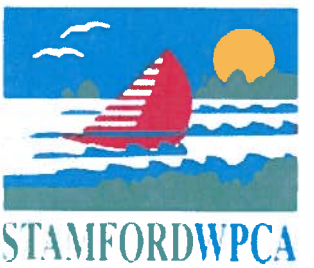

WASTE–TO–ENERGY PROJECT

STUDY REPORT

(January 2011)

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Executive Summary

Because of the high cost of energy and the dependence of the United States on foreign oil and non-renewable energy sources, the Stamford Water Pollution Control Authority (SWPCA) proposed a project to demonstrate that dried and pelletized wastewater residuals can be used as a renewable energy source to generate electrical power. The goal of Stamford's Waste-to-Energy project was to determine the technology needed to convert pellets of dried wastewater residual into a renewable fuel which can in turn be used to generate power.

Expansion of electrical demand in the downtown area of Stamford has exceeded the ability of Connecticut Light and Power to supply sufficient electricity. Stamford pays very high energy costs ($0.185 per KW/hr). This has created incentives for SWPCA to evaluate processes to capture energy from biosolids.

Initial review by SWPCA of established approaches to recovery energy and disposal of biosolids (i.e. digestion, composting, etc) indicated they were not well suited to the circumstances at the SWPCA facility due to high capital costs, limited site space, and the high volumes of residuals remaining to be transported offsite. Further investigations by SWPCA identified gasification of the pelletized sludge they currently produce as a technology of interest. This report documents investigation of industry experience with gasification of wastewater residuals, commercial interest, and ongoing research. In addition to a comprehensive review of ongoing technology development, systematic testing was also completed to insure the most promising alternatives were directly applicable to SWPCA's circumstances.

Finally, SWPCA identified a vendor who could supply equipment to convert biosolids to energy. The project has had several iterations including importing biosolids to augment the biosolids from SWPCA to generate one to three megawatts and another one using a combination of wood and biosolids; however, the final concept is to use only biosolids with an expected output of 0.5 megawatts to demonstrate the technology.

Technology Review and Assessment

Existing facilities operated by SWPCA process solids separated from the wastewater into a dried pelletized product. This drying process provides treatment of the resulting biosolids such that they comply with provisions of 40CFR Part 503 for Class A. This treatment, however, requires a relatively high input of energy (natural gas) and no conversion of the inherit carbon into energy. It was initially recognized that the high residual carbon inherit in pelletized biosolids potentially make it an excellent fuel. Past operation of an incinerator at the SWPCA plant site, however, raised several concerns, so investigations focused on emerging combustion alternatives, such as gasification.

The first step in the technology review was conducting a literature review. This process, conducted in April 2007, included an extensive search of industry papers, data, research, and presentations compiled both by industry technologists and a

technical research service (NERAC). This process identified 119 items applicable to the proposed project. These items were reviewed and categorized to confirm if the review had been exhaustive and to determine which vendors should be included for further consideration.
Based on the literature review, 18 vendors were subsequently contacted. These contacts included an initial telephone conversation, followed by a written description of the project circumstances and questionnaire. The questionnaire included key success factors identified by the project team which sought to determine the maturity of the technology the vendor might propose, experience with biosolids and within the U.S. market, and the potential size and cost of facilities. Eight vendors returned completed questionnaires. Review of these responses led to the recommendation that five vendors be considered for pilot-scale testing. Further conversations with these five indicated that two (Primenergy and Kopf) were initially interested in participating in piloting. A third vendor (Nexterra) subsequently was identified and participated in the piloting.

Alternatives Development and Testing

Once industry experience and research into gasification was identified and initial vendor interest in project development using SWPCA biosolids confirmed, initial testing was conducted to better characterize the biosolids pellets. This was done in three steps, first by laboratory analysis, then by bench and pilot-scale testing, and finally by hands-on experience of SWPCA staff in operating a small scale gasifier at their plant site.

Analysis of SWPCA biosolids was initially completed by Hazen Research, Inc (Hazen), using established ASTM test methods, for a number of characteristics applicable to its use in gasification. This testing was done in June/July 2007 using dewatered sludge cake samples taken on eight occasions and alternatively dried to a condition representative of that anticipated from the pellitizer. Results of Hazen analysis indicated the biosolids were generally well suited for gasification compared with a database of different types of potential renewal fuels (PHYLLIS) maintained by the Energy Research Center of the Netherlands (ECN). The following specific observations were made regarding SWPCA biosolids:

- Ash content was less than other similar municipal biosolids
- Ash fusion temperatures are above typical operations temperatures of gasification reactors, indicating that clinkering in the reactor or off-gas is unlikely
- Volatile carbon levels and high heating values are high (due to the lack of digestion) indicating it will readily be converted to syngas upon gasification
- Mercury levels are similar to other municipal biosolids, indicating typical control technologies will be effective.

Initial bench and pilot-scale testing was conducted by the University of North Dakota Energy and Environment Center (UNDEERC), a non-profit organization associated with the University, in December 2007. The UNDEERC bench-scale facility is a fluidized bed reactor rated at 1-4 lb/hr. Testing using this equipment was generally found to be problematic, due to fouling of the small-scale reactor and associated analysis equipment associated with the various contaminants within the biosolids.

Testing using the UNDEERC pilot-scale unit (Truss Plant), a downdraft-type unit, provided results indicating the process worked successfully. This larger unit, which began operation in October 2007, operated at higher temperatures and provided results using SWPCA biosolids consistent with published values. Initial testing using the Truss Plant indicated the following:

- Concentrations in the produced syngas of hydrogen (14.7%), carbon monoxide (13.8%), methane (2.8%), and carbon dioxide (15.7) were similar to those obtained when the unit operates fueled with biomass (wood).
- The higher heating value of 146 BTU/scf is similar to typical syngas values
- The cold gas efficiency of 70% is similar to biomass gasification units reported in literature.
- Successful operation of an internal combustion engine fueled by the produced syngas to generate electricity.

Given encouraging results from the initial pilot-scale operation, a second phase of testing was completed. This testing included additional monitoring based on the operational characteristics of the first test. Overall the following conclusions were made:

- Gasification using SWPCA biosolids successfully produces syngas consistent with quality required for fueling of engine/generators
- The downflow design of the Truss Plant unit is not appropriate for long-term use with SWPCA biosolids due to difficulties in controlling reaction temperatures below the ash fusion temperature.
- Clinker formation occurs and would need to be addressed in the configuration (likely upflow) and design of a facility designed for processing of SWPCA biosolids
- Tar formation in the gas is likely and will need to be addressed by gas treatment systems if it to be used for extended periods with internal combustion engines.
- Other parameters of concern include operational issues associated with the presence of siloxanes, and resulting air emissions associated with concentrations of mercury and ammonia.

In addition to off-site testing, SWPCA constructed a small scale gasifier unit at the Stamford plant site. While testing of this unit was generally informal and no results are included in this report, SWPCA felt operational experience with this unit proved to be very valuable. In particular, gasification experience with the SWPCA biosolids pellets provided staff insight into which feed rates and operating temperatures typically provided the best results. Also, they were able to identify key qualitative indicators of gasifier performance, such as the appearance of well-converted ash.

Technology Selection for 1 to 3 Megawatt WTE Facility

As indicated above, the investigations of gasification vendors resulted in requests for proposals (RFP) sent initially to two vendors (Primenergy and Kopf). Initial review of responses by both these vendors indicated that they represented technologies potentially applicable to SWPCA biosolids, as measured by the criteria established in the selection process. Given the success of the initial pilot-scale testing at UNDEERC, additional pilot testing using SWPCA biosolids was then completed at facilities operated by each of these two vendors. Later, a third vendor (Nexterra) expressed interest, was deemed qualified, and similar pilot testing was conducted. Below is provided a summary of the key factors that differentiated these vendors as a result of their proposals and pilot testing.

Primenergy - Unlike the other two vendors, Primenergy is strictly a thermal energy process. Syngas produced by biosolids gasification is combusted to produce steam, which is then used in a steam turbine. Pilot testing indicated the Primenergy gasifier was less efficient in converting the carbon in the biosolids to syngas, as evidenced by a higher carbon residual in the produced ash. Overall Primenergy had the lowest overall conversion efficiency of the fuel to electrical energy and the highest cost per unit of electrical power produced.

Kopf – Facilities operated by Kopf represent the only current facilities using syngas produced by the gasification of primarily biosolids to power internal combustion engines. This includes a proprietary system of gas cleaning which Kopf currently markets for this purpose and provides performance guarantees. All existing Kopf facilities are located in Germany, where all their technical support staff are based. Pilot testing using SWPCA biosolids at the Kopf facility were initially unsuccessful due to the heating value being significantly higher than that of biosolids typically used at their facilities. This was due to the local biosolids being digested prior to drying, unlike SWPCA. Kopf has indicated that subsequent testing with SWPCA biosolids have been successful, as evidenced by supplied analysis resulting from this testing. However, this testing was not witnessed by SWPCA representatives and there has been difficulty reconciling the analysis provided with theoretical analysis.

Nexterra – The majority of Nexterra gasification experience is with units fueled with wood biomass and has only recently pursued the biosolids market. Nexterra biomass gasifiers are located at several locations across North America. Due to their later entry to the market, pilot scale testing by Nexterra using SWPCA biosolids was completed several months after the other two vendors. This testing was generally successful, indicating a good conversion of the fuel and efficient conversion of the biosolids to the syngas. This testing was observed by SWPCA representatives and corresponds well with the vendor-supplied technical data.

Nexterra is currently developing gas cleaning systems to allow use of the syngas produced from biosolids in internal combustion engines and has an exclusive business relationship with GE (the leading vendor developing engines for use with Syngas). Originally Nexterra proposed a phased approach to implementation of gasification at SWPCA as follows:

- Phase 1A – Installation of a biomass gasifier to supply alternative heat for operation of the existing biosolids dryer
- Phase 1B – Testing of the Phase 1A gasifier using SWPCA biosolids as the fuel source.
- Phase 2 – Installation of a separate gasification, gas cleaning, and engine-driven electrical generation facility to be fueled using biosolids.

However, the proposal has now been changed based on further successful testing of the gas cleaning system. The concept will be as originally proposed by SWPCA to DOE which is dried biosolids to syngas.

Power Generation

This section of the report looks at options for the use of syngas to generate power at the SWPCA site. It concludes that internal combustion engines are better suited for this purpose than fuel cells or gas turbines. This evaluation provides a preliminary consideration of potential use of waste heat and the means which electrical power generated might be supplied to the plant and the utility grid.

Air Emissions

Air emission will occur both from operation of a biosolids fueled gasifier, as well as the engines powered by the produced syngas. These emissions would be additive to those from the existing plant, as permitted by the State of Connecticut, Department of Environment Protection (DEP). Uncontrolled emissions from such a facility consistent with the biosolids capacity of existing plant facilities would exceed threshold limits for NOx, VOC, and CO. This would require permitting based on a "major modification" as classified by the USEPA Clean Air Act regulations. The effectiveness of air pollution controls provided with the project and/or operating conditions incorporated into the permit may allow permitting requirements to be mitigated.

Solid and Liquid Wastes

Gasification systems typically produce both solid and liquid waste that require disposal.

Solid waste is primary the ash product produced during gasification and particulate matter discharged by bag house or other emission control facilities. Preliminary information provided by vendors indicate that ash and other solid waste will be of a small volume and non-hazardous.

Liquid wastes would typically be associated with scrubbers or other systems associated with gas cleaning, and may be high in ammonia. It is generally assumed these streams would be discharged to the wastewater treatment system, although

potential impacts on treatment systems (particularly denitrification systems) is needed before any such discharge is initiated.

Conclusions and Recommendations

Investigations documented in this report confirm:

- There is commercial interest in development of biosolids as fuel for gasification facilities.
- Several gasification systems are currently operating successfully using biomass fuel. Adaption of this technology to suit biosolids, particularly pelletized biosolids is demonstrating success, with some facilities currently sustaining operations.
- The greatest potential for use of syngas generated from gasification is fueling of internal combustion engines

Testing using the biosolids pellets produced by SWPCA documented in this report results in the following conclusions:

- Biosolids produced by SWPCA retain a higher fuel value for gasification, since they are not digested prior to drying. The pelletize form of these biosolids also appears to be well suited to use in gasification systems.
- Testing of gasification systems fueled by biosolids indicates encouraging results for electrical power generation and warrants a full-scale demonstration project.
- Conditioning technology for syngas produced from biosolids is in the developmental stage; however at a stage where performance guarantees can now be given by Nexterra.
- The phased approach originally proposed by Nexterra represented a means to systematically further prove the viability of biosolids gasification for electrical power generation, while effectively managing SWPCA's project risks. Based on the successful testing of their gas clean-up system that phased approach will no longer be necessary. They have proposed a 0.5 megawatt demonstration project which will directly convert SWPCA biosolids pellets to electrical energy using their gasifier to produce syngas which will fuel a GE Jenbacher engine.

Recommendation:

Given that Nexterra and GE are willing to provide process guarantees for a biosolids to syngas to electrical energy system, the recommendation is to move forward with the demonstration facility. The demonstration project will use a Nexterra gasifier to produce syngas from the Stamford biosolids and then use that syngas to generate electricity using a GE Jenbacher engine.