby reduce the cost effectiveness of biogas to energy systems. The economic analysis results performed by the project team are presented in Table 2-4.

Table 2-4: Economic Performance of Gas Cleaning

	Units	With Project SagPak HOX-Based	With Project SagPak C-Based	With Project Chiller	With Project H2S Scrubber	With Project Iron Sponge
		Inlet Outlet	Inlet Outlet	Inlet Outlet	Inlet Outlet	
		(July/05 - Aug/05)	(July/05 - Aug/05)	(July/05 - Aug/05)		
Cost As Tested						
Installation Cost	$	53,815 [1]	53,815 [1]	151,570	417,860 [2]	157,500 [3]
Annual Operating Cost	$	8,750	8,750	8,750	8,750	8,750
Annual Chemical/ Media Use Reduction	$/year	-	-	53,815	79,200	NA
Economic Analysis						
Total Annual Savings (= Environmental benefits less operating costs)	$/year			$45,065	$70,450	
Present value of annual savings; 6% discount rate, 10 project life	$			$331,682	$518,518	
Net Present Value (NPV) of investment	$			$180,112	$100,658	
Simple Payback	years			3.36	5.93	
Rate of Return (IRR)				27%	11%	

NA: Not applicable

[1] Price of media replacement

[2] Price of one complete unit

[3] Price of modifications to existing system and media addition

Initial estimates of the installed costs were developed for the Process Selection Report for Wastewater Treatment Plants under Task 2.2.1. These estimates are shown in Table 2-5.

Table 2-5: Initial Estimated Costs for Custom Biogas Treatment Systems

Low-Cost System	**Installed Cost**	**$/Mscfd, 5-Year Payout**
H_2S Removal (1)	$ 29,280	$ 0.25
Gas Drying System (2)	$ 3,850	$ 0.05
Siloxane Removal (3)	$ 6,400	$ 0.05
TOTAL COST	$ 39,530	$ 0.35
Optional System	**Installed Cost**	**$/Mscfd, 5-Year Payout**
H_2S Removal (1)	$ 29,280	$ 0.25
Gas Drying System (4)	$ 34,000	$ 0.16
Siloxane Removal (3)	$ 6,400	$ 0.05
TOTAL COST	$ 69,680	$ 0.46

(1) H_2S removal system recommended is a single-vessel using SulfaTreat – 410HP media with air injection. The SulfaTreat media is safer to handle when spent, and is more reliable in low-flow, low-pressure applications requiring minimal and consistent pressure drops with reduced H2S outlet spiking. The system is sized to achieve a 1-year turnaround for media replacement.

(2) The low-cost gas drying method is using desiccants. Costs are based on utilizing Van Air's Dry-O-Lite. The system is sized to achieve a 36 to 37 day period between desiccant refills. A longer period may be possible by increased vessel height and/or addition of a second vessel in series flow.

(3) The Siloxane removal system is a single-vessel using a granular coal-based activated carbon. The system is sized to achieve a 1-year turnaround for media replacement.

(4) The optional system utilizes a Van Air refrigerated gas dryer designed to treat up to 300 scfm with more consistent and lower gas dew points than the desiccant system.

Note: The custom unit can be integrated into the IR system that includes their screw compressor rather than adding a separate compressor.

The capital costs associated with gas cleaning proved to be substantially greater than initially estimated. Also, due to the apparent lack of information about U.S. installations of biological treatment of H_2S, no initial cost estimates were provided for the biological removal method in the Process Selection Report for Wastewater Treatment Plants under Task 2.2.1. Despite the higher than anticipated installed costs, the cost effectiveness, both in terms of simple pay back and rate of return, was computed and found to be favorable for the gas drying and the H_2S removal systems. The biological scrubber has a high upfront installed cost but was a fairly simple low cost system to operate and maintain.

3

Evaluation of Technology Transfer Activities

The mission of the Commerce Energy PIER program is not only to research and develop methods of improving renewable energy production and affordability, but also to effectively demonstrate and transfer the accomplishments to the industry stakeholders so that these advances can be incorporated into California energy markets in order to benefit all its citizens. This section presents the extent to which learning and technology advancements accomplished at waste water treatment pilot test facilities were communicated to other Commerce Energy PIER participants and to members of the waste water treatment (WWT) and renewable energy communities.

During the interviews with individuals from the environmental quality, utility, waste water treatment, and equipment manufacturing industries, questions were asked about whether WWT industry members were familiar with this project, how operating data and results from Project 2.2 were transferred, and to whom the information was communicated. Both PIER participants and non-participants were surveyed to determine how they felt about the transfer of technological information regarding the optimization of energy recovery through anaerobic digestion.

3.1 Communication of Operating Data, Concerns, and Project Results

Seven respondents answered questions about whether findings from Project 2.2 were communicated effectively. Six of the respondents are PIER Program participants and most of them were directly involved with Project 2.2. On the whole, they agreed that data from the tests of ultrasound systems used for solids destruction and the benefits of biogas cleaning were successfully communicated to other PIER Program participants, the California Energy Commission (CEC), and the Project 2.2 Technical Advisory Committee (TAC).

When individuals were asked about whether Project 2.2 findings were discussed with energy industry members and whether energy researchers are aware of the project, eleven interviewees replied. More than half of the responses were positive and were from PIER program participants; it was clear from the collection of responses that utility and environmental industry members were less aware of the Commerce Project 2.2 details than WWTP operators, and equipment manufacturers, designers, and installers.

Commerce Project 2.2 and the results of other similarly enhanced energy recovery projects from anaerobic digestion have been presented at conferences, authored in trade journal articles and company newsletters, and discussed with those industry members interested energy generation and waste water treatment. One surveyed PIER participant mentioned that presentations on the PIER Program projects have been made at conferences held by the Women's Engineering Society (WES), the American Water Works Association (AWWA), and the California Water Environment Association (CWEA).

CH2M Hill provided Itron with a compiled list of thirteen (13) conference papers related to anaerobic digestion, the role of ultrasound systems in solids destruction, co-digestion of dairy waste, and biogas cleaning. These papers were authored by six different individuals and all were presented at conferences held during 2005, providing further evidence of the technology transfer that has occurred to date. Most of these authors were involved in some way or another with Commerce Project 2.2. Conferences at which these papers were presented include the California Water Environment Association (CWEA) Annual Conference, the Residuals and Biosolids Management Conference, the Innovative Uses of Biosolids and Animal and Industrial Residuals Conference, the Water Environment Federation (WEF) Residuals and Biosolids Management Conference, and the Water Environment Federation Technical Exhibition and Conference (WEFTEC).

Twenty-seven individuals responded to an inquiry about whether the energy community is interested in initiating similar types of projects. Seventeen of the respondents agreed that there is interest and that this interest stems from the environmental benefits of using biogas, the reduction of waste that needs to be eliminated, and the reduced cost of energy use through self-generation. Of these respondents, one made the point that microturbines are highly reliable, generate fewer emissions, and operate more quietly than traditional internal combustion engines. These seventeen respondents include both PIER and non-PIEr program participants who are employed in the utility, waste water treatment, environmental quality, and equipment manufacturing industries.

Of the group of negative or neutral respondents, three stated that there is not enough interest; two interviewees believe there hasn't been enough success to date and the other commented that current attitudes of investor-owned utilities prevents the development of renewable energy projects.

The remaining interviewees gave mixed answers about the energy community's interest in future projects related to enhanced energy recovery through anaerobic digestion and biogas cleaning. Some felt that while the energy community is interested in developing similar projects, no one is willing to carry out the projects. Members of the utility industry stated that they were interested, but that they would like to see more developments in additional transmission capacity to make the most of the renewable energy generated from the anaerobic digesters and microturbines. Others said that waste water and waste management industry members have more of an interest because they have to deal with waste volume and the impacts upon water quality in the region. One respondent pointed out that waste water treatment industry members in the U.S. are more conservative than those in the U.K. He stated that the industry members in the U.K. are more willing to take risks because waste water treatment is privatized, unlike in the U.S.

4

Market Impacts M&E

This section addresses the effects of the Commerce Project 2.2 advancements on the potential market acceptance of biogas generation from anaerobic digestion. To determine the likely market impacts, an assessment is made of how well the technical and economic feasibility of ultrasound processes and optimized gas cleaning systems has been demonstrated. The market impacts discussed here are based on qualitative judgments regarding the cost-effectiveness of the ultrasound and gas cleaning system demonstrations as well as their effectiveness in mitigating non-cost barriers.

4.1 Current Biogas Usage

In order to assess the current state of the use of renewable energy at waste water treatment facilities, interviewees were asked about their observances of treatment plants burning biogas for energy at both the mini-grid and state levels. Responses from two PIER program participants were recorded. One stated that "*quite a few*" treatment plants burned biogas for energy at the mini-grid level, while the other respondent said that almost all plants with available anaerobic digester capacity were using biogas as a fuel. At the state level, the first individual did not possess enough information to make a judgment, while the other stated again that most of the waste water treatment plants with anaerobic digesters were producing and using biogas as a fuel. While both respondents observed the use of biogas for fuel at waste water treatment plants, both also stated that gas cleaning systems are not as prevalent due to cost.

Interviewees were also asked to indicate how important past and current information regarding ultrasound systems, biogas cleaning technologies, and microturbines was on their decision to implement these types of systems into their facilities. A scale of 1 to 3 was used with 3 indicating the highest level of importance. Regarding the role of information on the adoption of biogas cleaning systems, two PIER program participants and one non-participant responded, all indicating a response of '2'. One of the PIER program participants and the non-PIER participant responded about microturbines; the non-participant said the role of information was extremely important indicated by a value of '3' while the program participant gave a value of '2' regarding this same equipment.

The same scale of 1 to 3 was also used to evaluate the importance of system compatibility on the decision to adopt ultrasound systems, biogas cleaning technologies, and microturbines. Regarding the adoption of ultrasound technology, system compatibility was rated a ‘3’ for the individual PIER participant who replied. For biogas cleaning technology adoption, three respondents answered. One respondent indicated that system compatibility was very important (a ranking of ‘3’), while the other two ranked system compatibility for gas cleaning systems as fairly important (a ranking of ‘2’). Two interviewees responded about the importance of compatibility with regard to microturbines; again, one indicated a value of ‘3’ while the other gave a value of ‘2’. At least for the interviewees who responded, one can conclude that information and system compatibility play a somewhat important to very important role for the adoption of ultrasound systems, biogas cleaning technologies, and microturbines.

4.2 Obstacles

In order for future enhanced energy recovery through anaerobic digestion projects to be successful, it is important to address the obstacles that have been faced to date when such projects have been carried out. Gathering information about these obstacles helps to ease the difficulties of implementing biogas production and biogas cleaning in the future. Two responses were recorded when interviewees were asked about the difficulties faced by waste water treatment plants when adopting biogas to energy systems. One replied that biogas to energy projects are not as clean, while the other plainly stated that the main obstacle is cost.

Interviewees were asked whether the Project 2.2 pilot, in particular, has helped to demonstrate that obstacles regarding biogas production and biogas cleaning can be overcome. Eight responses of mixed opinions were recorded. Five of those who responded to this inquiry agreed that the test project at the City of Riverside did show that obstacles can be overcome. Of these five positive responses, varying comments were made. One stated that prior to this pilot project, people felt it was not feasible to successfully generate biogas through anaerobic digestion and then be able to use it in microturbines. This demonstration, along with others, has helped to change public opinion. The interviewee did mention that successful demonstrations of interconnectivity were still lacking and progress in this area would be beneficial.

Another individual said that while obstacles can be overcome, the actual adoption of anaerobic digesters for enhanced biogas generation is complicated by the technical costs faced by the individual agency, as these may vary depending on who is adopting these systems. Two of the remaining respondents felt that because ultrasound did not lead to increased solids destruction, this project failed to meet expectations. The last respondent felt that no single project can have enough of an impact to conclusively demonstrate that obstacles, such as those faced in Project 2.2, can be overcome.

In the case of the effect of future obstacles, namely whether future emissions standards affect decisions to implement projects related to the production and use of biogas as fuel, the responses were more mixed. About half of the respondents believed that emission standards affecting pollutants such as NO_x, volatile organic compounds (VOCs), and particulate matter (PM) do have a negative effect, while others felt that the improvements in the quality of the gas used precludes the standards from becoming binding

On a related note, interviewees with an expertise in environmental quality were asked whether they foresee waste gas emission standards being implemented in the future. The individual respondent for whom an answer was recorded stated that there were no standards currently being planned and that the air quality agencies were not worried about other significant sources of waste gas. This interviewee did say that any new sources of waste gas emissions are likely dealt with through the Federal EPA New Source Review program and that would reduce the need for additional standards to be put in place.

4.3 Technical Feasibility and Cost-Effectiveness

Interviewees were asked whether they believe biogas to energy projects, in general, are technically feasible and cost-effective. Of the six respondents who replied to these questions, all were confident that these projects were technically feasible. However, mixed responses were recorded when these individuals were surveyed about cost-effectiveness. Only one respondent said biogas projects are cost-effective, while the others gave more conditional responses such as "*they can be*" or "*it is still to be determined*." Three others said they were not sure or did not know about how cost-effective projects are involving biogas to energy projects.

Those surveyed were also asked about the technical feasibility and cost-effectiveness of equipment utilized during Project 2.2, namely, ultrasound systems for biosolids destruction. The individuals were asked about the use of ultrasound under non-ideal digester gas conditions (in other words, when systems are stressed and ultrasound would be beneficial). Of the seven who responded, three were unsure of the technical feasibility of use of ultrasound systems. Three others believed they are feasible, while one said it was not because it did not enhance solids destruction. Survey answers regarding the cost-effectiveness of ultrasound systems were split similarly. Based on our review of the results and consideration of the industry stakeholders interviewed, ultrasound pretreatment appears to be technically feasible, however, the cost effectiveness is very uncertain.

Five responses were recorded when interviewees were asked about the technical feasibility and cost-effectiveness of gas cleaning systems. Four felt biogas cleaning technologies were technically feasible while one commented that he was unsure. There was slightly more uncertainty among the respondents regarding the cost-effectiveness of gas cleaning systems, as three individuals said they were not sure while the other two said there were. Generally speaking, the overall opinion regarding gas cleaning systems has been that they tend to be expensive and are therefore not as readily adopted. When adopted though, gas cleaning tends to have more of a beneficial impact on biogas production processes when compared to ultrasound systems. Clearly gas cleaning and moisture removal are technically feasible. The cost effectiveness of the biological scrubber appears promising, but should be tested at a larger scale. The cost effectiveness of other gas cleaning systems will likely be very site specific with local environmental regulations and electricity prices being very influential.

4.4 Future Biogas Projects

The future of biogas to energy projects penetrating the market was also assessed by asking individuals if they were familiar with any other projects being planned as a result of projects implemented under the PIER Program. Of the seventeen individuals who responded, eleven were aware of related projects though they were not sure if these projects were planned as a direct result of Commerce Project 2.2. A majority of the projects described by the interviewees are related to funding and installation of digesters at dairies for the purpose of co-digestion, though there was mention of projects involved in gas cleaning to remove siloxanes and carbon media for H_2S. One interviewee had spoken to a few individuals who are interested in pursuing codigestion projects to increase biogas production for use as fuel.

In general, ultrasound pretreatment has limited applicability unless the technology or its application is improved. The biogas cleaning technologies tested through this project clearly have more broad applicability to the mini-grid, California and the US WWT biogas to energy markets.

5

Summary & Conclusions

5.1 Meet the Goals of the PIER Project

Project 2.2, Enhanced Energy Recovery through Optimization of Anaerobic Digestion and Microturbines, under the Commerce Energy Contract No. 500-00-036 had four specific goals. These were:

- Increase and optimize digester gas production through thermal hydrolysis and ultrasound processes.
- Develop and optimize cost-effective gas cleanup systems.
- Evaluate and quantify environmental benefits that result from using microturbines at sewage treatment plants.
- Evaluate performance and cost during operation so sewage treatment plants have greater certainty of cost and reliability of using microturbines.

Under this project, the Commerce Energy (CE) team tested two ultrasound pretreatment systems for optimizing WWT digester gas production, three gas cleaning systems and one moisture removal system. Two of the gas cleaning systems addressed hydrogen sulfide removal and one addressed siloxane removal using a chiller followed by two different media.

Based on the results of the testing under this project, ultrasound pretreatment technology may have limited market potential within California. The removal of hydrogen sulfide from digester gas has a large potential for application in California. The siloxane removal has a more limited market potential in California. Its potential benefits, primarily O&M cost reduction, are greatest when WWT digester gas is used to fuel microturbines. The moisture removal technology tested has the potential for environmental benefits to WWT facilities in California using digester gas as a fuel source for producing electricity.

The two ultrasound systems tested encountered many problems; one more so than the other. The underlying technology was the same for these systems but the operational approaches were different. One system utilized a small number of larger ultrasound horns whereas the other system was designed with more horns of smaller size. The large horn system pretreated only a portion of the sludge stream and the small horn system pretreated the entire sludge stream. The large horn system was never successfully operated whereas the small horn system was partially successful in demonstrating its capabilities. The testing of the small horn system resulted in sufficient information to assess its real strength. This strength is with stressed digester systems where the digester retention times are less than optimal. The results showed that digestion could be accelerated but the overall digester gas production would not exceed the baseline under optimal digester retention times. Even with the small horn system operating correctly, the cost effectiveness was not very attractive.

The two hydrogen sulfide removal technologies tested were an optimized iron sponge and a biological scrubber. The iron sponge is not a new technology but it was configured to see if it could be optimized by creating a partial but continuous regeneration of the removal media through an air injection system. The biological scrubber is a new technology in the United States that utilizes bacteria to remove hydrogen sulfide from biogas. The optimized iron sponge was tested with WWT digester gas whereas the biological scrubber was tested with diary waste biogas.

The biological scrubber proved to be a very effective alternative to the baseline removal approach of using ferric chloride to pre-treat the waste sludge before it enters the digester. The system was easy to construct and operate and required little attention from facility operators. The optimized iron sponge testing demonstrated that the life of the removal media could be cost effectively extended, but was not cost effective enough to totally replace ferric chloride as a primary hydrogen sulfide removal treatment.

The moisture removal system utilized chiller technology to cool the biogas causing water vapor to condense and thereby dry the gas. This system also showed evidence of siloxane removal as well, but further testing is necessary to determine its effectiveness. The siloxane removal system tested two removal media on the biogas after it had been through the moisture removal system. One material was graphite based and the other was polymer based. Both media proved to be effective in removing siloxane to levels that did not damage the operation of the microturbines fueled by the biogas. However, the start of the testing had been delayed and the life of the media was not confirmed.

The evaluation portion of this project, summarized by this report, sought to address three issues. First, were the pilot system performance and reliability testing criteria appropriate and sufficiently comprehensive? Second, were the technology transfer effectiveness goals of the project met? Third, were the project’s market impact goals met?

The testing and performance criteria were found to be appropriate and sufficiently comprehensive. Given the constraints of the project, the testing produced sufficiently credible results. Due to delays in the testing of the siloxane removal system, the planned testing was not completed by the end of the Commerce contract period; however the preliminary results showed promise.

In meeting the technology transfer goals, the CE team presented project results for the gas cleaning technologies at industry conferences. These are viewed by stakeholders to be a very effective means of transferring the knowledge gained through the project. The biological scrubber showed real promise in being a cost effective method for the removal of hydrogen sulfide from dairy waste biogas. The CE team, including the host facility, recommended that all the biogas systems continue to be operated.

The market effects of this project in California are not known at this time. However, stakeholders see the gas cleaning technologies for WWT biogas to energy systems as having the potential to improve the cost effectiveness of removing hydrogen sulfide, siloxane, and moisture from biogas resulting in lower emissions and greater cost effectiveness of the use of microturbines in biogas to energy systems.

5.2 Conclusions

Despite the disappointing operational performance of the ultrasound pretreatment systems, one of them showed that under certain conditions ultrasound pretreatment could be a solution to improving biogas production. In particular, if a WWT facility is stressed and the volumes of sludge are sufficiently large that optimal digester retention times can not be maintained, ultrasound pretreatment can enhance the production of biogas. However, due to the costs associated with these systems, they don’t appear to be a cost effective long term solution.

The biological scrubber showed real promise for removing hydrogen sulfide from dairy waste biogas. This technology should be tested at a larger scale using biogas from digested biosolids at a WWT facility to confirm its effectiveness in that situation. This market is relatively large in California and its apparent cost effectiveness could have a significant market impact. The Energy Commission may wish to facilitate this by providing match funding to stimulate a larger scale project involving WWT digester gas.

In order to facilitate greater acceptance of the use of microturbines for biogas to energy projects, the poor operational history of these units needs to be overcome. The general consensus among industry stakeholders is that this technology doesn’t work. Microturbines are viewed as being too sensitive to the quality of biogas. This perception will not be easy to turn around even with a successful demonstration of cost effective gas cleaning. The siloxane removal media tested were not run through their entire life cycle. The preliminary results were promising and this test should be funded to completion and an effort should be made to disseminate the results. Microturbines still hold promise, but gas cleaning will determine their future success in this market.